CHEN 3600 Computer-Aided Chemical Engineering

Department of Chemical Engineering

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**MEMORANDUM**

**Date:** February 13, 2012

**To:** Dr. Timothy Placek, Undergraduate Program Chair

**Subject:** Detailed Analysis of Kiln Temperature Data

**Executive Summary**

On Monday, January 30, Dr. Placek’s Computer-Aided Chemical Engineering class was given the task of analyzing two sets of data from a kiln. The class was asked to include a detailed analysis of the data, informative plots, and basic descriptive information about the data sets, as well as technical commentary and meaningful summarizations of the data characteristics. The first set of data contained temperature values for various times for a slow bisque firing to cone 05, while the second contained similar information for a fast glaze firing to cone 6 using the same kiln.

The computer software, MATLAB, was incorporated to aid in the analysis of the various data plots of temperature and time. Numerous plots were prepared in order to depict the various trends in temperature data, such as temperature-vs.-time plots, temperature-rate-vs.-time plots, temperature-difference-vs.-time plots, and temperature-rate-vs.-temperature plots. The plots were then analyzed to determine general trends and meaningful relationships in the temperature data.

 After careful analysis, it was found that the firing sections for both the slow bisque and fast glaze firings could be divided into three distinct regions with unique heating rates. Furthermore, after the kiln has been turned off, one can see a characteristic exponential decay in temperature for both types of firings. Interestingly, the temperatures within the kiln were not as uniform as one would expect. Instead, the temperature differences varied over time, depending on the firing of the kiln. It was also determined that the exterior surface of the kiln, as well as the floor beneath the kiln and the air within the room, were greatly affected by the processes that took place within the kiln. It seems that every element within the room was ‘aware’ of the kiln, but to varying degrees.

**Purpose**

The purpose of this assignment was to analyze two sets of temperature data from a kiln to determine important relationships, while developing explanations for the various data characteristics. Following this analysis, it is expected that one can apply these trends to explain similar phenomena within a number of different kiln firings.

**Theory**

The kiln used in this study was an L&L Cone 12: E23S-JH for Crystalline Glaze Firing Kiln. This kiln was constructed of 2.5 in K25 firebrick wrapped in a stainless steel covering. The lid of the kiln consisted of 3 in K25 firebrick with a stainless steel wrapping (L&L CONE 12 KILN). The K25 firebrick used in this kiln has a very low thermal conductivity with relatively little temperature dependence (Specification Sheet for K23 and K25 Firebrick).

Temperature values were recorded using an Omega Engineering Series CN7800 microprocessor based temperature process controller from six different locations. Two built-in Type S thermocouples in the interior of the kiln were used to measure the temperature of the top and bottom interior sections of the kiln. These thermocouples had aluminum oxide coverings for protection. Additionally, four Type K thermocouples were used to measure the external temperatures of the top and bottom side sections of the surface of the kiln, the surface of the kiln lid, and the surface of the floor beneath the kiln. Despite common assumptions about the accuracy of thermocouples and receivers, the Omega receiver only has a rated accuracy of ±0.25% of the input range, according to the manufacturer. For Type S thermocouples, which cover a range from 32 oF to 3092 oF, the rated accuracy corresponds to ±7.65 oF. Type K thermocouples, on the other hand, would have a rated accuracy of ±6.75 oF for a range of -328 oF to 2373 oF (DIN Ramp/Soak Controllers).

For ventilation purposes, a Vent-Sure Downdraft Kiln Vent System was incorporated to ensure a more uniform heat distribution, drawing warmer air from the top of the kiln down the kiln chamber. The ventilation system also introduces a fresh source of oxygen into the kiln atmosphere, which can cause changes in the appearance of glazes (EnviroVent 2 Ventilation System).

Candling is an essential part of kiln bisque firing intended to remove all water from the kiln prior to higher temperature firings. If water within the clay rapidly reaches its boiling temperature (212 oF at 1 atm), the water boils. Furthermore, if this occurs rapidly due to a fast heating process, it could result in the explosive expansive of the water into steam, thereby destroying the object being fired and potentially damaging the heating elements within the kiln (Dynatrol Reference Instructions).

Orton Pyrometric Cones are very useful instruments used to judge when a firing is complete, for instance, “when the cone tip reaches a point level with the base, it is considered properly fired.” Each type of cone is made from different compositions of materials. Different firings require different cone levels, depending on the length of time and temperature at which the cone is fired. Faster firings, for instance, require higher level cones, whereas slower firings require lower level cones (Temperature Equivalent Chart for Orton Pyrometric Cones).

The temperature change for an infinite cylinder being heated or cooled is given by the equation

$\frac{T\_{s}-T\_{b}}{T\_{s}-T\_{a}}=0.692e^{-5.78\frac{αt}{r^{2}}} +0.131e^{-30.5\frac{αt}{r^{2}}} +.0534e^{-74.9\frac{αt}{r^{2}}}$ (1)

where t is the amount of time of heating or cooling, TS is the constant surface temperature of the cylinder, Tb is the average slab temperature, Ta is the initial slab temperature, and r is the radius of the cylinder (McCabe, Smith, Harriott, 2005). The kiln is not infinite, nor is it an exact cylinder, so this equation will not give an exact equation for the temperature of the kiln at a particular time. However, the rate of cooling of the kiln should follow a similar pattern to Eq. (1) when the kiln is turned off after being fired.

**Results and Conclusions**

Fast Glaze Firing

Upon viewing the plot of the top interior temperature against time in Fig. 1, one can see that there seem to be three separate heating regions, as well as a region of unrestrained cooling, in which the kiln is turned off and allowed to cool. In the first section, the temperature appears to change at a constant rate of 550 oF /h from time t = 0 h to t = 2.75 h, as seen by Fig. 2. In the second section, from t = 2.75 h to t = 3.5 h, the rate of heating decreases linearly from 550 oF /h to approximately 360 oF /h before experiencing a sharp dip. In the third section, the change in temperature in the kiln appeared to change at a constant rate of approximately 200 oF /h from time t = 3.5 h to t = 4.8 h. At the end of this heating period, the kiln shut off, as per schedule, and the heating rate experienced a significant spike from roughly 200 oF /h to -1908.0 oF /h. When the kiln shuts off, the heat generated by the elements begins to decrease until virtually no heat is being generated. It is at this point of initial shut off that the rate of heat loss is greatest. Over time, this rate decreases in a fashion similar to that of an exponential function. It is interesting to note that the initial temperature of the top interior section was 192.4 oF. This indicates that temperature data was not recorded until some time after the kiln had begun the heating process. It is also interesting to note that it took approximately 4.8 h for the kiln to reach its maximum temperature of 2220.5 oF, but it took nearly twice as long (9.2 h) for the kiln to cool ninety five percent of the way from its maximum temperature back to its initial temperature.



Figure 1 – Temperature profile of the top internal kiln section.

 Figure 2 – Profile of the top internal instantaneous temperature change (temperature derivative).

In Fig. 3 one can see a pattern very similar to that of the plot of the top interior temperature for that of the bottom interior. Again, there are three distinct regions of heating, as well as a region of unrestrained cooling. From time t = 0 h to t = 2.0 h, the kiln was heated at a constant rate of 550 oF /h, similar to that found for the top interior section of the kiln. In the second section, the rate of heating again decreased linearly from 550 oF /h to roughly 350 oF /h from time t = 2.0 h to t = 3.5 h before experiencing a sharp drop similar to that of the top interior temperature. Similarly, the third heating section featured a constant heating rate of approximately 200 oF /h from time t = 3.5 h to t = 4.8 h before experiencing a similar drop in heating rate. Unlike the top section, the initial temperature of the bottom section was 200.9 oF. This 8.5 oF difference can be attributed to a number of different factors. As discussed earlier, the Type S thermocouples have an accuracy of $\pm $7.65 oF. This means that for any given scenario, the two thermocouples could read temperatures that differ in size from 0 to 15.3 oF. This sort of range provides a large possibility for error, and could explain the 8.5 oF difference. However, the difference in temperature can most likely be attributed to the fact that when the kiln was loaded, there was a greater concentration of material in the bottom section of the kiln. As the kiln was heated, this material absorbed a great deal of heat. This heat then radiated from the surfaces of the materials, in addition to the heat radiated from the sides of the kiln. Since the top section of the kiln was filled predominantly with air, the temperature measured was due primarily to that of the radiation of heat from the kiln walls. The temperature of the bottom section, on the other hand, was also affected by the radiation of heat from the materials being fired. This additional source of radiation and retained heat is the most logical explanation for this phenomenon. Similar to the top section interior, it took about 4.8 h for the kiln to reach its maximum temperature of 2225.3 oF. Furthermore, it took about twice as long for the kiln to cool ninety five percent of the way back to its initial temperature (9.3h), just as it did for the top section interior.



Figure 3 - Temperature profile of the bottom internal kiln section.



Figure 4 – Temperature derivative profile of the bottom internal kiln section.

When comparing Figs. 1 and 3 to one another, one can see that the two correspond quite closely to one another. This is to be expected because the kiln is designed to ensure uniform heating throughout its volume. When the difference in temperatures is plotted against time, however, one can see that the differences are not as small as they initially appear. In fact, Fig. 5 shows that the bottom of the kiln remained at a higher temperature than the top section for much of heating process and the entire cooling process. In fact, the bottom section of the kiln was 31.8 oF warmer than the top section at one point after the kiln was turned off. As mentioned earlier, this difference in temperature is likely due to the radiation of heat from pieces being fired in the bottom of the kiln. There was, however, a brief period of time in which the temperature of the top section was greater than that of the bottom. This corresponds to the time at which the heating rate in the kiln was decreased. In fact, the top section was 17.2 oF warmer than the bottom section just before the kiln reached its final period of constant heating. It is possible that the decreasing heating rate allowed convection to become a prominent factor in heat transfer within the kiln. However, this seems unlikely because of the downward pull of the ventilation system.



Figure 5 – Profile of temperature differences in the top and bottom interior.

From Figs. 2, 4, and 5, one can see sharp spikes in the temperature data at increasing time intervals that correspond closely to one another. When plotting the instantaneous temperature change against temperature, as in Fig. 6, one can see that these spikes appear to happen at specific temperatures, during both the heating and cooling stages of the firing. It is important to note that when heating, the temperature change spiked down to a cooler temperature, but when cooling, the temperature change spiked up to a warmer temperature. During a consultation with Dr. Placek, it was found that the Type S thermocouples inside the kiln were covered with aluminum oxide to protect them from any of the pieces being fired. He hypothesized that these spikes in the data were due to changing crystalline structures of aluminum oxide. This explanation is plausible because the spikes are associated with particular temperature; however, there is no direct evidence to substantiate. Another potential explanation for this phenomenon lies in the materials and glazes being fired. However, this seems exceedingly unlikely because spikes in temperature change are rather sharp and the materials being fired are rather far from the thermocouples.



Figure 6 – Temperature derivative profile of the top internal section with temperature.

While the temperatures inside the kiln are obviously important to the glazing and other chemical processes, the exterior temperature of the kiln is also of particular interest. As seen from the plots of the top and bottom section exterior temperatures of the kiln over time in Figs. 7 and 8, one can see that the exterior of the kiln was greatly affected by the heating process. In fact, the exterior temperature of the kiln reached as high as 615.5 oF for the top section and 592.4 oF for the bottom section. These maximum temperatures occurred at 5.3 h and 5.1 h, respectively. These differences in temperature and the time at which they occurred can be explained by the fact that, when the kiln was turned off, heat continued to penetrate the firebrick and steel covering of the kiln. Eventually, the temperature of the kiln’s exterior reached a maximum temperature some time after the kiln was turned off and the rate of heat flux through the walls decreased. The hot surface of the kiln also caused the air near the kiln to increase in temperature. As the air near the surface of the kiln was heated, it began to rise in convective currents. It is for this reason that the top section of the kiln reached a higher temperature than the bottom section. Hot air surrounding the bottom section of the kiln rose, coating the top section with additional hot air and serving as an additional source of insulation against heat loss. This also explains why the top section did not reach its maximum temperature until a period of time after the bottom section. It is important to note that the temperature of the kiln’s exterior reaches dangerously high temperatures that could cause severe damage.



Figure 7 - Temperature profile of the top exterior kiln section.



Figure 8 - Temperature profile of the bottom external kiln section.

When comparing the two plots of exterior temperature of the top and bottom to one another, one can see that the two correspond quite closely to one another. This situation is similar to that of the top and bottom internal temperatures. As in Fig. 9, when the difference in temperatures is plotted against time, however, one can see that, again, the differences are not as small as they initially appear. Unlike the internal temperature differences, however, the top exterior section of the kiln remained at a higher temperature than the bottom section for virtually the entire firing process. In fact, the top section reached as high as 39.1 oF above the bottom section at one point in time. Immediately after the firing process began, the temperature difference between the two sections began to rise. The temperature difference seemed to reach a peak near the point at which the top internal temperature of the kiln surpassed that of the bottom internal section. Interestingly, the temperature difference dropped dramatically near the time that the kiln was shut off. This is likely due to the fact that, when the kiln was shut off, the amount of heat penetrating the sides of the kiln decreased. This, in turn, reduced the level convection near the surface of the kiln. Furthermore, it was near this point in time that the bottom interior temperature of the kiln rose above that of the top interior. The second large peak is likely a result of the convection of air near the surface of the kiln.



Figure 9 – Temperature difference profile between the top and bottom exterior sections.

Upon inspection of the plots of the kiln lid and floor temperature against time, one can see that both of these regions were rather sensitive to the activities within the kiln. As seen in Fig. 10, the lid, reached a maximum temperature of 345.0 oF at time t = 5.3 h. However, there was a great deal more noise in this temperature reading than there was for the interior and side exterior sections of the kiln. This can be explained by the large amount of air circulating over the lid of the kiln due to the fan within the room, as well as the convection of air around the kiln. It is also interesting to note that the lid of the kiln did not reach as high of a temperature as the side exterior sections. This was due to the additional 0.5 in of K25 firebrick found in the lid. This firebrick is an excellent insulator and did not allow as much heat to penetrate the lid.



Figure 10 - Temperature profile of the surface of the kiln lid.

As seen in Fig. 11, the temperature reading for the floor, on the other hand, had a significantly greater deal of noise with fairly consistent oscillations in temperature, mostly likely a result of the air conditioning unit’s close proximity to the kiln, as well as the large separation between the thermocouple and the bottom of the kiln. Despite these factors, the temperature of the floor did manage to reach 129.1 oF at one point. While this is not an exceedingly dangerous temperature, it is not advisable to approach or leave items underneath the kiln when it is in operation.



Figure 11 – Smoothed temperature profile of the floor directly beneath the kiln.

Slow Bisque Firing

The slow bisque firing is the result of a pre-programmed heating procedure in the kiln’s controller and fires to a cone 05. The slow bisque program brings the kiln to an initial “candling” temperature, maintains that temperature for a period of several hours, and then fires the kiln to a much higher temperature. Finally, the kiln shuts off, allowing the kiln to drop in temperature and eventually return to room temperature. This allows the kiln temperature plot to be broken up into 4 general regions, similar to those of the fast glaze firing: the initial heating phase, the candling phase, the firing phase, and the cooling phase.

Figures 12 and 13 show the temperature profiles for the thermocouples in the top and bottom of the interior of the kiln during the slow bisque run. The initial heating phase is straightforward. Both plots increased at an approximately linear rate, with a slope of 55.0 oF/h from time t = 0 to t = 2.0 h. However, comparing the two sets of data to one another yields some unexpected results. The difference between the top internal and bottom internal thermocouples is plotted in Fig. 14. The temperature measured by the bottom thermocouple was higher than that of the top throughout the initial heating phase. At time t = 0, the temperature of the top was 78.2 oF, while the bottom was 83.5 oF, for a temperature difference of 5.3 oF; at time t = 2.0 h, the temperature of the top was 180.3 oF, while the bottom was 188.9 oF, for a temperature difference of 8.6 oF. These temperature differences are fairly small, and could be due to the slight inaccuracies of the thermocouples, as mentioned earlier. Additionally, the temperature difference could be due to the kiln’s ventilation system. The kiln is vented by a duct at the bottom of the kiln with a fan that creates a pressure drop. Since warmer air is less dense than cool air, it would normally pool at the top of the kiln. The ventilation system, however, draws air toward the bottom of the kiln, creating a region of warmer air at the bottom of the kiln. This could cause the bottom of the kiln to reach a higher temperature at this phase of the firing. This temperature difference can also be attributed to the fact that there are a number of clay items being fired in the bottom section of the kiln, each of which retain a large amount of heat.

During the candling process, the kiln was held at a temperature just below the boiling point of water, so that moisture within the clay could evaporate without boiling. In this bisque firing, the candling temperature was maintained from time t = 2.0 h to time t = 17.0 h. During this time, the top thermocouple maintained an average temperature of 178.5 oF, and the bottom thermocouple maintained an average temperature of 187.4 oF. Fluctuations in temperature in this region were minimal, and were generally well within the tolerance of the thermocouples; this is to be expected, because the controller was programmed to keep the kiln at a fairly constant temperature during the candling process.

The firing phase contained the most rapid temperature increases in the process. This phase extends from time t = 17.0 h to t = 28.3 h for a duration of 11.3 h, and it can be subdivided into three regions, each with unique, approximately linear rates of temperature. The first of these regions from time t = 17.0 h to t = 22.0 h, had an average slope of 179.9 °F/h; the second region, from time t = 21.5 h to t = 25.2 h, increased at a rate of 164.5 °F/h; the third region from time t = 25.2 h to t = 28.3 h rose at a rate of 76.8°F/h. These three distinct regions of heating were due to the programming of the controller that powers the heating elements. The maximum temperature of the top interior was found to be 1851 oF, and the maximum temperature of the bottom interior was 1856.9 oF. These maximum temperatures were significantly lower than those achieved during the fast glaze firing. This is due to the fact that the slow bisque run is designed to fire at cone 05, which requires substantially less heat work than that of a fast glaze run firing to cone 6. Furthermore, the slow bisque firing occurred over a much longer time span than the fast glaze run, which took only 4.8 h. Lower cone numbers require lower temperatures to achieve the required amount of heat work, and longer heating durations reduce the maximum temperature required to achieve a particular cone specification. Since the slow bisque firing used a lower level cone 05 (as opposed to a cone 6), and the slow bisque firing occurred over a longer period of time than the fast glaze run, a substantially lower maximum temperature was required to obtain the same amount of heat work for the slow bisque run.

During the cooling phase, the kiln was shut off, and the top and bottom internal temperatures dropped at a rate resembling exponential decay, as seen in Figs. 12 and 13. This phenomenon can be explained by approximating the kiln as a cylinder and assuming that heat is lost from the inside of the kiln primarily through conduction through the walls of the kiln. From Eq. (1), temperature drop in a cylinder due to conduction follows a negative exponential; therefore, the exponential decay seen in the kiln temperature data fits this model (McCabe, Smith, Harriott, 2005).



Figure 12 – Temperature profile of the top interior kiln section for the slow bisque run.



Figure 13 – Temperature profile of the top exterior kiln section for the slow bisque run.



Figure 14 – Profile of the difference between the top and bottom of the kiln interior for the slow bisque run.

Figure 15 shows the instantaneous rate of change of temperature with respect to time plotted against time. While the temperature change with respect to time was nearly linear in each of the three regions of the firing phase, it is important to note the presence of several spikes in the instantaneous temperature change. As seen from Fig. 16, the spikes occurred at specific temperatures rather than at specific times during the heating process. In fact, the spikes occurred at the same temperatures (507°F, 837°F, 1222°F, and 1616°F) during both the heating and the subsequent cooling of the kiln. It is particularly compelling that, as seen in Fig. 6, similar spikes were seen at the same temperatures during the fast glaze run. This indicates that the spikes in the instantaneous temperature change were consistent for these temperatures across different types of firings of the kiln. Thus, the spikes appear to be associated with the thermocouples reaching specific temperatures, rather than with the particular way in which the kiln was fired. This finding supports the hypothesis that the spikes were the result of the changing structure of the aluminum oxide thermocouple coating.



Figure 15 –Variation of instantaneous temperature change with time for slow bisque firing.



Figure 16 – Variation of instantaneous temperature change with temperature for slow bisque firing.

Figures 17 and 18 show the temperature profiles for the thermocouples in the top exterior and bottom exterior of the kiln for the duration of the run. During the initial heating phase, the top and bottom exterior temperatures rose, but at a slower rate than those of interior. The top exterior temperature increased from about 74.7 oF to 102.8 oF from time t = 0 to t = 2.5 h, whereas the bottom exterior temperature rose from a temperature of 70.5 oF at time t = 0 to a temperature of 105.9oF at time t = 2.5 h. Interestingly, the exterior temperature began to rise approximately 0.51 h later than the interior temperature. Additionally, the exterior temperature readings continued to increase after the interior temperature plateaued; the exterior temperatures rose until time t = 2.5 h, whereas the interior temperatures ceased at time t = 2.0 h. This time delay can be explained by the fact that temperature increase of the exterior was due to conduction through the firebrick of the kiln wall. The K25 firebrick used in the kiln has a very low thermal conductivity, making it a very strong insulator. For heat transfer by conduction to occur through an insulator, there must be a substantial difference between the interior and exterior temperatures. For this reason, there was no measurable increase in the exterior temperature until the interior had reached a value significantly higher than the initial internal temperature. Similarly, the exterior temperature continued to increase until it reached a thermal steady state in which the heat transfer from the interior of the kiln was offset by the heat lost to the room. However, this thermal equilibrium had to occur some period of time after the internal temperature reached its maximum because of the amount of time it took for heat to penetrate the firebrick. This explains why the exterior temperature continued to increase after the interior temperature had stopped increasing.

During the kiln firing, the exterior of the kiln increased in temperature with a profile that resembles that of the interior of the kiln, but is smaller in magnitude. The top exterior section reached a maximum temperature of 538.2 oF, while the bottom exterior section reached a maximum temperature of 517.6 oF. Although these temperatures are significantly lower than those inside the kiln, they are still not safe to touch and would likely result in severe burns.



Figure 17 – Temperature profile of the top exterior section of the kiln for the slow bisque run.



Figure 18 – Temperature profile of the bottom exterior section of the kiln for the slow bisque run.

Figure 19 illustrates the temperature of the floor below the kiln during the slow bisque run. Interestingly, the floor temperature did not increase during the initial heating phase, despite its close proximity to the kiln. The floor stayed close to room temperature, indicating that, for the relatively low temperature increase of the initial heating process, the thermal resistance of the air between the kiln and the wall, combined with the floor’s ability to act as a sink for heat, sufficiently prevented any significant temperature change. In fact, during the kiln’s initial temperature increase and candling phase, the floor temperature actually decreased. This can most likely be attributed to the air conditioning unit. It is possible that the temperature setting of the air conditioner was turned down at the start of the slow bisque firing, causing the room and the floor to decrease in temperature. This would explain the characteristic drop in temperature from 70.5 oF to 64 oF during the candling phase. Although only a small amount of heat would be transferred through convection and radiation from the kiln to the floor during the candling process, the room and air conditioning unit evidently acted as a sink for this heat, preventing the floor temperature from rising appreciably. When the kiln rapidly started to increase in temperature during the firing phase, however, the floor temperature did increase, revealing the limit to which the room and air conditioner were able to act as a sink. After the kiln was turned off, the floor began to decrease in temperature. Throughout the slow bisque firing, the floor remained much cooler than the inside or exterior surface of the kiln, reaching a peak temperature of only 122.5 oF.



Figure 19 – Profile of the floor temperature for the slow bisque run.

Upon examination of the plot of room temperature over time in Fig. 20, one can see that there is a great deal of ‘noise’ in the plot. The underlying cause of this noise is mostly likely the air conditioning unit, which is set to operate at 60 oF. As the kiln heats up, heat is released through the sides, top, and bottom of the kiln, as well as the ventilation tubing, causing the temperature of the room to rise. As this heat begins to circulate in the room, the thermostat for the air conditioning unit senses this rise in temperature and begins a cooling cycle. When the thermostat senses that it has reached an appropriate temperature of approximately 59 oF, the unit will stop cooling at its maximum. This cycle of cooling seems to take place very consistently every half hour. The measurements for room temperature were taken during a separate occasion, most likely corresponding to a slow bisque run. During the first 16 hours, which correspond to the candling process, one can see that the average temperature of the room remained fairly constant at about 60.3 oF. The oscillations in the plot were due to the cooling cycles of the air conditioning unit. As the kiln began the heating process and rapidly reached higher temperatures, the temperature of the room began to rise. Once the temperature in the kiln reached a certain value, the air conditioning unit could no longer produce enough cold air to keep the temperature of the room near 60 oF. In fact, when the temperature in the kiln was near its peak, the temperature of the room reached as high as 77.1 oF. These results, however, can be misleading. Despite Dr. Placek’s efforts to ensure that the room was at a uniform temperature, one could still sense appreciable temperature differences between different areas of the room when the kiln was firing. This would likely explain why one can still see cycles of cooling even as the temperature in the room approaches its maximum. If the air in the room were well mixed, the air conditioning unit would never cease operating at its maximum cooling as the temperature in the room began to rise because it would sense that the room was getting warmer. However, if the air were not well mixed and cool air was able to accumulate around the air conditioner, the unit may sense that it has reached an acceptable temperature, despite the temperature of the rest of the room. This is likely the case for this unit.



Figure 20 – Temperature profile of the air within the room.

**Attachments:**

Attachment 1 – Published MATLAB code for Fast Glaze and Slow Bisque Firings

**References**

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