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**MEMORANDUM**

**Date:** February 9, 2012

**To:** Dr. Timothy Placek, Assistant Professor

**Subject:** Interim Report 1

**Executive Summary**

For this interim report the goal was to take a set of data obtained from two runs of the L&L CONE 12 kiln system organize the data, and analyze it for useful information about the kiln and the processes it undergoes while in operation. In this analysis the data was broken up into distinct subsets based on how it was gathered. The key foci of the analysis performed were: the general trends generated by the temperature data, the difference in temperatures between the top and bottom interior thermocouples, and the anomalies in the room temperature while the kiln was in operation. These three topics combined helped provide insight into the overall ability of the kiln to operate correctly and efficiently.

MATLAB was used to make sense of the data provided. This included graphical illustrations, mathematical expressions, and locating important points of data. These tools allowed for an accurate and precise comparison of data.

These areas of focus were chosen due to the fact that each revealed distinct indications about the operation of the kiln. The general trends were analyzed because they provided information about the control scheme of the kiln. The difference in temperatures illustrated the regions that exist within the kiln and the distinct phenomena that cause these regions. The room temperature data points out the fact that heat is constantly leaking from the kiln while it is in operation.

**Analysis**

The data was collected from two consecutive firing runs of the L&L CONE 12 kiln system. The first of these runs was a slow firing bisque run at cone 05 to remove any excess water within the clay and provide a porous structure for the application of the glaze. The second run was a fast glaze run at cone 6 to cook and set the glaze onto the pottery.

Temperature data was collected at various points in and around the kiln during the runs using six thermocouples. Two of the sensors were type S which are made of platinum and rhodium. Due to the increased accuracy these precious metals provide, they were placed at the interior top and bottom positions of the kiln to provide the most accurate and precise readings for the thermal controller (Tempsens).

The other four thermocouples were type K which are made of a nickel and chromium alloy (Tempsens). These were placed at the top and bottom exterior and the lid and floor of the kiln to provide additional data about the kiln firing process. Using MATLAB the data was analyzed for a deeper understanding of the condition in and around the kiln while it was in operation. See Appendix for MATLAB code.

**Discussion**

The general trends of the top and bottom interior temperatures for the slow bisque run follow the same pattern. This allows them to be discussed together as one process. For additional information about the bottom interior temperature see Appendix. Based off graphing the interior top temperature, the data can be broken into four distinct regions as shown in Fig. 1. The first ramp up period of the kiln is represented by the region between points A and B. In this region the temperature rose from 76 oF to 181oF at an average rate of 270.2 oF/h. From points B to C, the kiln was held at an average temperature of 522 oF for fifteen hours. This holding period is called the candling period and serves to remove any excess water that remains inside the clay. Between points C and D ramp up occured at a rate of 40.7 oF/h and took the kiln to 1,615 oF. At this temperature, the rate changed to 64.77 oF/h until the final max temperature of 1851 oF was reached as show by the region between points D and E. From point D to F the kiln cooled off at a rate described by Equation (1) below:

 $T=9.00 x 10^{10} t^{-5.299}$ (1)

with an R² of 0.9987.



Figure 1

The fast glaze firing data, as seen in Fig. 2, follows the same general trends as the slow bisque run with some distinct variations. Once again the top and bottom interior temperature both follow the same general trend. For additional information about the bottom interior temperature for the fast run see Appendix. Based off the interior top temperature the initial ramp up rate, the period between points A and B, begins at temperature of 192 oF at a rate of 938 oF/h and was held until the temperature reaches 1951 oF. At this temperature the rate changed to 509 oF/h until the max temp of 2220 oF was reached as shown by the region between B and C. The rate of cooling T (oF/h), from points C to D in the kiln is described by Equation (2) below:

 $T=4423.9e^{-0.188t}$ (2)

where t is time in hours. The R² value for Eq. (1) is 0.9916.



Figure 2

The external Type K thermocouples for both runs follow the same general trends as stated above for the type S as shown by comparing Fig. 1 to Fig. 3. However the changes in heating rate are not as well defined for the type K’s. There are also some slight differences due to their positions on the kiln. They were located between the thermal brick and the exterior wall and due to this the thermal brick’s insulating properties kept them from experiencing the high temperatures that the types S’s did. Their placement behind the thermal brick also caused a 0.525 hour delay between the type K peak and the type S peak. See Figure 4 below for further detail.



Figure 3



Figure 4

The next part of the data analyzed was the difference between the top and bottom interior and top and bottom exterior temperatures. As with the previous figures, the data was broken down into distinct regions.

For the slow run type S, because of the longer run time due to the candling period the top and bottom temperatures changed at relatively the same rate until the cooling period began as seen in Fig. 5. At this time, the top cooled faster until point A at which the point the top and bottom began to cool at about the same rate as show by the sharp increase toward peak B. From here, the thermal mass in the bottom of the kiln started to have a visible effect on the bottom of the kiln causing a negative difference in temperature for the remainder of the graph.



Figure 5

For the fast run type S thermocouples, shown in Fig. 6 below, the bottom was consistently a hotter temperature until point A. This change was due to the top temperature overtaking the bottom hence the reason the graph begins a positive trend. The first plateau at marker B is a time frame when the rate of change of the top and bottom was relatively equal. The next increase in DT was due to another change in the rate of heating of the bottom. The decrease in the graph from points C to D is a result of the bottom overtaking the top as a result of a change to the overall ramp rate. The third plateau at point E is a time frame where the top and bottom temperatures tracked together after the overall ramp rate change. The reason for the constant negative difference in temperature after this point was due to the fact that while the overall temperature was decreasing the thermal mass of the shelves and pottery caused the bottom half to cool at a slower overall rate.



Figure 6

For the exterior difference in temperature for type K thermocouples, both fast and slow, the top were consistently hotter than the bottom hence the positive aspects of Fig. 7. The overall trend in each change in temperature was relatively the same according to the type S trends for each run, but after the kiln began cooling, unlike the interior, the exterior bottom cooled faster than the top. This is due to the fact that the type K sensors measured the external temperature which did not see the effect of thermal mass due to the insulating thermal bricks. The shift in the peaks between the fast and slow run was due to the candling period of the slow run.



Figure 7

The room temperature data provides additional information about what was happening outside the kiln during the process. The additional noise, seen in Fig. 8, was from the air conditioner turning on and off. The general uptrend of the data was generated by the inability of the air conditioner to compensate for the increase in energy released as heat from the kiln. As the kiln and room heats up, the air conditioner will cut on, but will cut off after a certain time interval due to mechanical constraints.

While the kiln was in operation the floor type K thermocouple gave a max temperature, for both runs, of approximately 120°F as shown by Fig.9. This is a 50°F increase from the starting room temperature of 70°F. The thermometer located in the room while the kiln was running measured a 17.1°F increase in the room temperature. These numbers show that the kiln is not adiabatic while in operation. There is a non-negligible amount of heat lost during the firing process as shown by the room temperature data.



Figure 8

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Figure 9

**Conclusion**

The areas of foci chosen each revealed distinct indications about the operation of the kiln. The control scheme of the kiln is quite precise as evident by the overall stability of the kiln internal temperature and the minimal temperature differences between the top and bottom interior sections. The difference in temperatures between the interior top and bottom and the exterior top and bottom sensors show the effect of the mass inside the kiln absorbing the heat generated by the kiln to change the chemical and physical structure. The room temperature and floor temperature data illustrate the immense insulating properties of air and the amount of heat escaping from the kiln while in operation is non-negligible. The overall conclusion of this analysis is that the kiln control system is very effective and the amount of heat both absorbed by the mass in the kiln, and the air within the room is measurable and significant.

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**References**

Tempsens. (n.d.). *Thermocouples reference data*. Retrieved from <http://www.tempsens.com/thermocouple_pdf/Thermocouple_Reference_data.pdf>

**Appendix**

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Figure A-1

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Figure A-2



Figure A-3



Figure A-4

See attached for MATLAB code