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**MEMORANDUM**

**Date:** February 13, 2012

**To:** Dr. Tim Placek, Undergraduate Program Committee Chair, Chemical Engineering Department, Auburn University

**Subject:** Interim Report I - Analysis of L&L Kiln Data

**Executive Summary:** Interim Report I is the first in a series of reports to be delivered on the topic of L&L kiln data analysis. The kiln in question was fitted with both S and K thermocouples placed at specific interior and exterior locations to record the temperature data of each of the two firing runs to be considered. The area of the kiln is divided into two zones, an upper mid-section and lower mid-section. Two type S thermocouples are employed to record the temperature, one for each zone inside the kiln. A total of four type K thermocouples are also utilized in temperature recording. One type K thermocouple is placed on the exterior upper mid-section, a second on the exterior lower mid-section, another is placed on the exterior surface of the kiln lid, and the final is located on the floor directly beneath the kiln. The data was collected from runs corresponding to Orton Pyrometric Cone firing ramp specifications. This data was converted to XLSX format and then uploaded into the MATLAB® program. MATLAB® was used to plot and interpret the information accordingly. Upon further study, the Cone 05 data was found to fit a firing ramp of 27 F/hr and the Cone 6 data was found to be indicative of a firing ramp of 108 F/hr.

**Introduction and Purpose:** The primary objective of this report is the analysis and interpretation of two sets of time-temperature data runs recorded from an Orton cone 05 and cone 6 firing schedule for an L&L Cone 12 Kiln: E23S-JH. The overall goal is to provide a thorough breakdown of the supplied data, just as in a “real world” engineering situation. In order to achieve this goal, the MATLAB® program was applied as a tool for the manipulation of the two Microsoft Excel files provided for study. An examination of this problem was considered from three angles of approach: standard time-temperature data, an approximate derivative of the time-temperature data, and a range registered between thermocouple pairs placed in various locations.

A small amount of background information is pertinent before a initiating a discussion of the results, beginning with the kiln. The L&L Cone 12 Kiln: E23S-JH has an interior diameter of 23$\frac{3}{8}$”, an interior height of 18”, and an interior volume of 4.7$ft^{3}$. The lid is in a top opening position and the kiln is plated in 14 gauge stainless steel. The kiln sits on a four-legged stand composed of the same stainless steel as its sides. It consists of two 9” sections with elements that have four wraps per section. The interior sides and bottom of the kiln consist of 2$\frac{1}{2}$” K25 insulating firebrick while the lid utilizes 3” K25 bricks. The control panel for the two zones is mounted separately. The “upper mid-section” and the “lower mid-section” zones each come equipped with a type S thermocouple to monitor interior kiln temperature and feed information to the controller. The kiln is designed to fire up to an Orton cone 12 level and reach 2400F.

The kiln is fitted with the two type S thermocouples as mentioned, as well as four additional type K thermocouples. Thermocouples operate on a principle of voltage difference generated due to a temperature gradient formed along a portion of length of connected wires. This voltage difference is then passed along to the controller for interpretation based on the trial being run. Both thermocouple types are constructed with a negative leg and a positive leg. The S type thermocouple is built with a negative leg of pure platinum and a positive leg consisting of a 90% platinum and 10% Rhodium alloy. These thermocouples are considered to be accurate up to a range of 2700F. Type S thermocouples produce a different EMF reading than type K which means the voltages created must be interpreted separately by the controller while all data is simultaneously collected. In contrast to the type S, the type K thermocouple is considered accurate to 2500F. The type K 8awg wire consists of nickel and rhodium alloys.

The kiln was fired to run for both an Orton 05 cone and cone 6 schedules. Orton cones are a tool used to measure the effects of temperature and time exposure within a kiln. The combination of these effects is generally referenced as “heat work” and “heat energy” and this information can be used to determine much about the firing process. Properly fired cones to bend to a 90 degree angle, anything less means the cone was not exposed to enough heat energy inside the kiln; anything more means the cone received over-exposure. The cone’s numbers correspond to a heating rate dependent the maximum temperature and time needed to be reached within the kiln to fire the cones to the desired 90 degree angle. The Orton ramp rates of the cones are desired in order to prevent a temperature shock from occurring, which can result in the deformation or destruction of any desired product. Thermal shock occurs when the firing schedule allows the clay to either cool or heat too rapidly leading to the disruption of the ceramic formation.

**Analysis:** For the data collecting runs, the kiln was set up such that the thermocouples were distributed over various locations for temperature collection. Two type S thermocouples were employed on the interior surfaces of the kiln; one in the upper mid-section of the kiln and the other in the lower mid-section. Four type K thermocouples were also used to measure the temperature of the exterior surfaces of the kiln: one in the upper mid-section, one in the lower mid-section, another on the top surface of the kiln lid, and the last thermocouple recorded temperatures of the floor directly beneath the kiln. Two separate firing runs of the kiln were performed to collect data. The slow bisque cone 05 firing run was performed on January 14, 2012 and the fast glaze cone 06 firing run was performed days later on January 19, 2012. An underlying assumption of this report is that these runs were performed under the general atmospheric pressure of the room and that the bypass box orifice opening was set to fifty percent capacity.

The recorded data was accessed from its original CSV format and then converted to Microsoft Excel XLXS files for import into the MATLAB® program. Once loaded, information was extracted and manipulated into row vectors representative of log scale time as well as the individual temperature readings. The log scale time vector was manipulated into a time vector with increments of thirty seconds-- which was the time interval used for instrument recording. The first variety of graph employed for study plotted the temperature vectors against their corresponding time vector points. Next, a vector was produced containing the rate of change in temperature and was plotted against the time vector. A smoothing function using an average filter and span of 45 was then applied to the newly created vectors and graphs depicting the rate of temperature change vs. time were constructed. Finally, the range of difference in corresponding thermocouple pairs and time points were also examined. The maximums and minimums as well as other key points on these graphs were also made note of.

**Results and Discussion:** A closer examination of both the time vs. temperature plots and rate of temperature change vs. time plots showed trends visible in all graphs for both cone firings. The graphical trends differ slightly between the two firing trials. S thermocouple data has selected for discussion because it is closest to the heat source as well as the cone indicators. Data provided by the remaining thermocouples reflects the same trends at different temperature values due to varying degrees of insulation based on position.

A single set of graphs for the Bisque Fire Data may be referenced in relation to the five stage slope trend observed and can be referenced in Figure 1 and Figure 2. It is important to note that the above graph generated for analysis depicts a functional relationship; however, in actuality, the produced lines are indicative of individual data points gathered over such a close time frame that the infinitesimal temperature changes between these time frames may be deemed of negligible value. Therefore results in the linear representation of the data as seen in all figures reported. The infinitely small, yet non-continuous spacing of the data points is a factor which contributes to some of the noise seen in all graphs.



Stage 5

Stage 4

Stage 3

Stage 2

Stage 1

Figure 1: Recorded temperature vs. time



Stage 5

Stage 4

Stage 3

Stage 2

Stage 1

Figure 2: Instantaneous rate of change of temperature

Using a ramp focused approach of analysis to summarize the stages nested within the first and second set of graphs, it can be seen that the initial stage depicted reveals a positive slope corresponding to a rise in the kiln’s interior temperature. The second stage initially appears as though no change in slope occurs and temperature is held constant within the kiln. This initial analysis is incorrect. As seen in Figure 3, it may be noted that the graph at this point has entered a time period of oscillation in which the slope of the temperature graph continually reverses its sign from a positive to a negative value. Entrance to stage three yields a positive slope of a value much higher than that of stage one. Temperature inside the kiln increased rapidly over this considered time frame. In contrast to this sharp increase in temperature, the fourth stage shows evidence of a tapering off of the heating due to a decrease in slope. The maximum temperature marks the end of stage four. After this absolute maximum of the temperature-time data is reached, the final stage begins. Stage five signifies an exponential reduction in both slope and temperature until the end of the experimental data terms provided.



Figure 3: Magnified view of temperature vs. time: Stage 2

Stages one and two correspond to the initial and secondary stages of clay kiln firing in, which the subject is generally heated to a temperature equal to that of the boiling point of water. The purpose of this is to evaporate any residual water that remains trapped within the clay and then enter a “soak” phase. Consider this soak phase in terms of a heat transfer perspective and it is discovered that this time is necessary in order to allow the rate of heat transfer to fully act upon the clay. The time allows the body to come to a uniform temperature before proceeding with the firing process. The idea of “holding” the temperature for the soak phase implies a constant temperature value is reached within the kiln, which is not the case for this process. During this time, the kiln is attempting to maintain a constant interior temperature as specified by its firing schedule. However, due to the firing mechanisms employed, the heat transfer is actually a transient process rather than a steady one as would be implied by obtaining a constant temperature value in this region. The transient state of the heat transfer of this process is due to the real-world notion that a substance cannot be heated at such a rate as to yield a perfectly constant temperature. This time dependent state can further be expounded upon in the idea that the heat fluctuations occur as “waves” which allows a better conceptual grasp of what is occurring visually on each graph. The application of the smoothing tool to the data helps to better distinguish between graphical noise and the small oscillations that occur due to heating fluctuations.

Viewing slope stage three in collaboration with the considered kiln ramps demonstrates the beginning of the transformation of the clay to essentially burn away unwanted organic materials, carbon, and sulfur to yield a true ceramic product. The fourth stage works in conjunction with the third stage on a deeper chemical level. This stage is important because it allows for the removal of the final residual water molecules which are chemically bonded within the clay’s structure. The end of this fourth stage, signified by the graph’s maximum peak, the clay has been transformed into a ceramic. The final stage is simply the exponential cooling process undergone by the clay inside the kiln. The time frame for this exposure is crucial, as the ceramic must be cooled at a reasonable rate in order to prevent thermal shock and product cracking or disfiguration.

The plots produced using the Glaze Fire Data generally mimic those of the Bisque Firing with one major exception. The first two stages visible in the Bisque Fire plots are absent from the Glaze Fire plots as demonstrated in Figure 4 and Figure 5. The cone 6 graphs depict a three stage process with no soak time.



Stage 3

Stage 2

Stage 1

Figure 4: Recorded temperature vs. time



Stage 1

Stage 2

Stage 3

Figure 5: Instantaneous rate of change of temperature

The maximum interior temperatures reached during the Bisque Firing were found to be 1851F for the upper mid-section and 1856.9F for the lower mid-section and both occurred at the same instance in time. The maximum interior temperatures reached during the Glaze Firing were recorded as 2220.5F for the upper mid-section and 2225.3F for the lower mid-section and also occurred at the same instance in time but at a different time than observed in the Bisque Firing Data. The maximum temperature values were then cross referenced with the Orton Temperature Equivalents Chart. It was concluded that the cone 05 firing occurred at a ramp rate of approximately 27F/hr for a time period of 50 hrs and the cone 6 firing at a ramp rate of approximately 108F/hr for 21 hrs. The Glaze Fire occurred at a rate four times faster than that of the Bisque Fire and the time required to complete the firing process was in the region of two and a half times shorter. This rate-exposure relationship is reflective of the total amount of heat energy the cones were bared to.

The magnitude of the difference between thermocouple pairs also provides revealing information about the firing process. The variance of temperature profiles between the upper mid-section and lower mid-section positions both interior and exterior to the kiln at these differ to a slight degree as seen in Figure 6 and Figure 7 which may be referred to in the Attachments section. These figures illustrate the point that temperature within the kiln is not held constant at any point in time. The average temperature differences for the Bisque Fire were calculated to be 6.15F and 11.13F for type S and the exterior type K thermocouples respectively. Again, the same information was computed for the Glaze firing where the S average was equivalent to 15.75F and the K exterior average 11.22F. The differences in the temperatures at these locations show a slight deviation in temperature as a function of position both interior and exterior to the kiln.

However, it may be considered that other factors influence the range of difference between the exterior type K thermocouples. It is presumed that neither the idea of constant mixing nor constant fluid property values may be applied to the air in the room surrounding the kiln. Anomalies may be present prior to the initiation of firing or develop due to the circulating flow of air provided by the kiln room’s heating and cooling system. Something else to consider are the differences in temperatures recorded amongst the exterior wall and lid K thermocouples which are visible in Figure 8 and Figure 9 in the Attachments section. A key factor in this examination is the thickness of the K25 IFBs at these locations. The firebricks located within the kiln lid area are ½” thicker than the firebricks lining the kiln walls. The effect of thermal resistance of the additional insulation results in a drop in the temperature readings at the surface of the kiln lid. The concept of thermal resistance may also be applied in a comparison of lid and floor temperatures available in Figure 9 and Figure 10 in the Attachments section. The stand of the kiln provides a pocket of air beneath the kiln yet above the floor. This pocket of air provides additional resistance and helps to conduct a certain amount of heat energy such that it is not immediately absorbed by the floor below.

**Conclusions:** Data analysis was performed within the MATLAB® program in order to generate temperature-time related graphs. It was found that the graphed data was indicative of two individual firing schedules for the kiln with which the experiments were conducted. The stage-like changes in slope may be correlated with the general concept of kiln firing schedules and ramps in order to better conceptualize what is occurring during the process at corresponding time and temperature points. When considering the Cone 05 data: stage one is indicative of heating to remove excess water, stage two was found to be a temperature holding phase, stages three and four demonstrate the transformation of the clay on a chemical level in order to produce the desired ceramic product, and stage five shows a portion of the exponential cooling phase. The Cone 6 data appears to exclude the first two stages, but in reality the same transformations are occurring within the clay so long as it is exposed to the required amount of heat energy. The supplied data was also found to demonstrate a contrast in temperature readings of various “paired” thermocouple types used in this experiment, meaning that identical thermocouple type temperature readings vary within different locations residing within the kiln due to the temperature’s dependency on position and the inability to maintain a constant temperature within the kiln.

**References:**

*A Guide to Using Orton Pyrometric Cones*

http://www.ortonceramic.com/resources/pdf/Guide\_Cones.pdf

*K25 Firebrick*

http://www.hotkilns.com/sites/default/files/pdf/114-3-data-sheet-k23%20&%20k25%20brick.pdf

*Kiln Firing Schedules and Ramps*

http://pottery.about.com/od/temperatureclayglazes/a/pyrochart.htm

*L&L Cone 12 Kiln: E23S-JH*

http://www.sheffield-pottery.com/L-L-CONE-12-KILN-E23S-JH-for-Crystalline-Glaze-p/lke23sjh.htm

*Orton Pyrometric Wall Chart*

http://www.ortonceramic.com/resources/pdf/wall\_chart\_horiz.pdf

*Thermocouple Codes/ Conductor Combinations and Characteristics*

http://www.thermalcorp.com/documents/TCCHART.pdf

*Thermocouples: The Operating Principle*

http://www.msm.cam.ac.uk/utc/thermocouple/pages/ThermocouplesOperatingPrinciples.html

*Type S Platinum Thermocouples*

http://www.hotkilns.com/type-s-platinum-thermocouples

**Attachment A:** Contains general plots used in analysis of Bisque Firing Cone 05 Data



Figure 6: Interior and exterior temperature variance



Figure 8: Exterior temperature distribution



Figure 10: Lid and floor temperature distribution

**Attachment B:** Contains general plots used in analysis of Glaze Firing Cone 6 Data



Figure 7: Interior and exterior temperature variance



Figure 9: Exterior temperature distribution



Figure 7: Lid and floor temperature distribution

**Attachment C:** Contains MATLAB code used in analysis of Bisque Firing Cone 05 Data

% IR#1 BISQUE FIRE PLOTTING CODE

clear all

clc

clf

bisque = importdata('Bisque Cone 05 Firing.xlsx');

bisque\_data = (bisque.data)';

log\_time = bisque\_data(1, 3:end);

% Temperature Vectors

s\_inside\_top = bisque\_data(2, 3:end);

s\_inside\_bot = bisque\_data(4, 3:end);

k\_ext\_top = bisque\_data(5, 3:end);

k\_ext\_bot = bisque\_data(8, 3:end);

k\_lid = bisque\_data(9, 3: end);

k\_floor = bisque\_data(11, 3: end);

scale = length(log\_time);

% Time Vector

time\_30 = linspace(1, 30\*scale, scale);

% End of Time

end\_time = time\_30(end)./3600; % hours

% Maximum Temp S Top

[s\_top\_max, s\_top\_loc] = max(s\_inside\_top);

% Time

s\_top\_max\_t = time\_30(s\_top\_loc);

% Maximum Temp S Bot

[s\_bot\_max, s\_bot\_loc] = max(s\_inside\_bot);

% Time

s\_bot\_max\_t = time\_30(s\_bot\_loc);

% Maximum Temp K Top

[k\_top\_max, k\_top\_loc] = max(k\_ext\_top);

% Time

k\_top\_max\_t = time\_30(k\_top\_loc);

% Maximum Temp K Bot

[k\_bot\_max, k\_bot\_loc] = max(k\_ext\_bot);

% Time

k\_bot\_max\_t = time\_30(k\_bot\_loc);

% Maximum Temp K Lid

[k\_lid\_max, k\_lid\_loc] = max(k\_lid);

% Time

k\_lid\_max\_t = time\_30(k\_lid\_loc);

% Maximum Temp Floor

[k\_floor\_max, k\_floor\_loc] = max(k\_floor);

% Time

k\_floor\_max\_t = time\_30(k\_floor\_loc);

% Produce S Time-Temp Graphs

figure(1)

plot(time\_30, s\_inside\_top, '-k')

title('Bisque Cone 05 - S Thermocouple Interior Upper Mid-section')

xlabel('Time (sec)')

ylabel('Temperature (degrees Fahrenheit)')

figure(2)

plot(time\_30, s\_inside\_top, '-k')

hold on

plot(time\_30, s\_inside\_bot, '--k')

title('Bisque Cone 05 - S Thermocouple Interior')

xlabel('Time (sec)')

ylabel('Temperature (degrees Fahrenheit)')

legend('Upper Mid-section', 'Lower Mid-section')

% Produce K Exterior Time-Temp Graphs

figure(3)

plot(time\_30, k\_ext\_top, '-k')

hold on

plot(time\_30, k\_ext\_bot, '--k')

title('Bisque Cone 05 - K Thermocouple Exterior')

xlabel('Time (sec)')

ylabel('Temperature (degrees Fahrenheit)')

legend('Upper Mid-section', 'Lower Mid-section')

% Produce K Lid/Floor Time-Temp Graphs

figure(4)

plot(time\_30, k\_lid, '-k')

hold on

plot(time\_30, k\_floor, '--k')

title('Bisque Cone 05 - K Thermocouple Lid and Floor')

xlabel('Time (sec)')

ylabel('Temperature (degrees Fahrenheit)')

legend('Lid', 'Floor')

figure(11)

plot(time\_30, k\_lid, '-k')

hold on

plot(time\_30, k\_ext\_top, '-.k')

hold on

plot(time\_30, k\_ext\_bot, '--k')

title('Glaze Cone 6 - K Thermocouple Lid and Walls')

xlabel('Time (sec)')

ylabel('Temperature (degrees Fahrenheit)')

legend('Lid', 'Upper Mid-section', 'Lower Mid-section')

% Magnitude of S ranges

s\_range = abs((s\_inside\_top - s\_inside\_bot));

k\_ext\_range = abs((k\_ext\_top - k\_ext\_bot));

k\_lf\_range = abs((k\_lid - k\_floor));

[s\_max\_mag, s\_max\_mag\_loc] = max(s\_range);

s\_mag\_pos = time\_30(s\_max\_mag\_loc);

[k\_ext\_max\_mag, k\_ext\_max\_mag\_loc] = max(k\_ext\_range);

k\_ext\_mag\_pos = time\_30(k\_ext\_max\_mag\_loc);

[k\_lf\_max\_mag, k\_lf\_max\_mag\_loc] = max(k\_lf\_range);

k\_lf\_mag\_pos = time\_30(k\_lf\_max\_mag\_loc);

% Average ranges

s\_AVG\_range = sum(s\_range)./length(s\_range);

k\_ext\_AVG\_range = sum(k\_ext\_range)./length(k\_ext\_range);

k\_lf\_AVG\_range = sum(k\_lf\_range)./length(k\_lf\_range);

% Produce Vector Graphs

figure(9)

plot(time\_30, s\_range, '-k')

hold on

plot(time\_30, k\_ext\_range, '--k')

title('Bisque Cone 05 - S&K Thermocouple Magnitudes')

xlabel('Time (sec)')

ylabel('Temperature (degrees Fahrenheit)')

legend('S Interior', 'K Exterior')

figure(10)

plot(time\_30, k\_lf\_range, 'k')

title('Bisque Cone 05 - K Thermocouple Lid&Floor Magnitudes')

xlabel('Time (sec)')

ylabel('Temperature (degrees Fahrenheit)')

% Produce S DIFF Graphs

slope\_s\_top = smooth(diff(s\_inside\_top), 45)';

slope\_s\_bot = smooth(diff(s\_inside\_bot), 45)';

time\_30(end) = [];

figure(5)

plot(time\_30, slope\_s\_top, '-k')

title('Bisque Cone 05 - S Thermocouple Interior Upper Mid-section')

xlabel('Time (sec)')

ylabel('Temperature Rate (degrees Fahrenheit per sec)')

figure(6)

plot(time\_30, slope\_s\_top, '-k')

hold on

plot(time\_30, slope\_s\_bot, '--k')

title('Bisque Cone 05 - S Thermocouple Interior')

xlabel('Time (sec)')

ylabel('Temperature Rate (degrees Fahrenheit per sec)')

legend('Upper Mid-section', 'Lower Mid-section')

% Produce K Ext DIFF Graphs

slope\_k\_top = smooth(diff(k\_ext\_top), 45)';

slope\_k\_bot = smooth(diff(k\_ext\_bot), 45)';

figure(7)

plot(time\_30, slope\_k\_top, '-k')

hold on

plot(time\_30, slope\_k\_bot, '--k')

title('Bisque Cone 05 - K Thermocouple Exterior')

xlabel('Time (sec)')

ylabel('Temperature Rate (degrees Fahrenheit per sec)')

legend('Upper Mid-section', 'Lower Mid-section')

% Produce K Lid/Floor DIFF Graphs

slope\_k\_lid = smooth(diff(k\_lid), 45)';

slope\_k\_floor = smooth(diff(k\_floor), 45)';

figure(8)

plot(time\_30, slope\_k\_lid, '-k')

hold on

plot(time\_30, slope\_k\_floor, '--k')

title('Bisque Cone 05 - K Thermocouple Lid and Floor')

xlabel('Time (sec)')

ylabel('Temperature Rate (degrees Fahrenheit per sec)')

legend('Lid', 'Floor')

**Attachment D:** Contains MATLAB code used in analysis of Glaze Firing Cone 05 Data

% IR#1 GLAZE FIRE PLOTTING CODE

clear all

clc

clf

glaze = importdata('Glaze Cone 6 Firing.xlsx');

glaze\_data = (glaze.data)';

log\_time = glaze\_data(1, 3:end);

% Temperature Vectors

s\_inside\_top = glaze\_data(2, 3:end);

s\_inside\_bot = glaze\_data(4, 3:end);

k\_ext\_top = glaze\_data(5, 3:end);

k\_ext\_bot = glaze\_data(8, 3:end);

k\_lid = glaze\_data(9, 3: end);

k\_floor = glaze\_data(11, 3: end);

scale = length(log\_time);

% Time Vector

time\_30 = linspace(1, 30\*scale, scale);

% End of Time

end\_time = time\_30(end)./3600; % hours

% Maximum Temp S Top

[s\_top\_max, s\_top\_loc] = max(s\_inside\_top);

% Time

s\_top\_max\_t = time\_30(s\_top\_loc);

% Maximum Temp S Bot

[s\_bot\_max, s\_bot\_loc] = max(s\_inside\_bot);

% Time

s\_bot\_max\_t = time\_30(s\_bot\_loc);

% Maximum Temp K Top

[k\_top\_max, k\_top\_loc] = max(k\_ext\_top);

% Time

k\_top\_max\_t = time\_30(k\_top\_loc);

% Maximum Temp K Bot

[k\_bot\_max, k\_bot\_loc] = max(k\_ext\_bot);

% Time

k\_bot\_max\_t = time\_30(k\_bot\_loc);

% Maximum Temp K Lid

[k\_lid\_max, k\_lid\_loc] = max(k\_lid);

% Time

k\_lid\_max\_t = time\_30(k\_lid\_loc);

% Maximum Temp Floor

[k\_floor\_max, k\_floor\_loc] = max(k\_floor);

% Time

k\_floor\_max\_t = time\_30(k\_floor\_loc);

% Produce S Time-Temp Graphs

figure(1)

plot(time\_30, s\_inside\_top, '-k')

title('Glaze Cone 6 - S Thermocouple Interior Upper Mid-section')

xlabel('Time (sec)')

ylabel('Temperature (degrees Fahrenheit)')

figure(2)

plot(time\_30, s\_inside\_top, '-k')

hold on

plot(time\_30, s\_inside\_bot, '--k')

title('Glaze Cone 6 - S Thermocouple Interior')

xlabel('Time (sec)')

ylabel('Temperature (degrees Fahrenheit)')

legend('Upper Mid-section', 'Lower Mid-section')

% Produce K Exterior Time-Temp Graphs

figure(3)

plot(time\_30, k\_ext\_top, '-k')

hold on

plot(time\_30, k\_ext\_bot, '--k')

title('Glaze Cone 6 - K Thermocouple Exterior')

xlabel('Time (sec)')

ylabel('Temperature (degrees Fahrenheit)')

legend('Upper Mid-section', 'Lower Mid-section')

% Produce K Lid/Floor Time-Temp Graphs

figure(4)

plot(time\_30, k\_lid, '-k')

hold on

plot(time\_30, k\_floor, '--k')

title('Glaze Cone 6 - K Thermocouple Lid and Floor')

xlabel('Time (sec)')

ylabel('Temperature (degrees Fahrenheit)')

legend('Lid', 'Floor')

figure(11)

plot(time\_30, k\_lid, '-k')

hold on

plot(time\_30, k\_ext\_top, '-.k')

hold on

plot(time\_30, k\_ext\_bot, '--k')

title('Glaze Cone 6 - K Thermocouple Lid and Walls')

xlabel('Time (sec)')

ylabel('Temperature (degrees Fahrenheit)')

legend('Lid', 'Upper Mid-section', 'Lower Mid-section')

% Magnitude of S ranges

s\_range = abs((s\_inside\_top - s\_inside\_bot));

k\_ext\_range = abs((k\_ext\_top - k\_ext\_bot));

k\_lf\_range = abs((k\_lid - k\_floor));

[s\_max\_mag, s\_max\_mag\_loc] = max(s\_range);

s\_mag\_pos = time\_30(s\_max\_mag\_loc);

[k\_ext\_max\_mag, k\_ext\_max\_mag\_loc] = max(k\_ext\_range);

k\_ext\_mag\_pos = time\_30(k\_ext\_max\_mag\_loc);

[k\_lf\_max\_mag, k\_lf\_max\_mag\_loc] = max(k\_lf\_range);

k\_lf\_mag\_pos = time\_30(k\_lf\_max\_mag\_loc);

% Average ranges

s\_AVG\_range = sum(s\_range)./length(s\_range);

k\_ext\_AVG\_range = sum(k\_ext\_range)./length(k\_ext\_range);

k\_lf\_AVG\_range = sum(k\_lf\_range)./length(k\_lf\_range);

% Produce Vector Graphs

figure(9)

plot(time\_30, s\_range, '-k')

hold on

plot(time\_30, k\_ext\_range, '--k')

title('Glaze Cone 6 - S&K Thermocouple Magnitudes')

xlabel('Time (sec)')

ylabel('Temperature (degrees Fahrenheit)')

legend('S Interior', 'K Exterior')

figure(10)

plot(time\_30, k\_lf\_range, 'k')

title('Glaze Cone 6 - K Thermocouple Lid&Floor Magnitudes')

xlabel('Time (sec)')

ylabel('Temperature (degrees Fahrenheit)')

% Produce S DIFF Graphs

slope\_s\_top = smooth(diff(s\_inside\_top), 45)';

slope\_s\_bot = smooth(diff(s\_inside\_bot), 45)';

time\_30(end) = [];

figure(5)

plot(time\_30, slope\_s\_top, '-k')

title('Glaze Cone 6 - S Thermocouple Interior Upper Mid-section')

xlabel('Time (sec)')

ylabel('Temperature Rate (degrees Fahrenheit per sec)')

figure(6)

plot(time\_30, slope\_s\_top, '-k')

hold on

plot(time\_30, slope\_s\_bot, '--k')

title('Glaze Cone 6 - S Thermocouple Interior')

xlabel('Time (sec)')

ylabel('Temperature Rate (degrees Fahrenheit per sec)')

legend('Upper Mid-section', 'Lower Mid-section')

% Produce K Ext DIFF Graphs

slope\_k\_top = smooth(diff(k\_ext\_top), 45)';

slope\_k\_bot = smooth(diff(k\_ext\_bot), 45)';

figure(7)

plot(time\_30, slope\_k\_top, '-k')

hold on

plot(time\_30, slope\_k\_bot, '--k')

title('Glaze Cone 6 - K Thermocouple Exterior')

xlabel('Time (sec)')

ylabel('Temperature Rate (degrees Fahrenheit per sec)')

legend('Upper Mid-section', 'Lower Mid-section')

% Produce K Lid/Floor DIFF Graphs

slope\_k\_lid = smooth(diff(k\_lid), 45)';

slope\_k\_floor = smooth(diff(k\_floor), 45)';

figure(8)

plot(time\_30, slope\_k\_lid, '-k')

hold on

plot(time\_30, slope\_k\_floor, '--k')

title('Glaze Cone 6 - K Thermocouple Lid and Floor')

xlabel('Time (sec)')

ylabel('Temperature Rate (degrees Fahrenheit per sec)')

legend('Lid', 'Floor')