Coal Dust Ignition

A Major Qualifying Project

Submitted to the Faculty
Of the

WORCESTER POLYTECHNIC INSTITUTE

In Partial Fulfillment of the requirements for the

Degree of Bachelor of Science

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Abstract

The goal of this project was to design, construct, and test a hot plate in the shape of a "V." The angles between the two hot plate sides are 45, 68, 90 and 180. The hot plate follows the same temperature criteria as the ASTM E2120 standard, whereby it can heat up uniformly within +/- five degrees Celsius. An array of 16 thermocouples was used to test the hot plate for uniformity in addition a thermal imaging camera was used. A numerical model was also implemented to test the influence of geometry on the temperature across the surface of the hot plate. The hot plate was tested with Pittsburgh seam coal dust to measure the ignition temperature of coal in a wedge shaped geometry. Further testing will be conducted to characterize the hazard of ignition of coal when trapped in a corner.

1 Introduction

The ignition of powders such as coal, PMMA, flour and other fine dusts has been a problem in facilities where these products are produced. The ASTM standard E2021 - 01 Standard Test Method for Hot Surface Ignition Temperature of Dust Layers is the current standard for testing of materials of this nature. The current standard only deals with the underside of the dust being heated, such as if the dust was sitting on the floor of a factory and on top of machinery. The current test is to gather data on the properties of materials to understand how they react when exposed to heat in a controlled environment. This information then has the ability to be used when determining the fire risk of the tested material. The end purpose of our work is to compare the difference in hot plate temperatures to the coal dust ignition temperatures with regards to different orientations of the heating surfaces. We are trying to find ways to avoid coal fires like the one in Centralia PA. A fire has been burning under this town for over 47 years and is estimated to burn for over another 100 years. The entire town had to be evacuated and over $40 million dollars has been wasted in attempts to stop this fire. The ongoing research, facilitated by our project, on coal and other combustible dusts could save other towns from suffering the same situation as Centralia PA.

2 Previous testing of dusts on hot plates

The current setup for conducting testing of ignition points of different thicknesses of powder uses a hot plate with a piece of metal at least 20 mm thick and larger than 200 mm in diameter. The powder to be tested is placed in a metal ring on top of the metal plate. The ring is to contain the powder that is being tested. There is a thermocouple mounted to the hotplate to record its temperature, which needs to reach at least 400 degrees Celsius. On top of this metal plate is placed different metal rings of varying depths, with a diameter of 100 mm. A thermocouple is then placed through slots in the ring so that it is located in the center of the dust to be tested. Another thermocouple is added within 1 meter of the apparatus; far enough away to not be effected by the apparatus. This thermocouple is to record the ambient temperature.

The ASTM standard E2021 has a requirement that the hot plate temperature must be maintained at plus or minus five degrees Celsius throughout the testing process. To insure that the current hot plate being used was accurate, we tested to see if there was any temperature gradient across the surface. The test setup is seen in Figure 1, which depicts eight thermocouples placed under fire bricks to hold them to the surface of the hot plate.

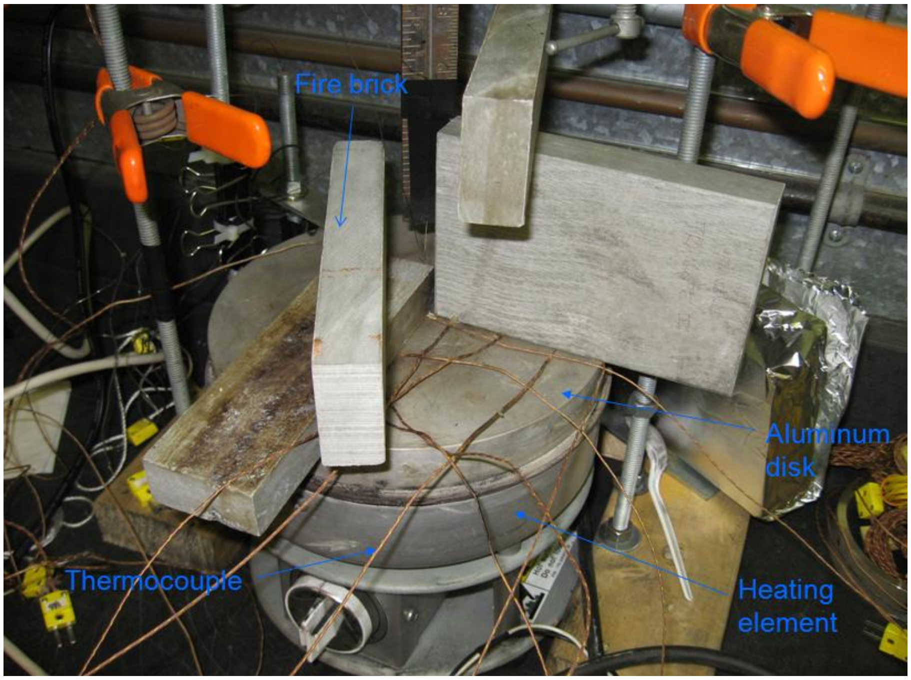


Figure 1: Thermocouples on circular hotplate

The data from the test can be seen in Figures 2 with the steady state data seen in Figure 3.

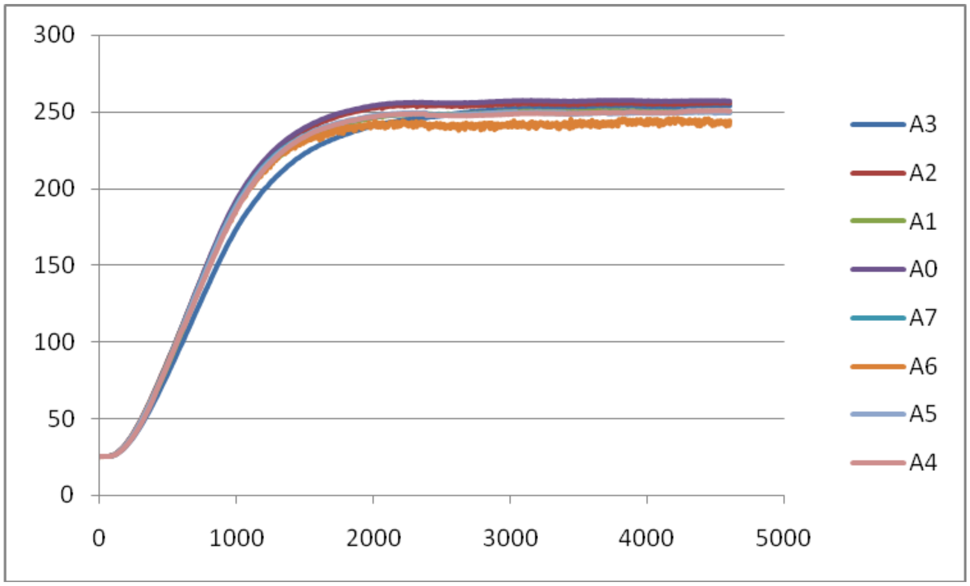


Figure 2: Data for circular hot plate

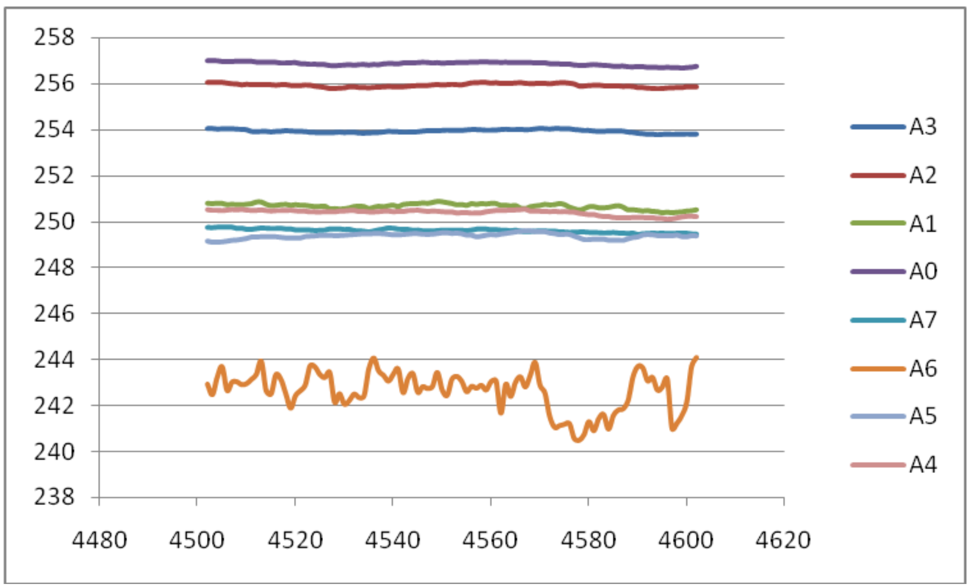


Figure 3: Steady State data for circular hotplate

From the data gathered it can be seen that the circular hotplate has a range of temperature of about eight degrees Celsius, except for one outlier. The reason for this outlier is believed that there must have been some problem with the connection between the thermocouple and the data logger because this thermocouple was located in the middle of the series as can be seen in Figure 4.

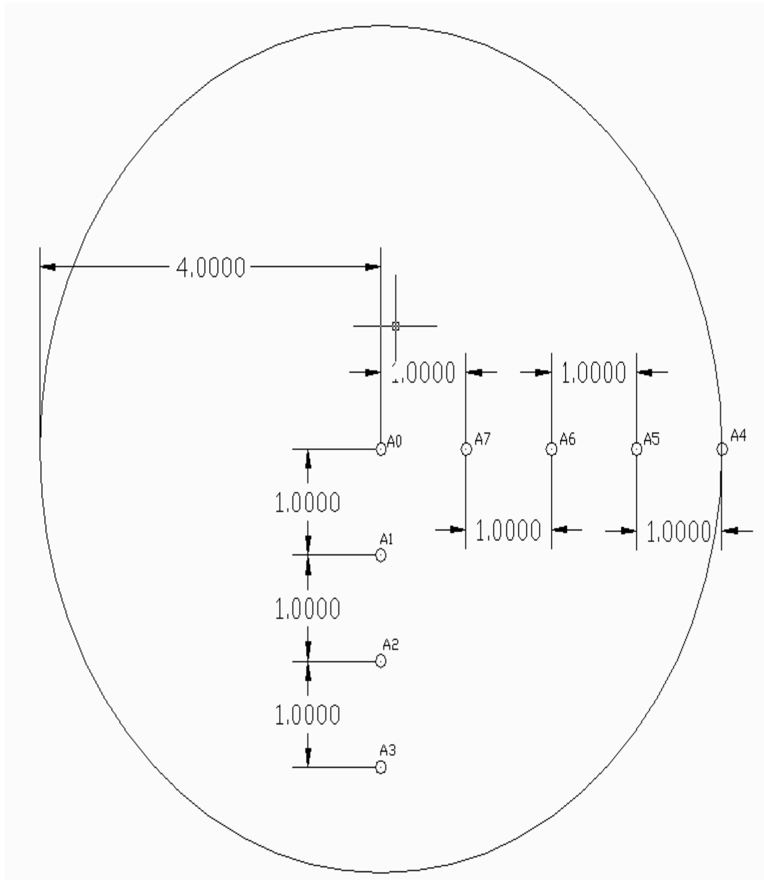


Figure 4: thermocouple location for circular hotplate

3 Experimental design

Major components

Heating elements: Chromalox OT-1250 120V 500W-heater

Aluminum stock: 1” by 2” T-6 6061 and 2” by 2” T-6 6061 aluminum stock

Temperature controller: Omega CN7533

Power supplies: 6VDC 400mA transformer

Thermocouple: type K

Wire: 14 gauge solid copper

Fasteners: ¼-20 stainless steel threaded rod, lock washers, and flat washers

Copper stock: ½” by 2” copper stock

Insulation: 1” ceramic blanket

3.1 Initial Designs

There are many reasons we settled on our final design, one being the ability of the hot plates to change angles. This was the major design requirement that needed to be met. Another important requirement was to have a constant temperature across the face of the hot plate within our required range. One of the last large requirements was that the system be able to reach a temperature of 600 Celsius. Our design needed to stand up to the same standards as the current testing apparatus.

One of our preliminary designs was the one shown in Figure 5. This is a view from the side of the apparatus. This designs advantage was that it could easily be set to any angle.

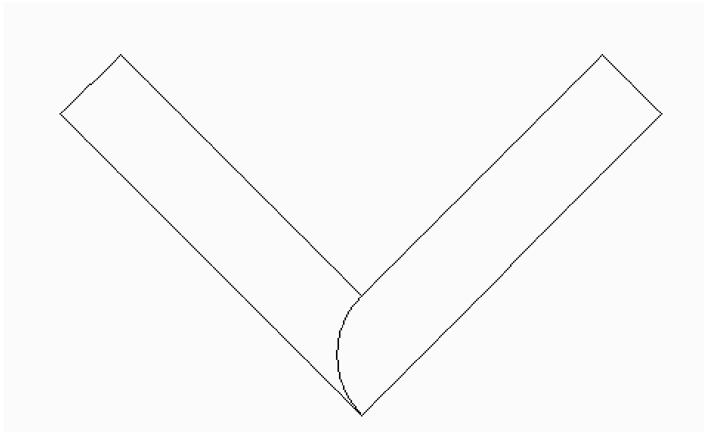


Figure 5: First design idea at 90 degrees.

This design also had numerous problems. The smallest angle that the apparatus could be set at was 90 degrees. Also when the angle was set at any position greater than 90 degrees the two sides of the apparatus would not meet at a defined angle as can be seen in Figure 6.

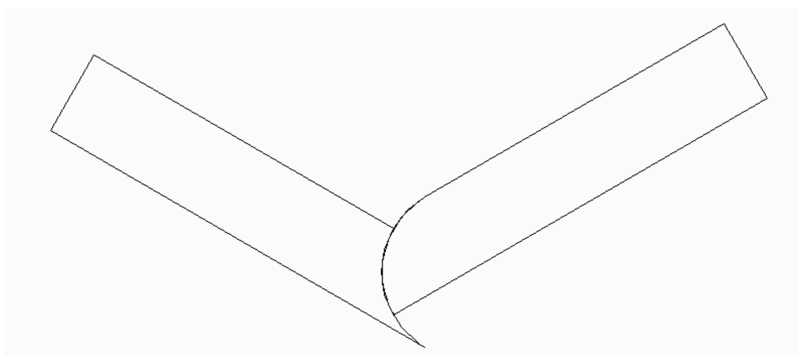


Figure 6: First design idea at 120 degrees

The next design was composed of more parts, but met more of the design requirements. This design required more work to change the angle between the plates because the jig (the part at the bottom of the apparatus) would need to be changed. Also it would require a different fixture for each desired angle. This design did allow for the two sides if the apparatus to come to designated angle. The different angles that were chosen for the final design can be seen in Figures 7, 8 and 9.

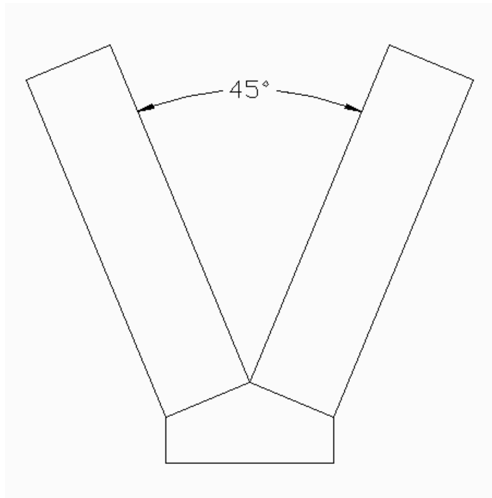


Figure 7: Second design at 45 degrees

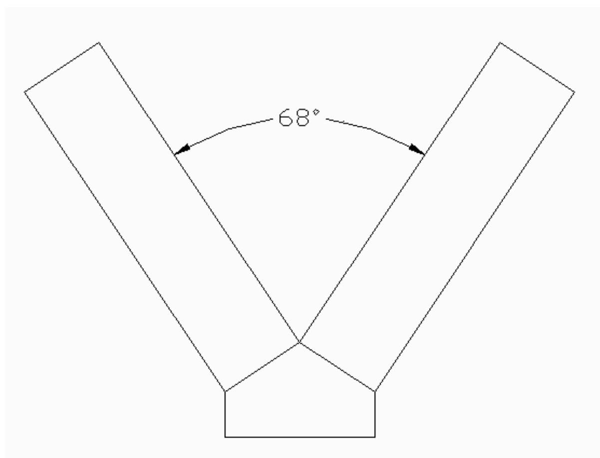


Figure 8: Second design at 68 degrees

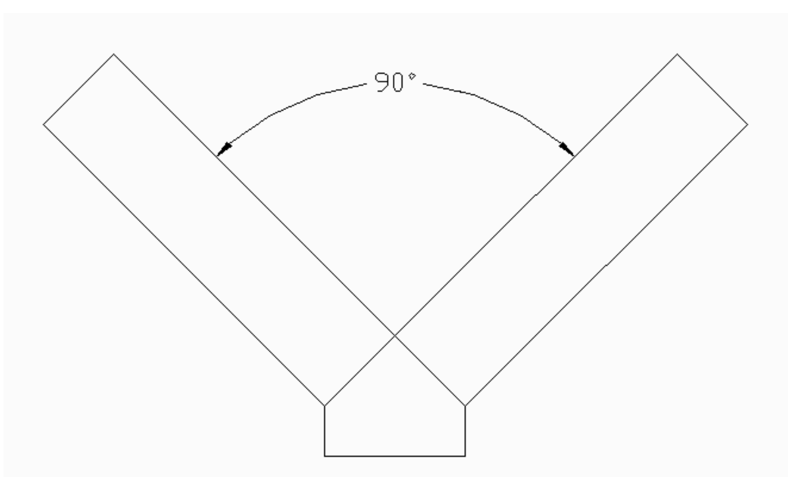


Figure 9: Second design at 90 degrees

In both of these designs the heating elements would be fastened to the outside of the large rectangular blocks, called hot plates. The heating elements are controlled by a temperature controller, with a thermocouple placed on the back of the heating element. The reason that the dimensions of the hot plates are so thick is to ensure even temperature across the surface of the hot plate.

3.2 Manufacturing

First we started with the simplest part, the two hot plates. The stock was oversized so we used an inch and a half end mill on a manual Bridgeport milling machine to get the stock to the correct size and to make the pieces square. Once we had the overall dimensions that we were looking for, (1 inch by 2 inches by 12 inches) we drilled the two holes, one in each end. The holes were half an inch in diameter and were drilled using a CNC (Computer Numeric Control) Bridgeport milling machine. The first hole was half an inch from the end of the part and half an inch from the top of the part in the 1 inch by 12 inch face. The second hole was 10.5 inches from the first hole and again half an inch from the top also in the one inch by 12 inch face. The final step was to drill and tap the heating element mounting holes into the 2 inch by 12 inch face. We used a number 7 drill bit to pre-drill the holes and used a ¼-20 tap to thread the holes. Once the holes were de-burred those two pieces were done.

Then we worked on the “Jig” pieces. They started off as a simple piece of stock. We started again using the one and a half inch end mill on a manual Bridgeport milling machine to make the stock square and the size which we wanted. Then we went to the CNC Bridgeport milling machine to mill the angled part of the jig. To get this angle we used a “Sine Bar” (a bar with a designated radius in which we can set one end at a certain height to obtain an angle) to indicate the head of the machine to the desired angle. Once we indicated the head to within about half a degree, we used a one inch end mill to mill the angle on one side of the part. Once one side was done we turned the part around in the vice and milled the other side. The hard part of this operation was to make sure that we did not make one side of the angle larger than the other side, making the point of the “V” not in the middle. Once the required angle was made, we then put the holes perpendicular to the angled part of the piece. They were an inch from the end of the part and in the middle of the angled face. The second hole was 10.5 inches from the first hole and also in the middle of the angled face. They were 3/8 inches holes and they were also tapped with a 3/8-16 tap. We then started the process again to make the other two angled parts. The parts were then de-burred and those parts were finished.

Finally we made the screws that went into the jig and through the hot plate out of aluminum. They were four inches long with a radius of .18 inches, with a 3/8-16 thread on both ends, one to screw into the jig and another to put a bolt on to keep the hot plates from moving.   Then on one end of the screw we put a slot on the end so that a screwdriver could be used to unscrew the screws from the jig. We also made the small screws to mount the heating element to the hot plate.

3.2.1 First set of Alterations

We accidentally let our hot plate get too hot and some of the components fused together. We tried to push the screws out with a 4 ton press but they would not budge. We then had to drill new holes through the screws fused to the hot plate. They were .31 inches in diameter in the same positions as before. Then we took the jigs and counter bored a flat on the bottom of the part to make room for a washer and a nut. Our new design had a steel threaded rod run totally through the hot plate and jig. It was held together with a few washers and nuts on the top and bottom. We gave the part plenty of clearance so that our hot plate would not bind up again. The depth of the counter bores differ depending on the angle of the jig.

3.2.2 Second set of Alterations

We realized that the heat from the heating elements were moving directly through the aluminum and not spreading out well enough. We decided to use a copper piece to help spread the heat before it went into the aluminum. To do this we used a piece of stock that was ½ inch thick and 2 inches wide and 12 inches long. First we kicked the head of the machine to 68 degrees. We used the sine bar again to indicate the angle of the head of the machine. We then used a 1 inch end mill to run down the side of the part. Once it was finished we flipped the part around and made the angle on the other side. Finally we brought the head of the machine back to the vertical position and used the ½ inch end mill to mill out a ¼ inch deep slot 1 ½ inches wide the entire length of the copper piece. This slot was big enough so that the entire heating element would fit into the slot.

3.2.3 Third set of Alterations

For the third set of alteration we needed reduce the mass in the jig because it was absorbing heat from the bottom of the hot plates. We used a half inch end mill for this operation. We took about a quarter of an inch per pass in the material. We did this because the properties of the materials were odd since this part has been heated and cooled so many times. We wanted to ensure that we did not ruin our project in one of the last steps.

We also made triangles to use as dividers to hold the coal dust in place. We did this by roughly cutting the stock into triangular pieces. We then clamped the two pieces together so that we could do them both at the same time in order to save time. We placed a steel 45 degree precision triangle in the jaws and placed the clamped pieces on the triangle. We then just took off enough to clean the edge up so that the entire top surface was machined. We then put the machined surface on the precision triangle and cleaned up the now top surface. Finally we put either one of the finished sides on the precision triangle and machined the top down to the desired height.

4 Results

To test the functionality of our apparatus we needed to ensure that the entire surface of the heated area heated evenly. To accomplish this, thermocouples were affixed to the interior surface of the apparatus at regular intervals to see the temperature difference across the plates. We were hoping to accomplish a variation of plus and minus 5 degrees Celsius across the face of the apparatus. During some of the testing there was some difficulty with a few of the thermocouple that did not register values that were logical.

4.1 Testing of heating elements

This was done to see if there are any parts of the heating elements that were extreme hot spots (areas of the heating elements that are considerably hotter than the average temperature). The first test was done by placing thermocouples on the surface of the heating element at a distance of one inch from the electric terminals, the next one was placed three and one half inches further along the heating element and the final one was placed another three and one half inches. Figure 10 shows recorded temperatures. Thermocouple one was the thermocouple one inch from the electric terminals on the heater and thermocouple two and three progressed down the heating element. Thermocouple four was placed in the same location on the other heating element as thermocouple one and followed by thermocouples five and six.

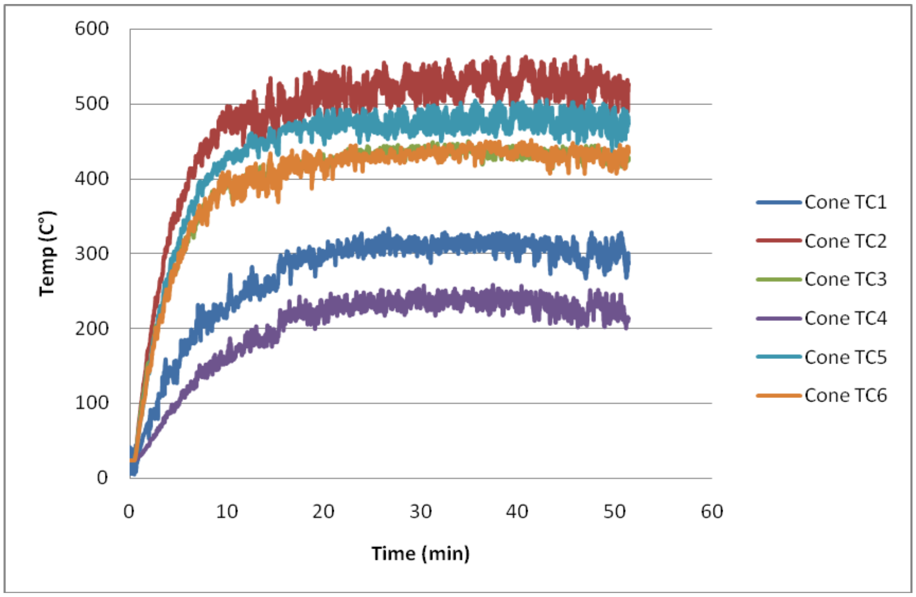


Figure 10: Test 1 data thermocouple temperatures

There is a considerable amount of noise in the thermocouples but the general trends of the temperature change can be seen. It can be seen that there is a variation of approximately 100 degrees Celsius.

The second test was done using a single heating element with thermocouples placed half an inch from the terminal, the next thermocouple was placed one inch further along the heating element followed by one and a half inches, one inch, two and a half inches and one and a half inches along the heating element. The thermocouples were placed in order of six, five, four, one, two, three. Figure 11 displays the different temperatures of the thermocouples over time.

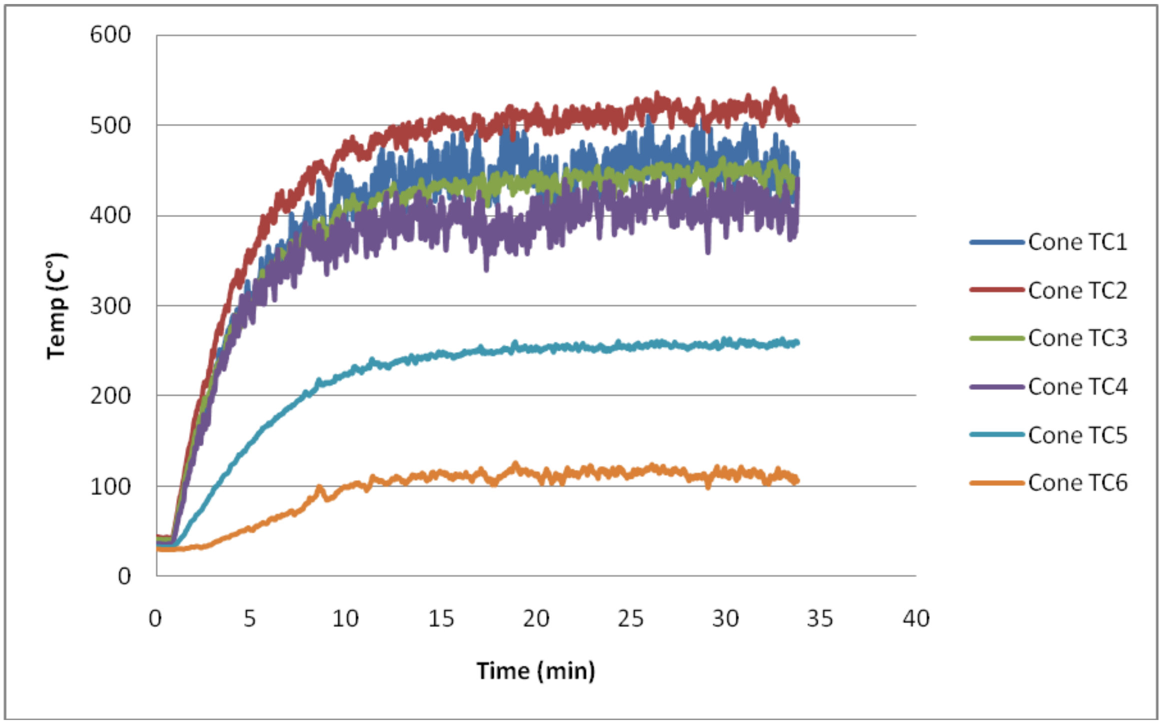


Figure 11: Test 2 data thermocouple temperature

In this graph it can be seen that thermocouple six and five are considerably lower than the rest of the other temperatures and this is most likely cause by the fact that those thermocouples were placed close to the edge of the heating element. As similar to the previous graph the temperature around the center of the heating element varies in a range of about 100 degrees Celsius. Both of these tests were run with the temperature controller set at it maximum temperature.

4.2 Testing of the apparatus

4.2.1 Testing with Cone Calorimeter Thermocouples

This next battery of tests was conducted with the entire apparatus assembled as can be seen in Figure 12.

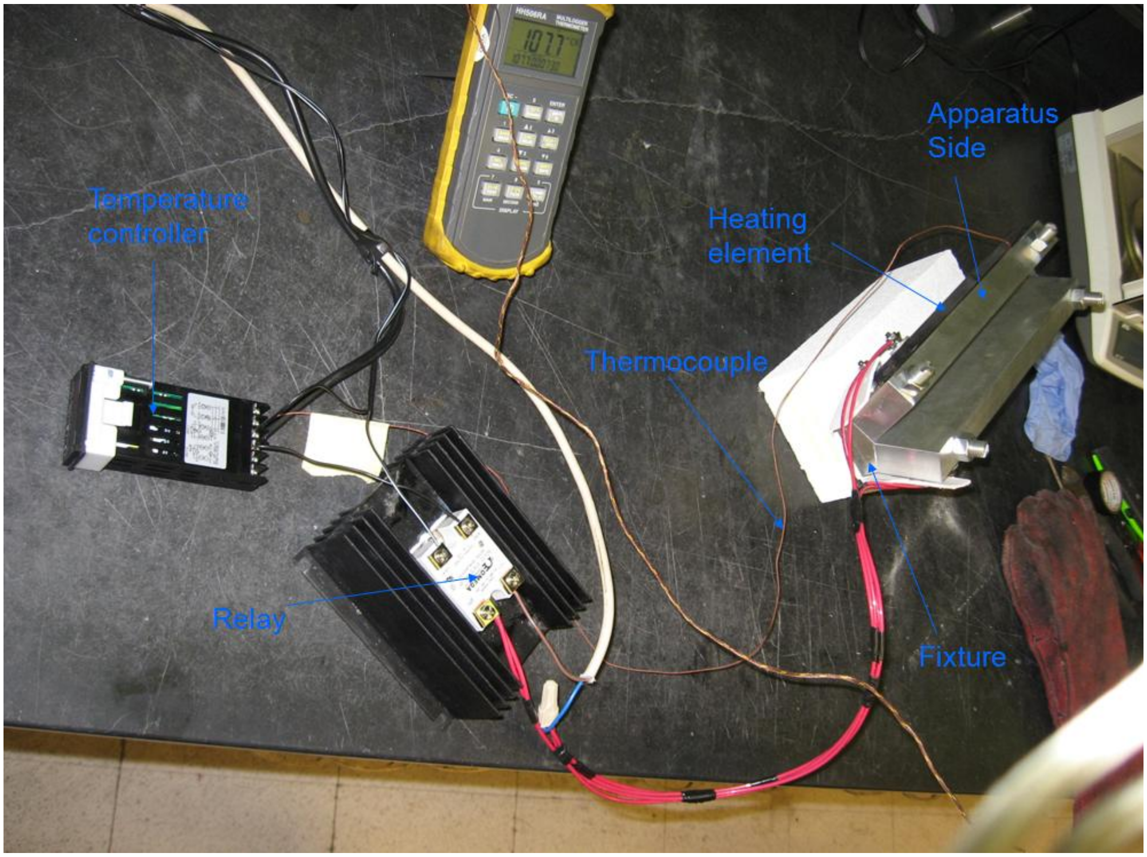


Figure 12: Assembled test appuratus

This test was run with the temperature controller set to 500 degrees Celsius. The location of the affixed thermocouples on one side of the apparatus can be seen in Figure 13. The circles in the drawing represent the location of the thermocouples.

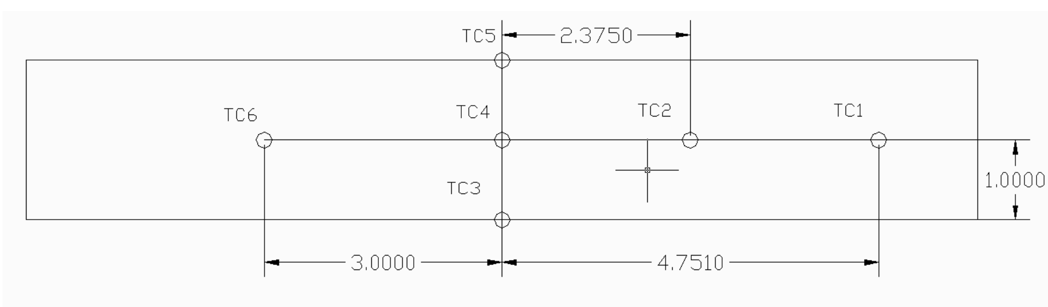


Figure 13: Location of thermocouples for testing

The data that was collected for this test can be seen in Figure 14.

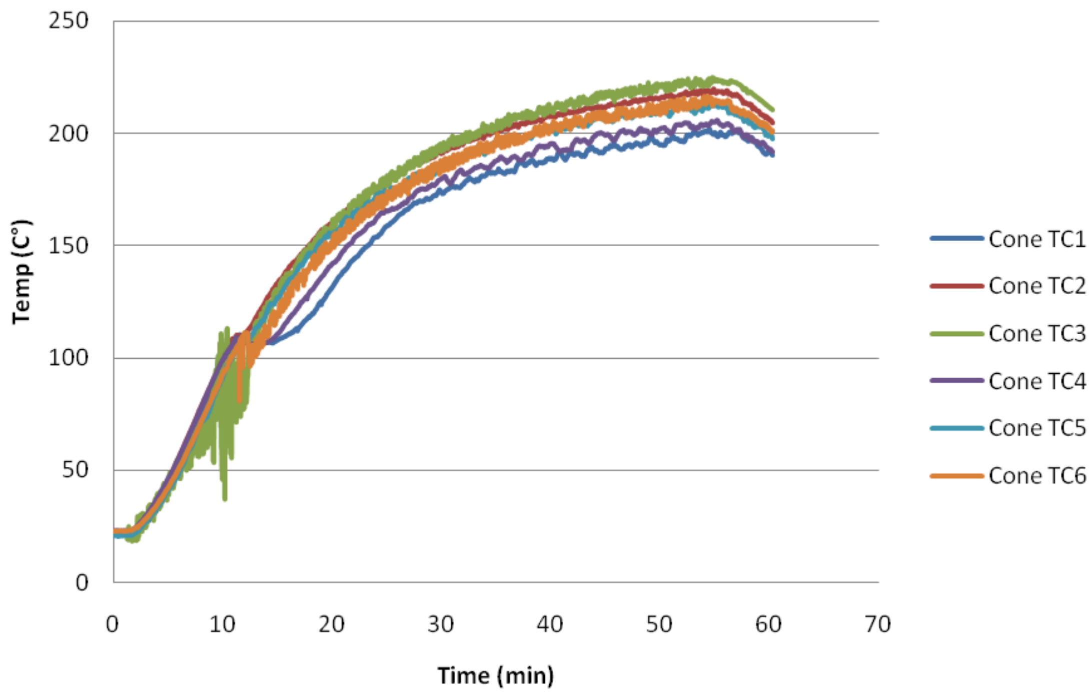


Figure 14: Test 1 of assembled apparatus

This test has a closer spread of temperatures than the tests of the heating elements alone. The spread in temperatures is around 25 degrees Celsius rather than the 100 degree Celsius difference in temperatures for the heating elements alone. The rapid fluctuation of thermocouple three at around 12 minutes cannot be easily explained. One possibility is that the thermocouple got knocked loose. The reason that the apparatus did not get to a higher temperature it is believed that the thermocouple connected to the temperature controller was defective and not providing proper feedback.

During the second test the temperature controller was set to its maximum value. Also thermocouple four was removed from its location and replaced with thermocouple six. Thermocouple four was placed between the heating element and the hot plate of the apparatus. The data collected from this test can be seen in Figure 15.

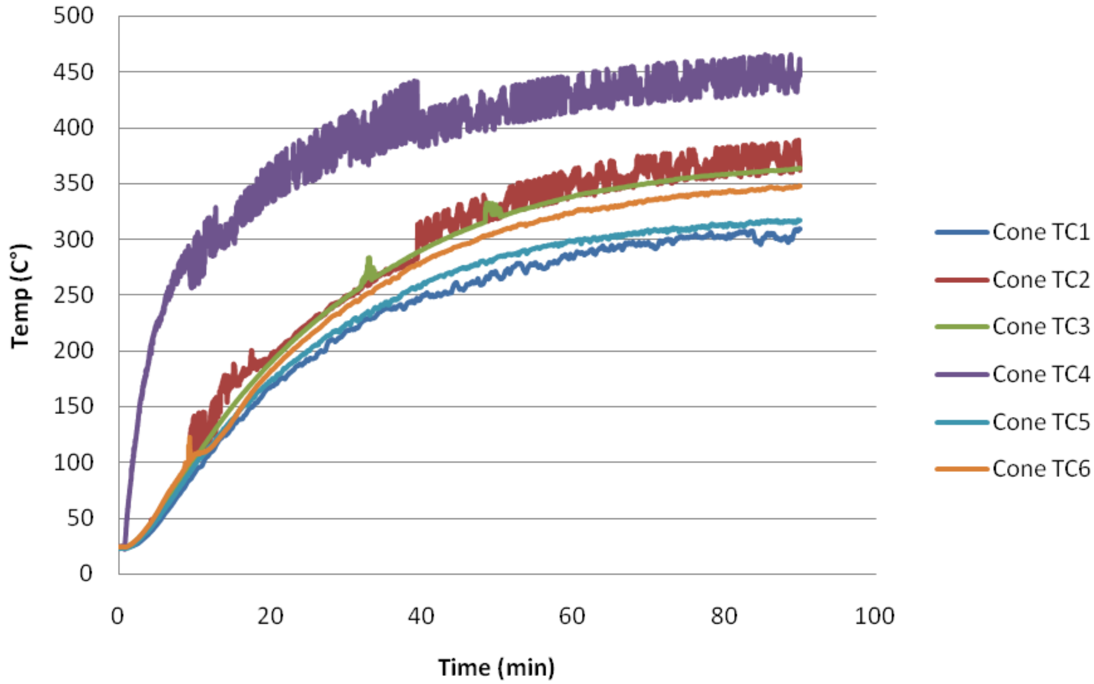


Figure 15: Test 2 of assembled apparatus

4.2.2 Testing using 16 Thermocouples

The next set of testing was conducted using two separate data logging devices each with eight channels to record a total of 16 different temperatures. Temperatures were collected from half of one of the sides of the apparatus. The location of the thermocouples can be seen in Figure 16.

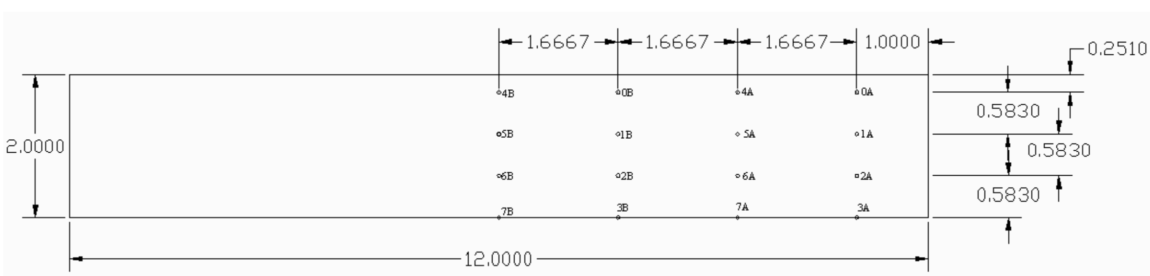


Figure 16: Location of thermocouples in test 4.2.2

Once this information was gathered an image of the temperature gradient was constructed so that the location of any hot spot could be determined. With so many thermocouples located so close to each other, it was very difficult to insure that all of the thermocouples were all touching the apparatus. The actual setup of the thermocouples on the heating element can be seen in Figure 17.

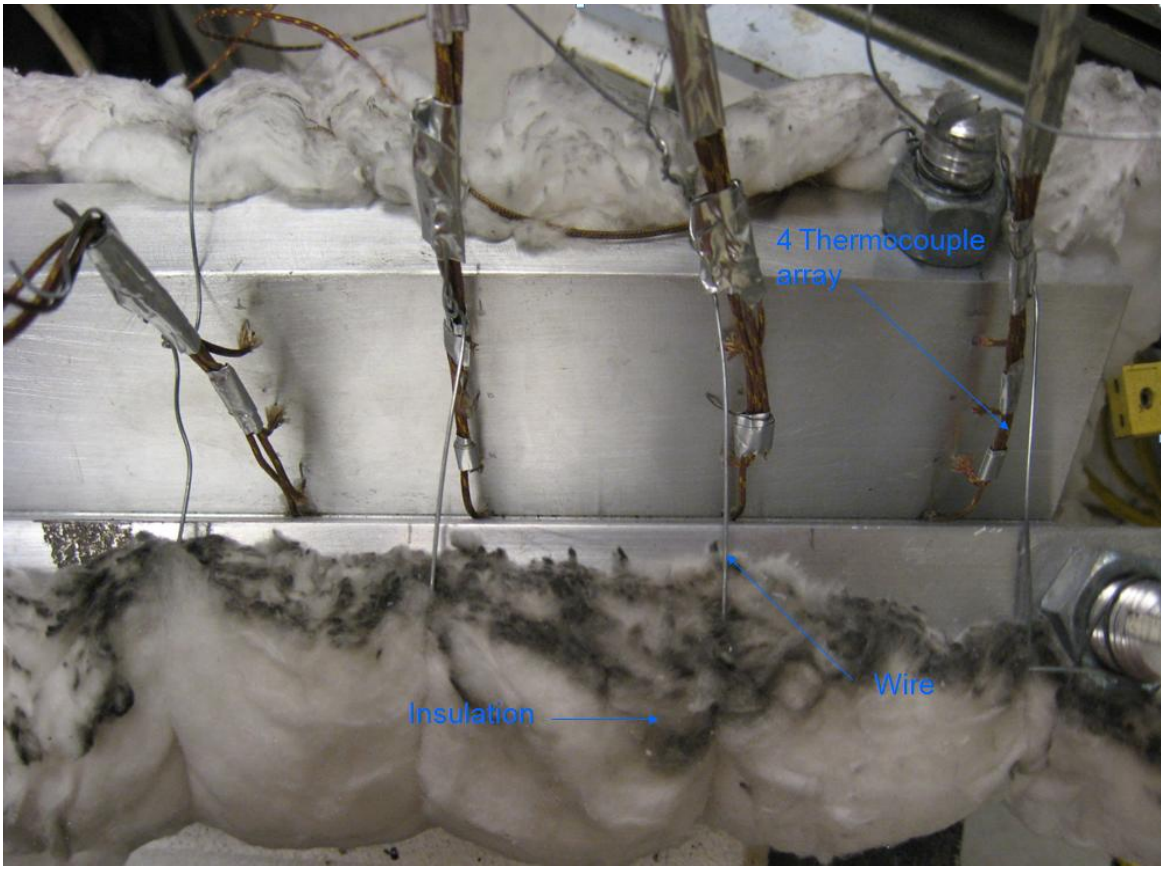


Figure 17: Thermocouples on apparatus

Figure 18 represents the first test with the thermocouples in this position. In the figure where the odd numbers on the axis intersect each other is the location of the thermocouples. Also to create this plot the last 100 seconds of data were averaged for each thermocouple. From the figure it can be seen that there is a large temperature gradient across the surface of the hot plate. Because of the large differences in the temperatures across the face we wanted to see if we could bet a finer resolution by using another type of testing method.

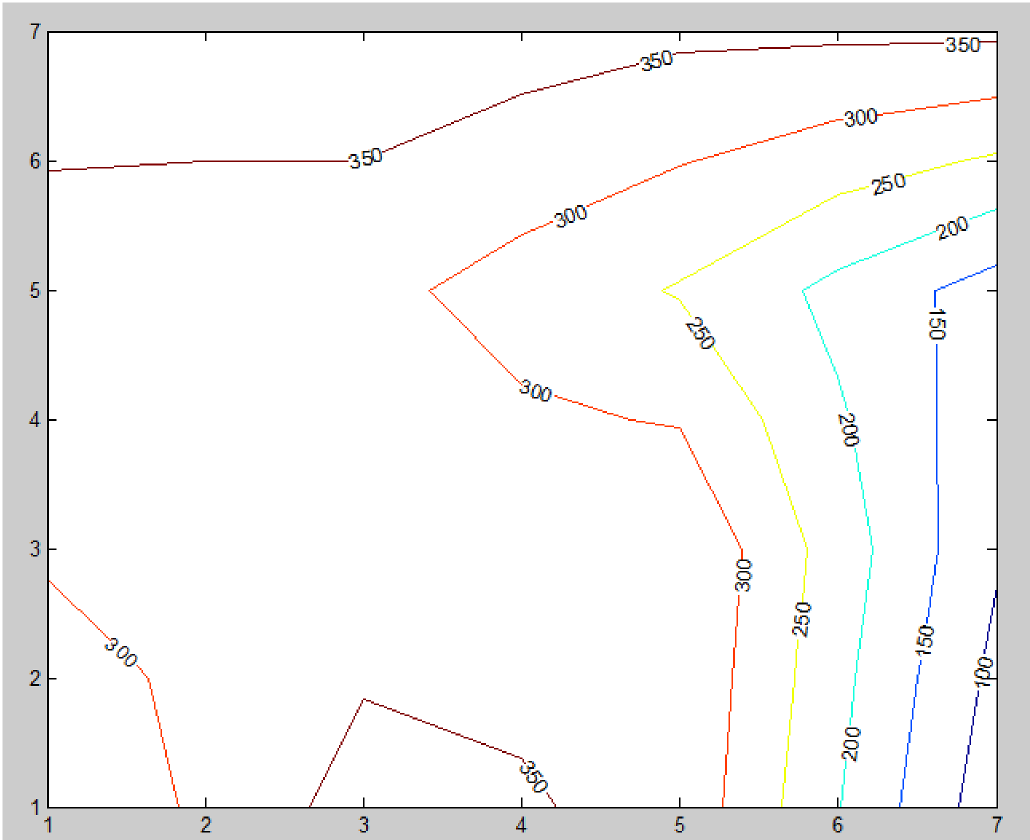


Figure 18: Contour graph of 16 thermocouples

4.2.3 Testing apparatus using thermal imaging camera

The next series of tests was conducted using a thermal imaging camera. The first test that was conducted was looking at one side of the hot plate with the 90 degree. This was to try and have a more detailed contour plot of the heat produced by the hot plate. In all of the tests using the thermal imaging camera, when the temperature was low, the image was relatively uniform but as the temperature increased the image was not accurate. This was caused by the fact that the thermal imaging camera views the radiation from the hot plate.

In the other tests the thermal imaging camera was looking down the hot plate so that both sides of the hot plate could be viewed by the camera. We conducted a large number of these tests with different configurations to see if we could obtain a more uniform distribution across the hot plate. The following two tests were the same as the first except that they had thermocouples located on one side of the hot plate. The next test the hot plate was set at the 45 degree angle setting. There was a considerable amount of heat coming from the bottom of the hot plate. In the 45 degree test and we believed that the heat was being transferred into the fixture at the bottom. To see if this was the problem we spaced the sides of the hot plate off of the fixture using two washers. This did not give us the desired results, so in the next test we used two layer of ceramic insulating paper between the sides of the hot plate and the fixture. This still did not give us the desired effect. This prompted us to do testing with the fixture removed.

4.2.4 Testing sides of hot plate using thermal imaging camera

The next two tests were conducted with one side of the hot plate being viewed by the thermal imaging camera. These tests were conducted to see if the sides of the hot plate itself heated up evenly. Form these tests it was realized that the center of the hot plate sides did radiate more energy that the rest of the piece. This prompted us to test each side of the hot plate with 16 thermocouples.

4.2.5 Testing sides of hot plate using 16 Thermocouples

In this test the apparatus was left disassembled from the previous tests. The thermocouples were place on the side of the hot plate in the same manner as they were in Figure 13 except that the spacing of the thermocouples was changed slightly so that the measurements down the side starting at .251inches with an interval of .499 inches down the face of the hot plate. The contour graph of the thermocouples can be seen below in Figure 19.

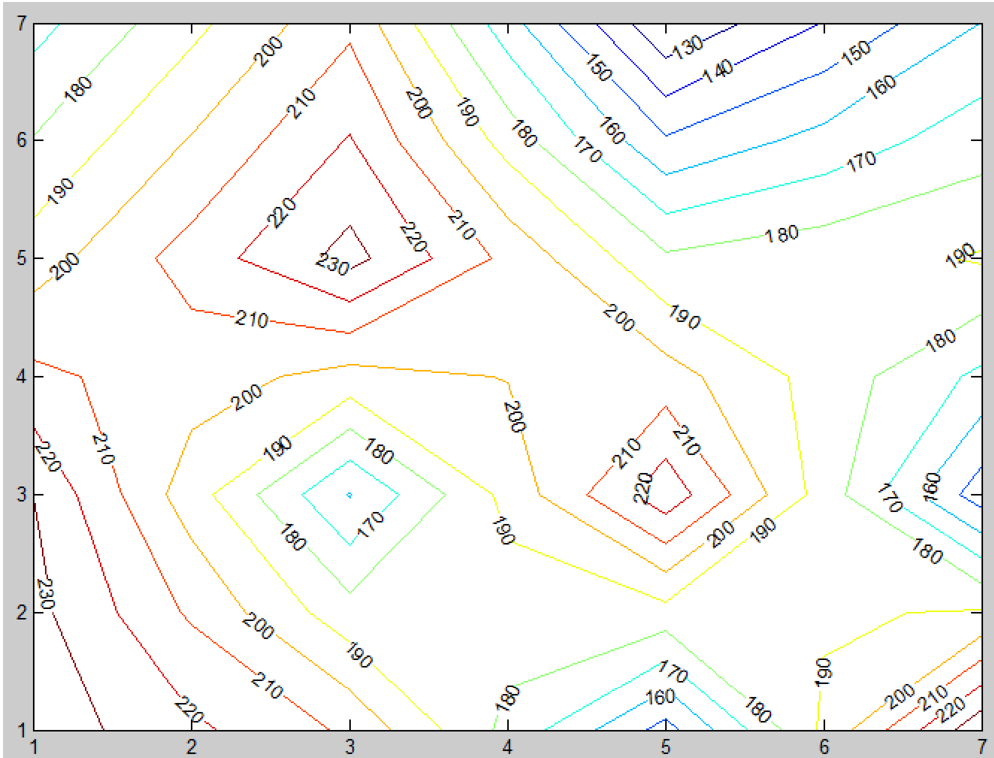


Figure 19: Contour graph of 16 thermocouples on single side

The reason that there are such great changes in the temperatures is because some of the thermocouples were not making good contact with the surface of the hotplate. The next test that was conducted was with the copper heat spreader in place, in the hopes that there would be a more even distribution of the heat across the surface of the hotplate. Firgure 20 is the ajusted contour graph with the copper heat spreader in place. The way that we adjusted that graph was when one of the thermocouple points was more than 25 degrees from the next lowest thermocouple we assumed that this thermocouple was not making good contact to the surface of the hot plate. We replaced this low number with the average of the three thermocouples. This adjusted contour gragh shows a very nice distribution of temperature across the surface to the hot plate.

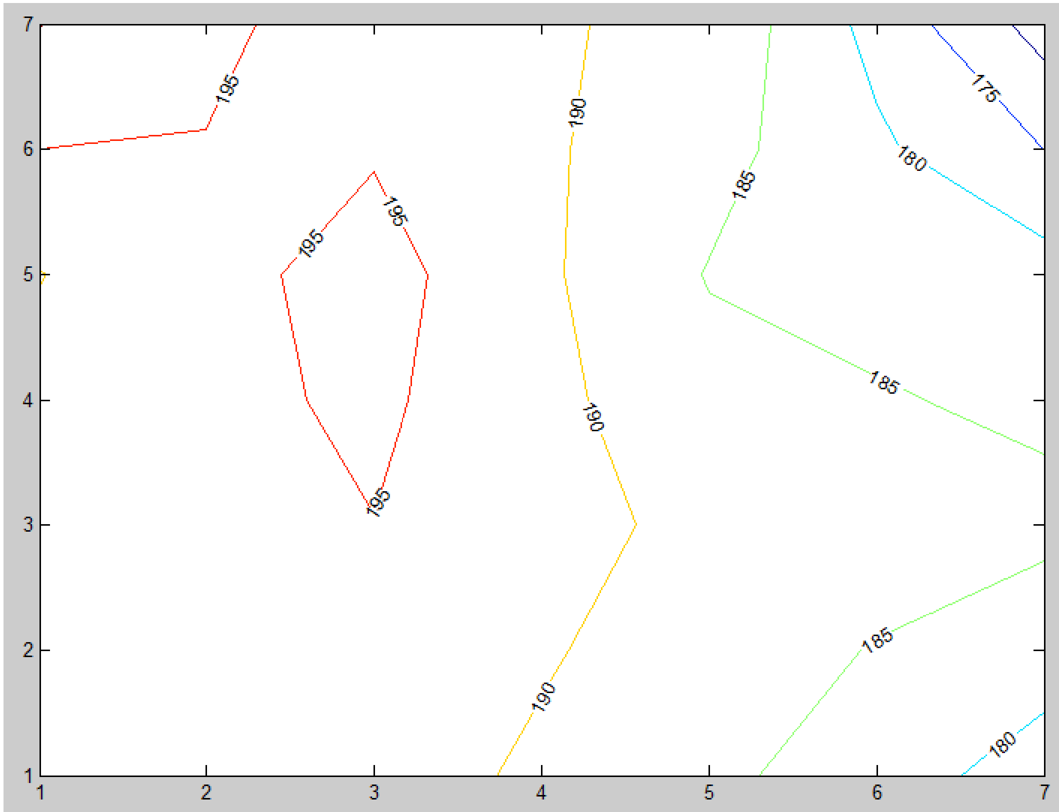


Figure 20: Adjusted contour graph of 16 thermocouples on single side with heat spreader

Next we wanted to see what the temperature distribution was across the center on the hot plate with the heat spreader installed. The location of the thermocouples can be seen in figure 21. Figure 22 is the adjusted contour graph of the thermocouples.

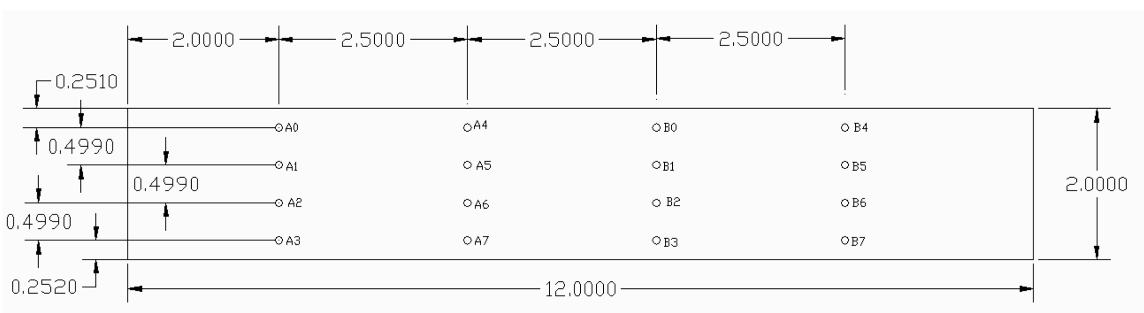


Figure 21: Location of thermocouples.

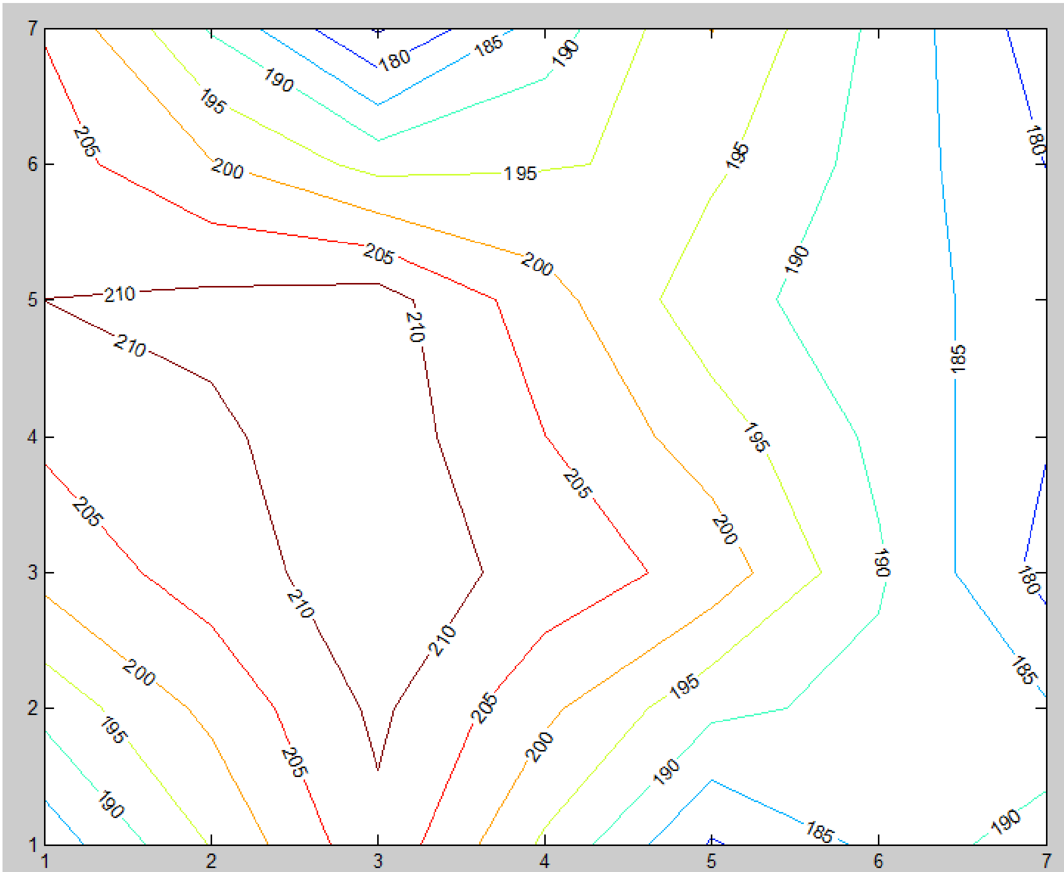


Figure 22: Adjusted contour graph of 16 centered thermocouples on single side with heat spreader

With the results from the tests with heat spreaders installed looking slightly promising we decided to reassemble the apparatus and test the apparatus as a whole.

4.2.6 Testing using 16 Thermocouples with heat spreaders installed

The first test we conducted was with the apparatus set at the 90 degree angle. We also put two layer of ceramic insulating paper on the hot plate that was not being measured to reduce as much radiation as possible from one side to the other. The location of the thermocouples can be seen in Figure 23. Figure 24 is the adjusted contour graph of the thermocouples and Figure 25 is an image of the test setup. The thermocouples were located in the center of the apparatus the in the same location as the previous test except with the spacing starting at .251 from the top with an interval of .538 inches to the bottom of the “V”.

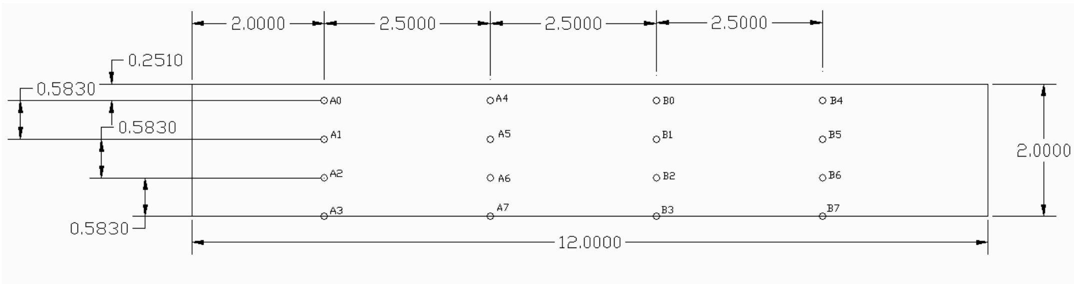


Figure 23: Thermocouples on apparatus with heat spreaders

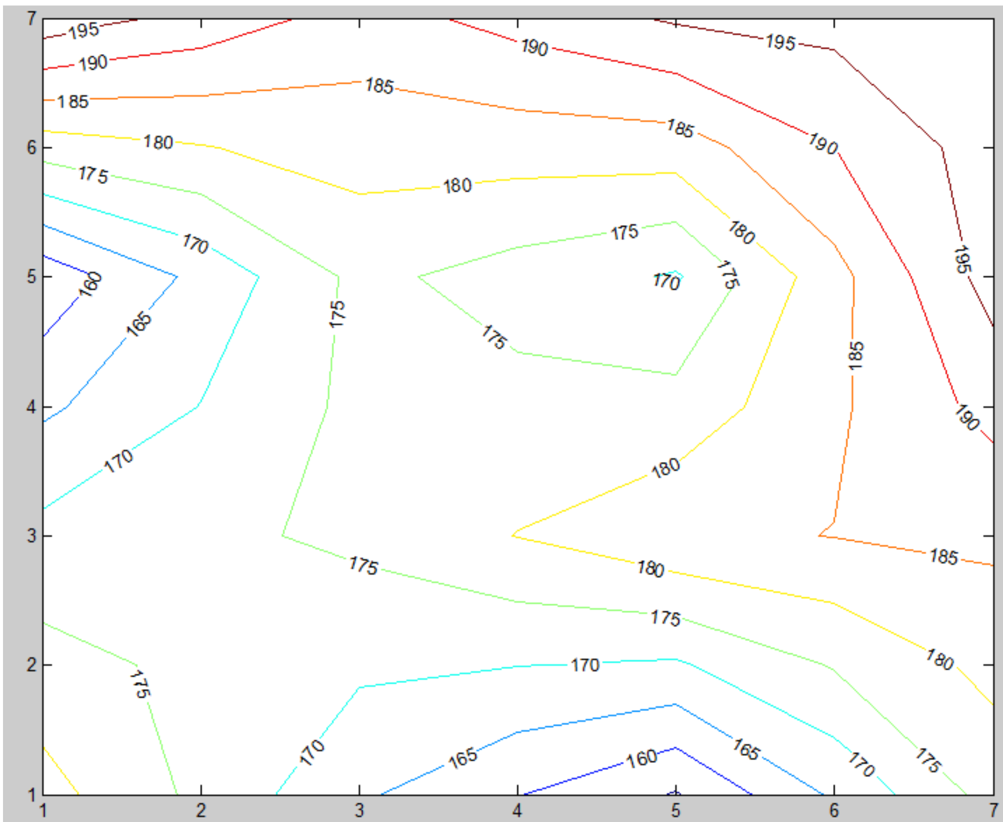


Figure 24: Adjusted contour graph of 16 thermocouples at 90 degrees

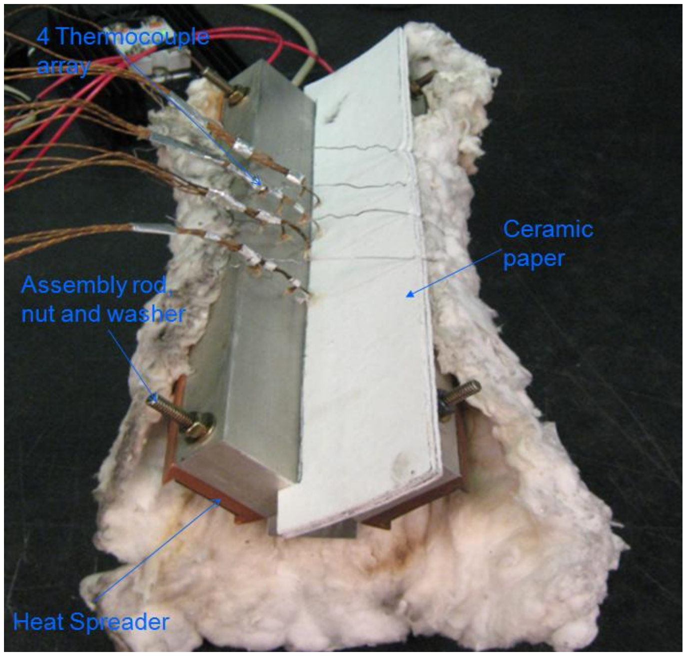


Figure 25: Test setup with ceramic insulation

The next test was conducted with apparatus set at the 45 degree angle with the same thermocouple arrangement. The adjusted contour plot can be seen in Figure 26.

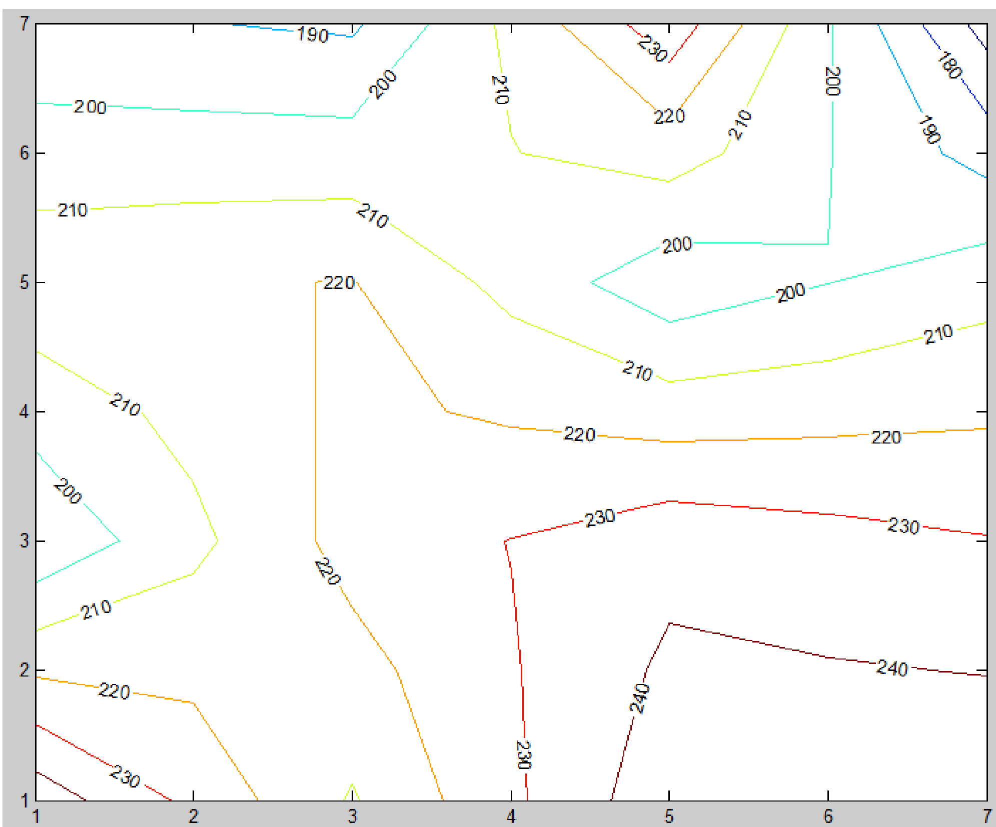


Figure 26: Adjusted contour graph of 16 thermocouples at 45 degrees

4.2.7 Testing using 16 Thermocouples with insulation on surface

The next test was with the apparatus disassemble and the 16 thermocouples placed on the plate and held down with ceramic paper and wires to try and insure that all of the thermocouple were making contact which is seen in Figure 27. The thermocouples were arranged and spaced in the same way as seen in Figure 21.

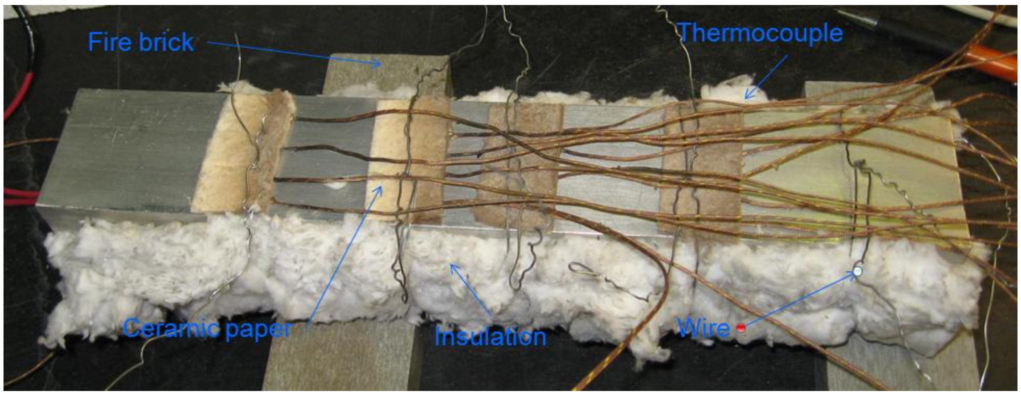


Figure 27: Thermocouples on flat plate

The data from this test showed that most of the thermocouples were in a good range except for two of them which recorded considerable lower temperature which can be seen in Figure 28. Because of this we continued to test the apparatus to try and produce a set of data where all of the thermocouples were making good contact with the hot plate.

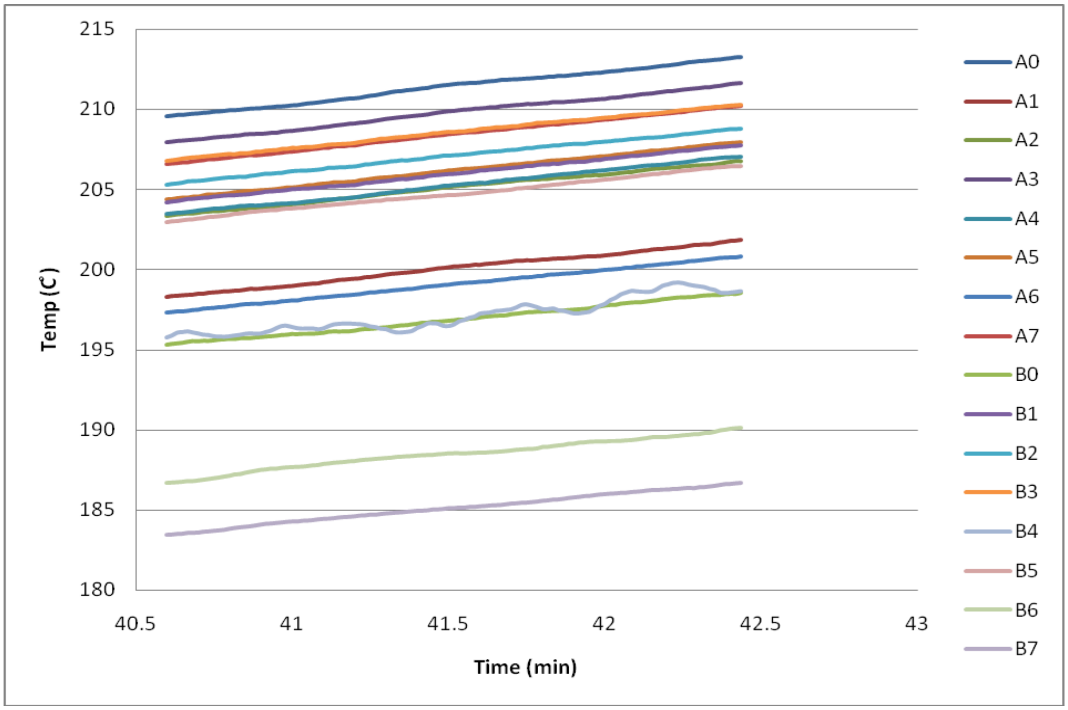


Figure 28: Hot plate with ceramic paper on face

After this test we were still not satisfied with the data so we proceeded to place fire bricks on top of the wires and insolation to try and force the thermocouple down onto the hot plate. This still did not produce satisfactory results.

4.2.8 Testing using 16 Thermocouples with fire bricks

After the tests with the insulation we completely removed the insulation and held the thermocouples down on the hot plate in a similar fashion to when we tested the circular hot plate. We added additional items to provide as much weight to try and insure that the thermocouples were making contact with the plate. The results that were produced satisfied us that all of the thermocouples were making contact with the hot plate or were significantly out of the range that they could be removed. In the next few figures the test setup, contour plot, and data from the test are shown.

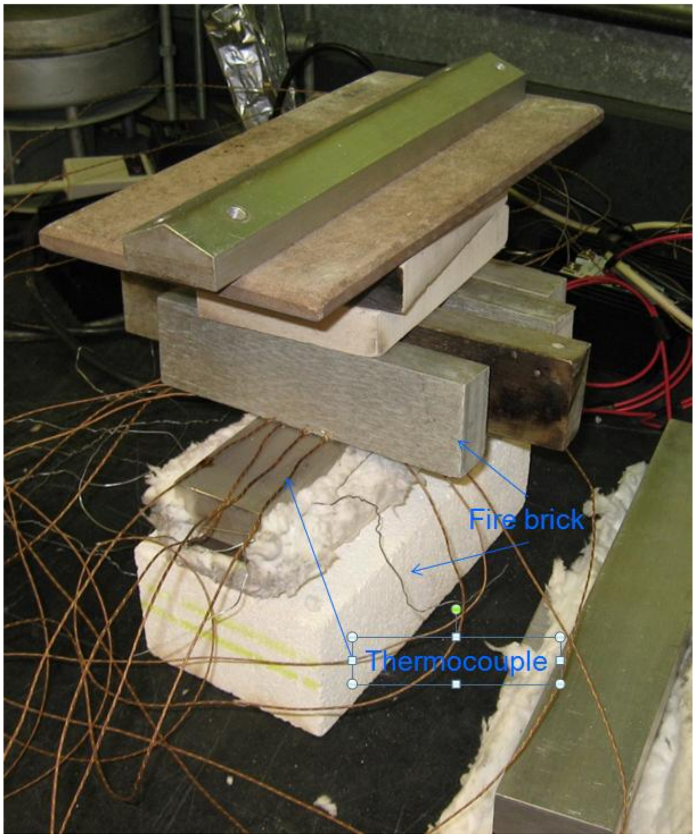


Figure 29: Test setup with fire bricks

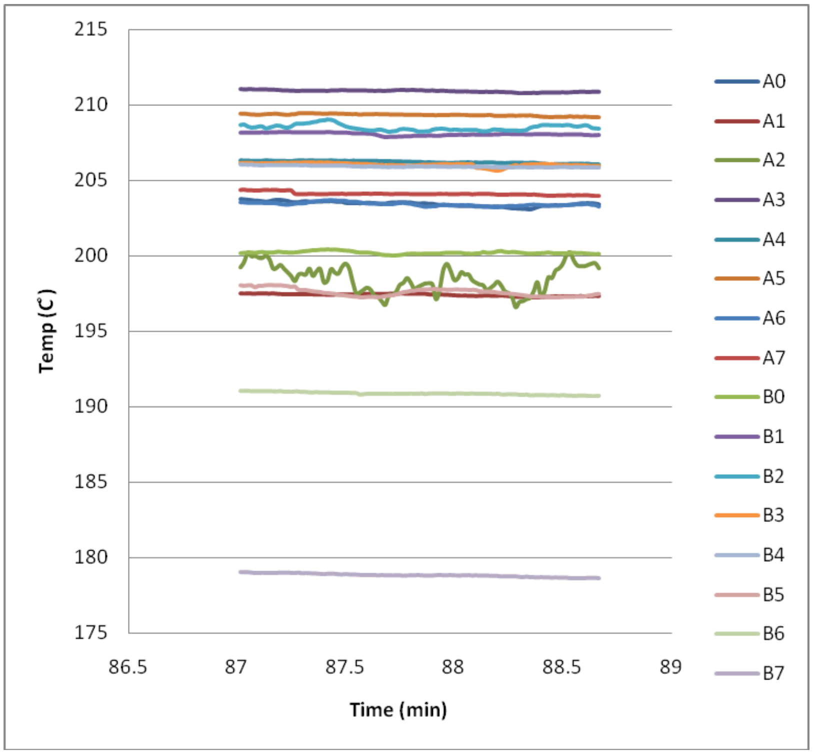


Figure 30: Thermocouple data with fire bricks

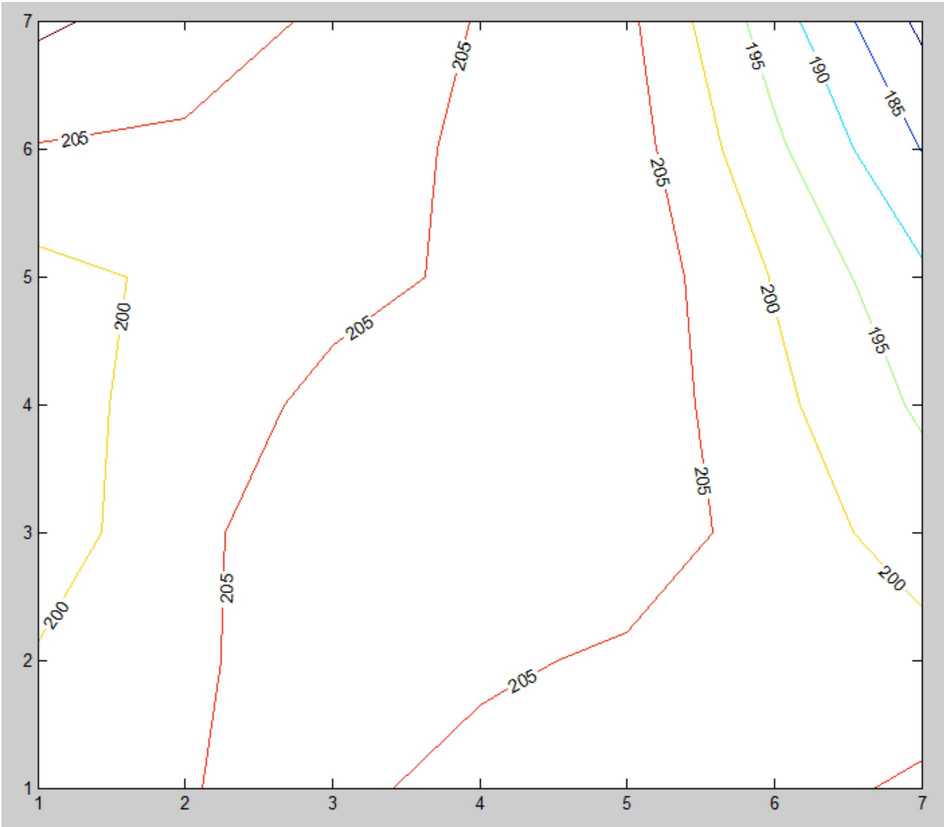


Figure 31: Contour plot of thermocouples with fire bricks

The contour plot depicts that the temperature variations across the surface of the hotplate was within a range of 10 degrees Celsius that we had been looking for except for the outlier in the upper right hand corner which we discounted because it was such a great difference in temperature from the rest of the data. The way that you look at the contour plot is that the top and bottom are the long sides of the plates while the right and left are the short sides of the plate. With this 10 degree range established we now were interested in how material in the assembled apparatus would heat up.

4.2.9 Testing using 16 Thermocouples with the use of sand

Before using the sand for this testing we screened the sand to remove any large particles or foreign debris. We also baked the sand in a toaster oven to remove all of the moisture out of the sand to insure that it would be uniform as possible.

The first test with sand was run with the apparatus set at the 90 degree setting. The test setup can be seen in Figure 32.

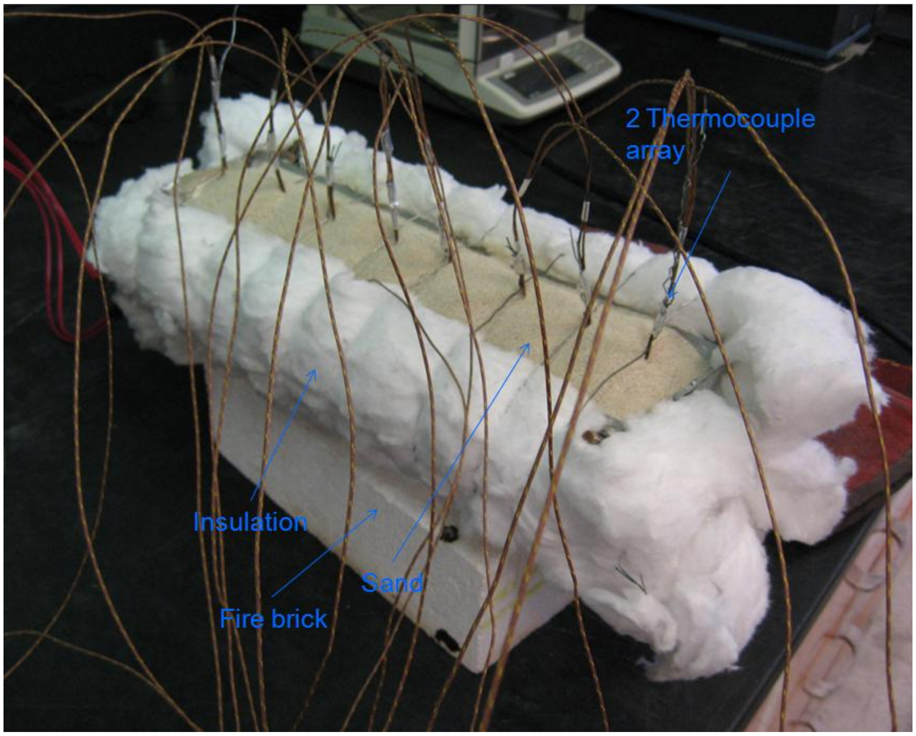


Figure 32: 90 degree test setup with sand

The location of the thermocouples in the sand can be seen in Figure 33.

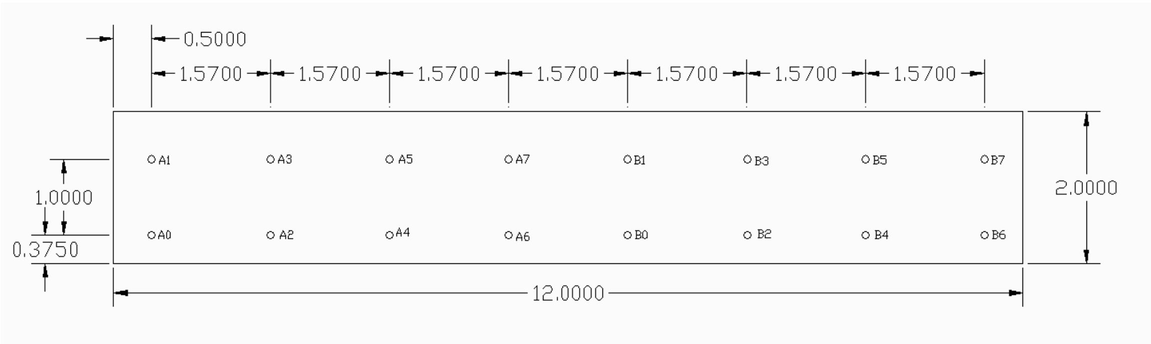


Figure 33: Thermocouple locations in sand

The location of the thermocouple in the contour plot is one row located along the x axis and the upper row located across the top of the contour plot. The contour plot depicts the temperature gradient through the sand.

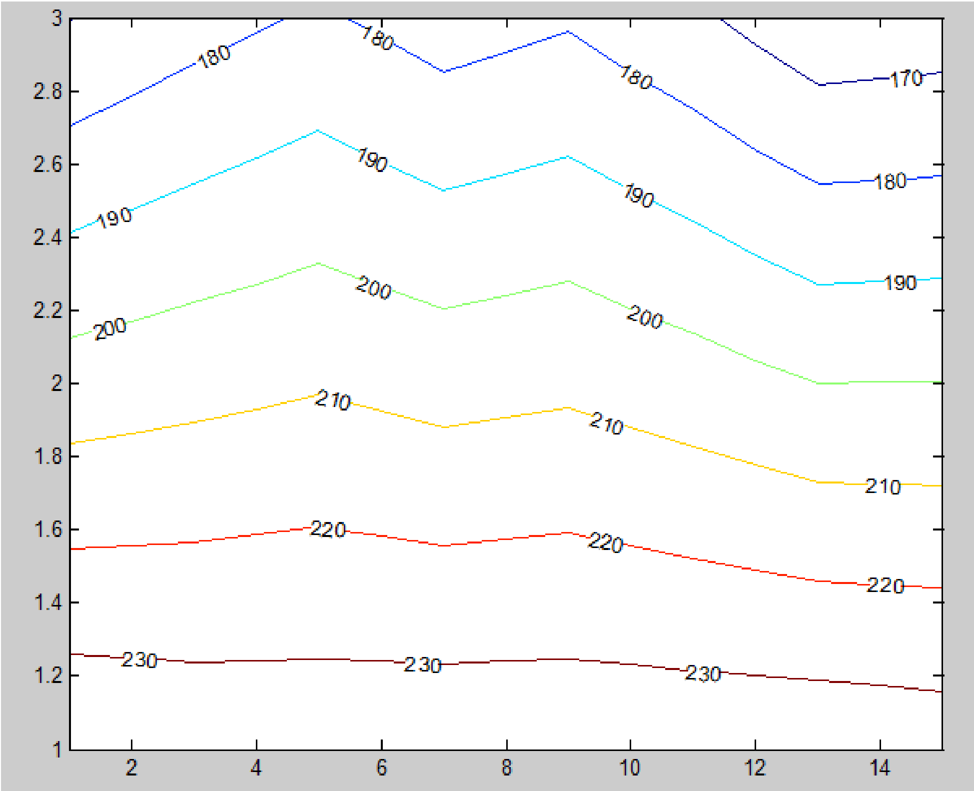


Figure 34: Contour plot of 90 degrees

The data from the thermocouples shows two distinct different lines that represent the thermocouples located close to the bottom of the "V" and the ones located close to the top of the "V". This data is seen in Figure 35.

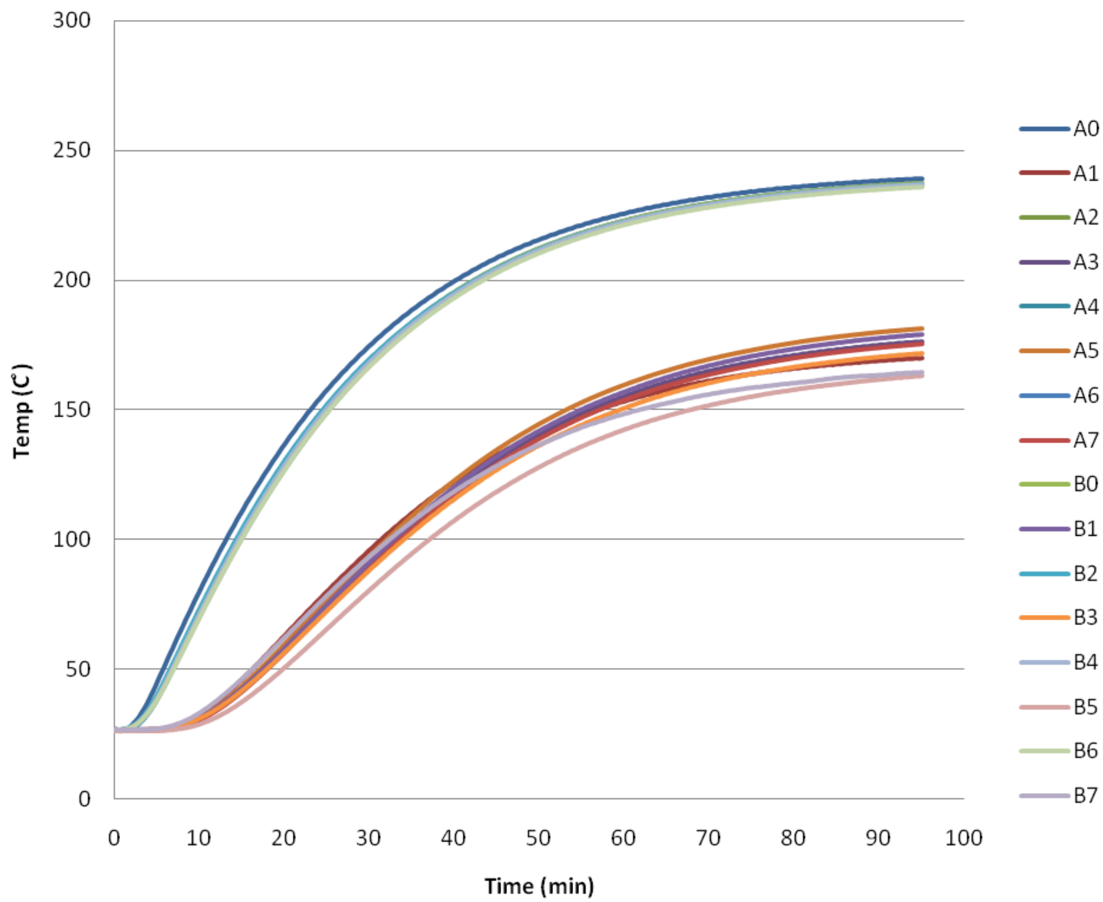


Figure 35: Thermocouple data for 90 degree apparatus with sand

The next test was conducted with the apparatus set at the 45 degree angle. The heating of the apparatus at the 45 degree angle did not produce as consistent temperatures for the upper most thermocouples as in the case of the 90 degree angle. The thermocouples that were located along the bottom of the apparatus were all within a 4 degree range when the apparatus was at steady state. The large range of the thermocouples along the top of the apparatus can be seen in Figure 36.

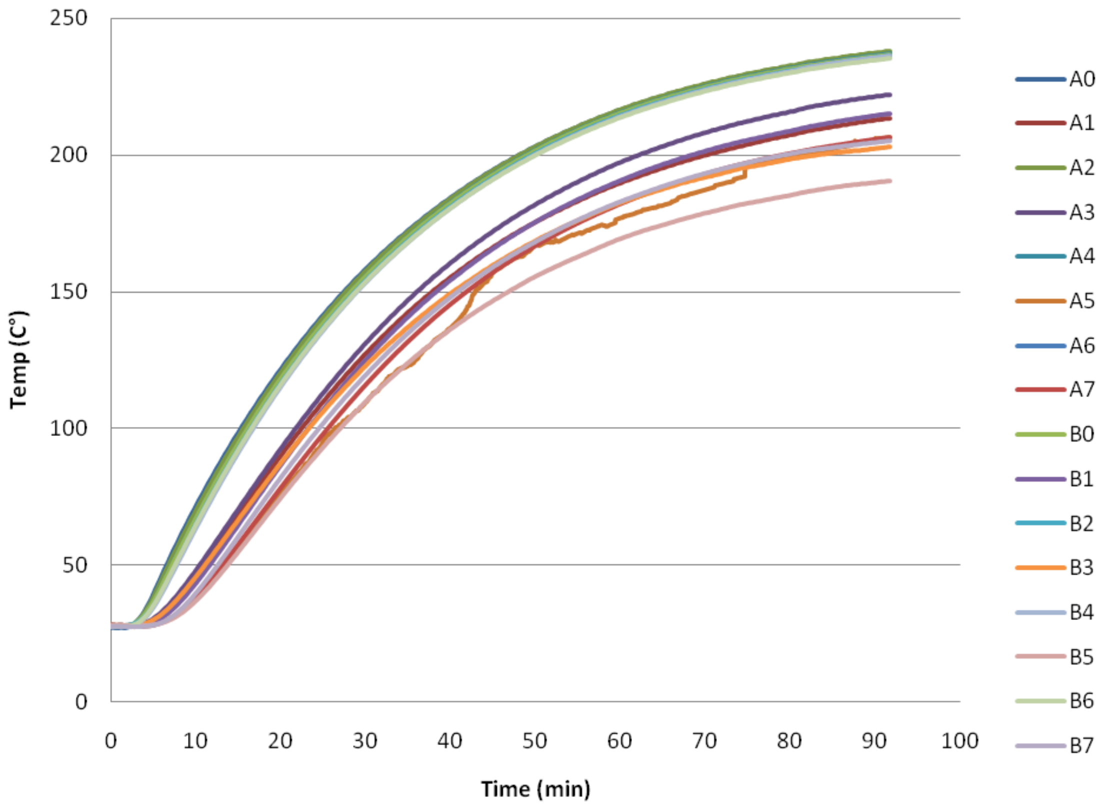


Figure 36: Thermocouple data for 45 degree apparatus with sand

This large variation in the data made it apparent that we needed to ensure that the apparatus was heating up as uniformity as possible. To do this the apparatus was going to be modeled using software that allowed for the heating of the apparatus to be simulated.

5 Modeling of Apparatus

The modeling of the apparatus and its associated parts was completed using the program TAS (Thermal Analysis System).

5.1 Modeling the heating element and side of apparatus

The first step in modeling the apparatus was constructing a model of just one side of the apparatus not connected to the fixture. This was done to see if the side of the apparatus heated up uniformly. The uniform heating of the single side can be seen in Figure 37.

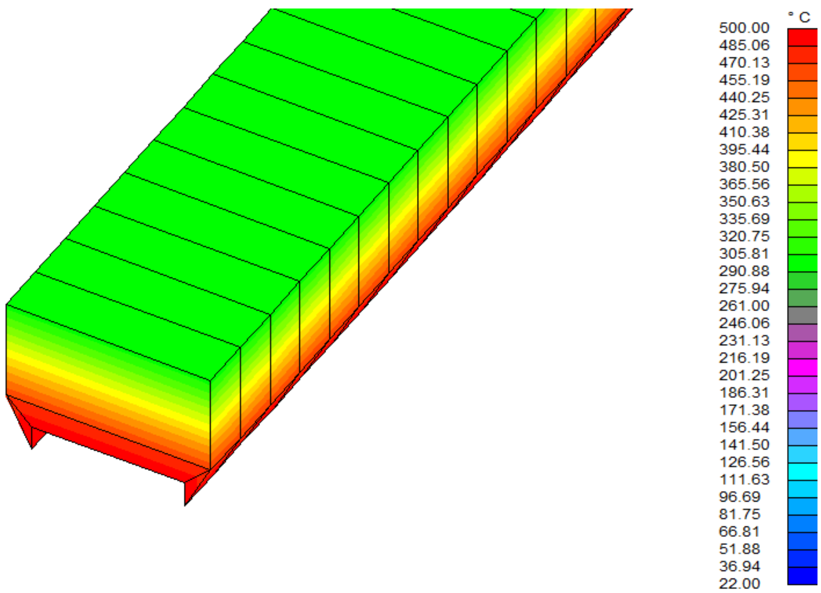


Figure 37: Flat side model

5.2 Modeling the apparatus at 90 degrees

Since we were satisfied with the data from the thermocouples, this was more of an exercise to insure that we were able to use the program correctly. The geometry of this setup was easier to model so that is the reason that it was attempted first. In Figure 38 it can be seen that there is only a small temperature gradient across the surface of the apparatus as indicated by the few lines running parallel to the length of the apparatus.

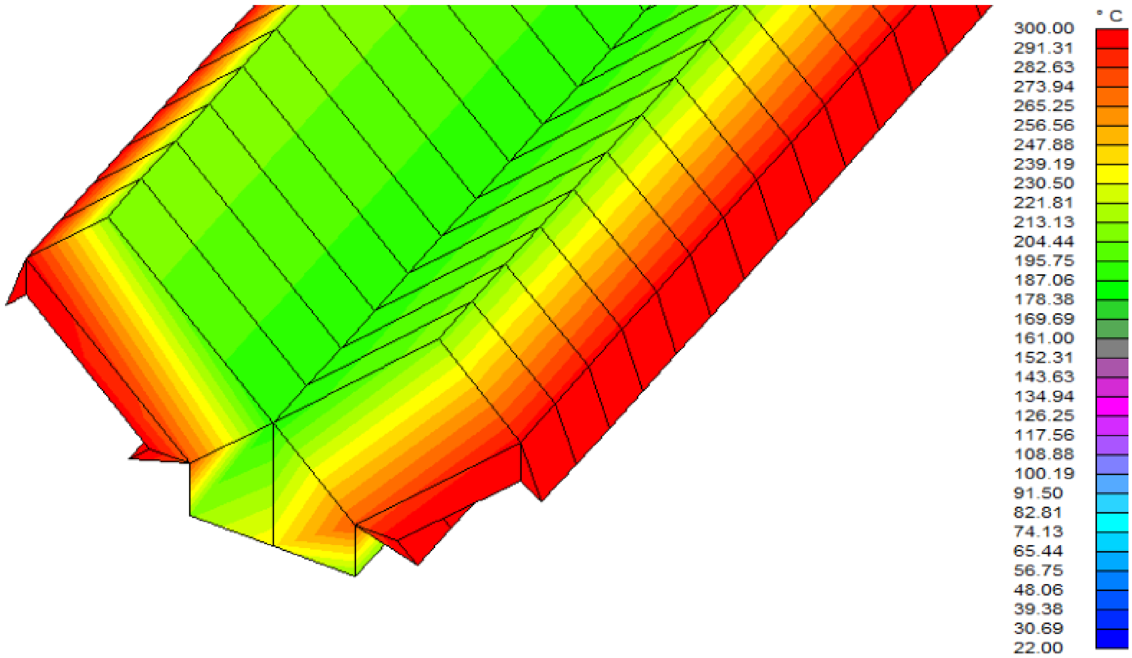


Figure 38: 90 degree apparatus model

5.3 Modeling apparatus at 45 degrees

When the 45 degree angle apparatus was modeled there was an interesting discovery. The faces of the apparatus were not heating up as uniformly as the 90 degree apparatus. A large portion of the heat was traveling into the jig. A second model was generated with a smaller jig and this resulted in less of a temperature gradient across the surface of the apparatus in the model. The apparatus model with the large fixture is seen in Figure 39 and the apparatus model with the small fixture is seen in Figure 40.

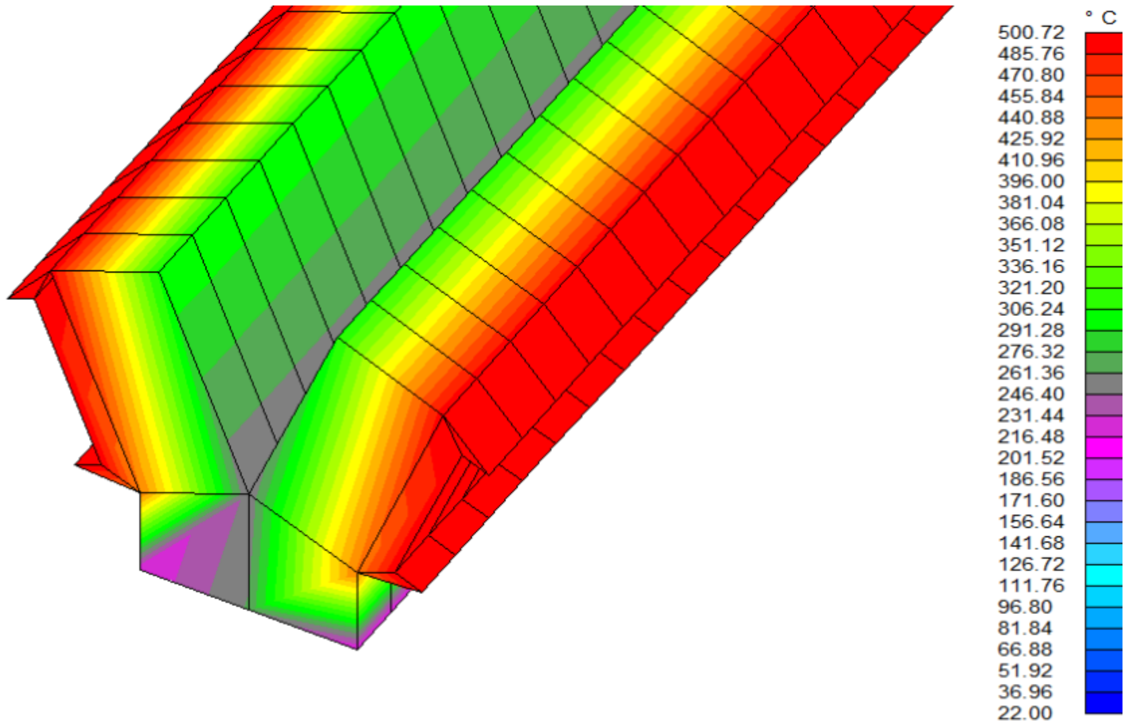


Figure 39: 45 degree apparatus model

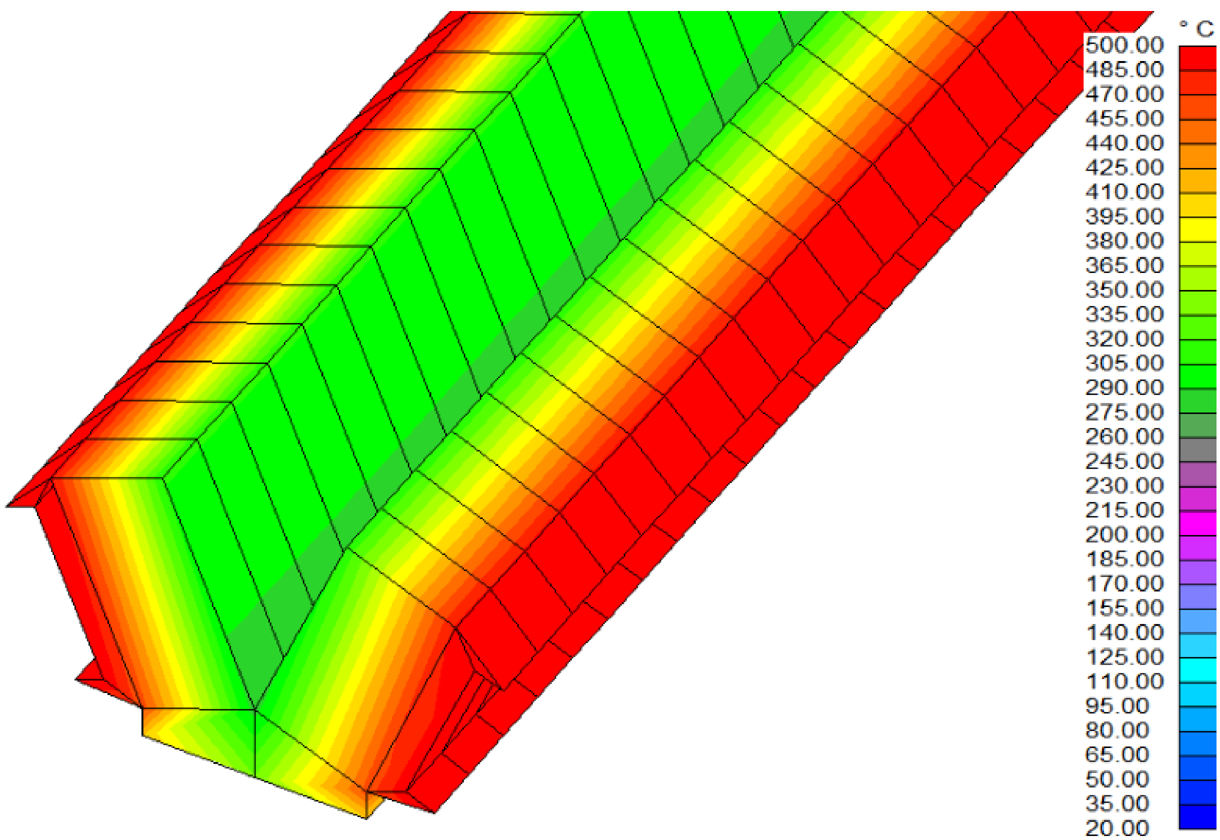


Figure 40: 45 degree apparatus with small fixture

This prompted our decision to make the third set of alliterations to our apparatus.

6 Coal Dust Experimentation

6.1 Heating of coal dust without Ignition

In this test the temperature controller was set to 170 degrees Celsius with the hope that the temperature of the apparatus would reach 110 degrees Celsius. The thermocouples were arranged in the same orientation as the previous test with coal dust. In Figure 41 it can be seen that the apparatus heats to a steady state, and then the coal was added at 40 minutes into the test. The hot plate surface temperature had reached 110 degrees Celsius before the coal dust was added. The dip in the temperature in Figure 41 is due to the addition of the coal dust. Since there is no spike upward in the data the coal dust never ignited. The test setup with the coal added is seen in Figure 43. In this test the "V" was entirely filled with coal dust. Figure 42 depicts the temperatures at different heights in the coal. The locations of the thermocouples are the same as the ones from Figure 42.

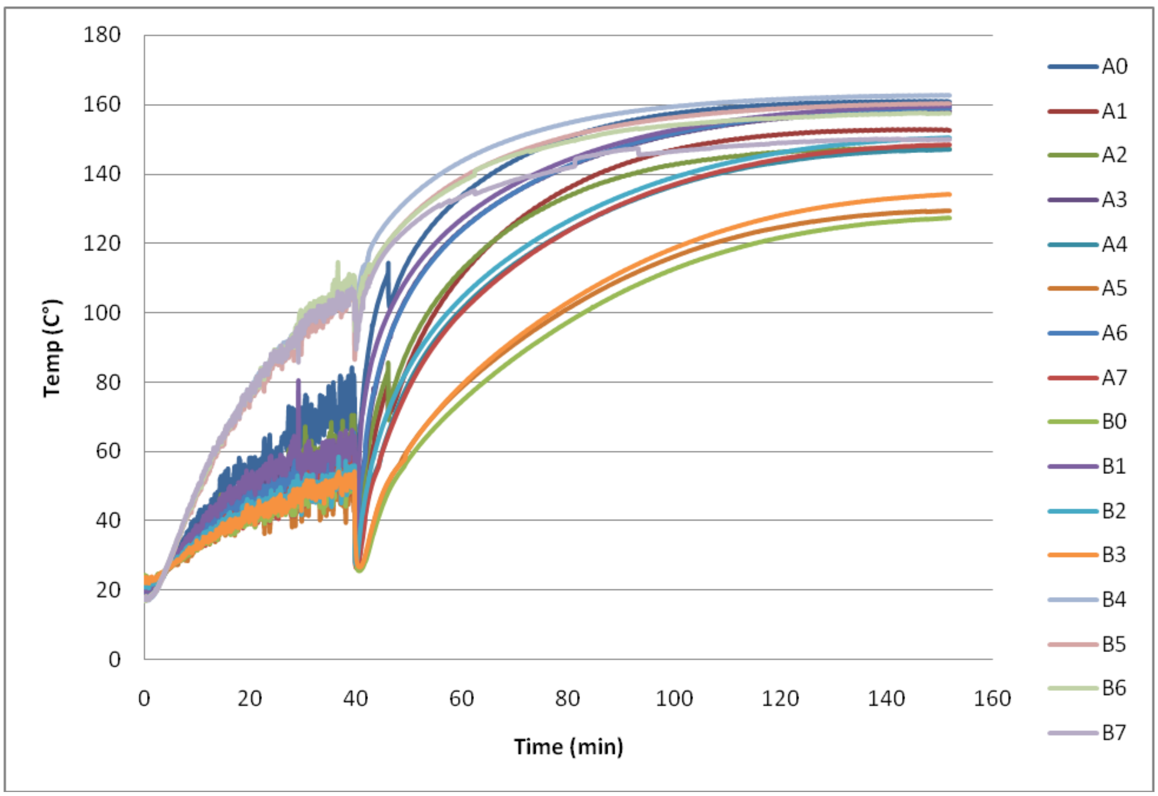


Figure 41: Heating of coal dust

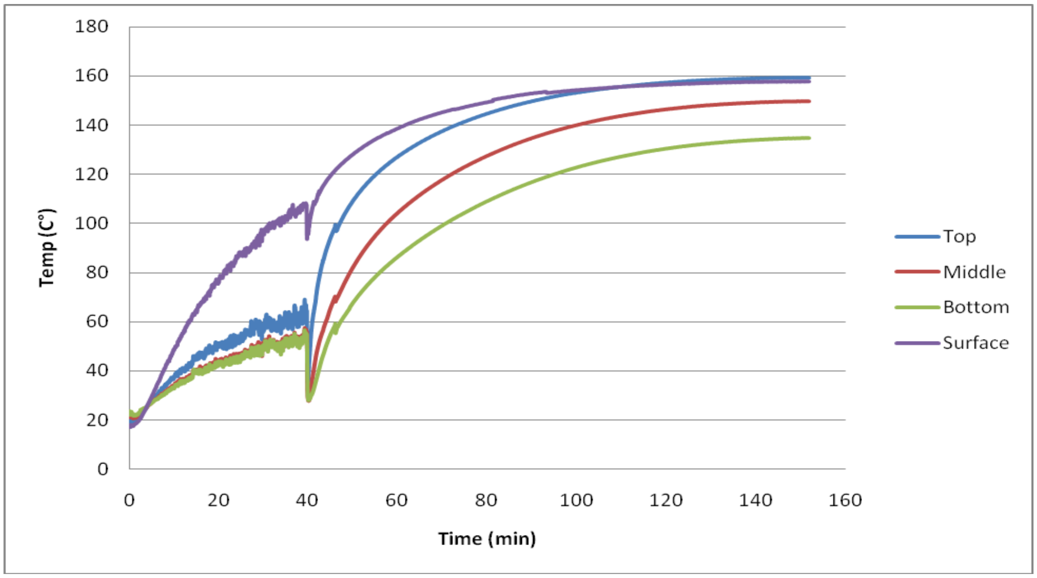


Figure 42: Averaged temperatures

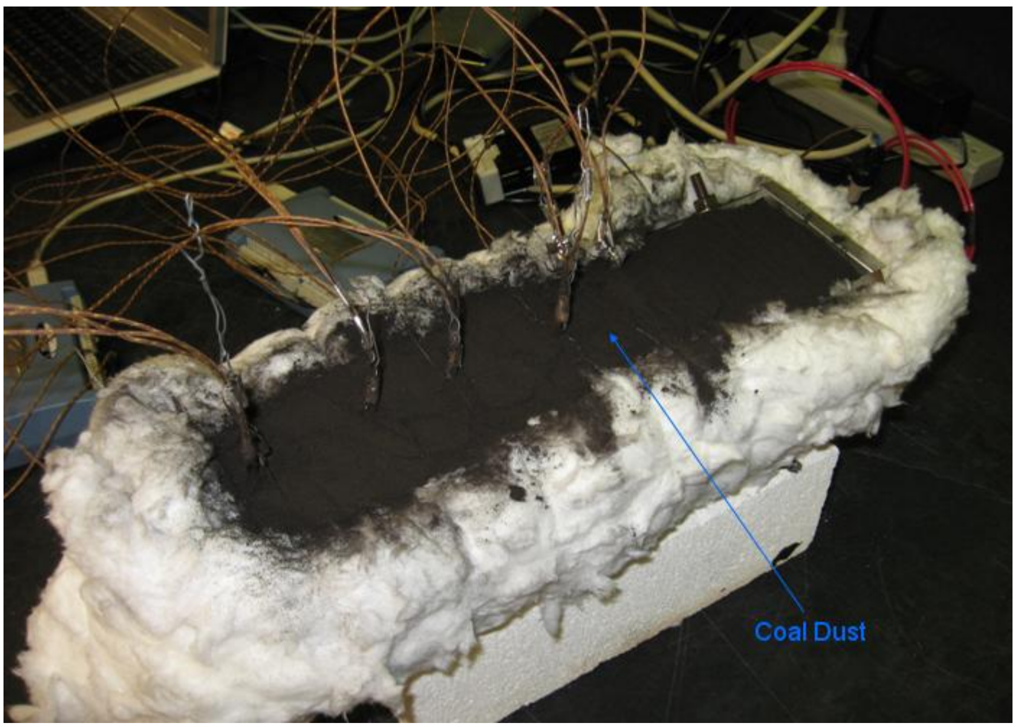


Figure 43: Apparatus with coal dust added

The next test was conducted with one inch of coal dust in the apparatus. The thermocouples were placed in the locations as seen in Figure 44 except that thermocouples B6 and B7 were not used.

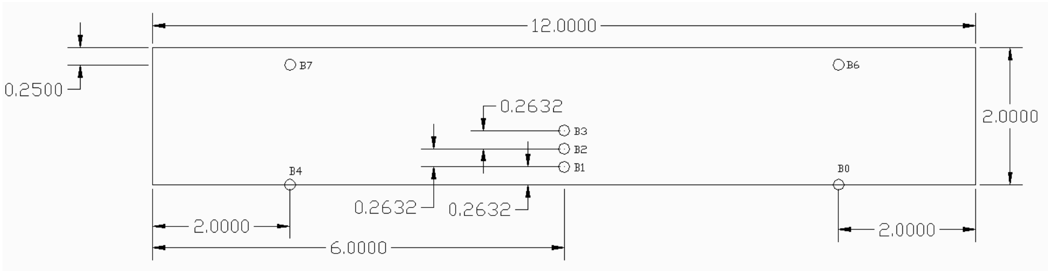


Figure 44: Location of thermocouples in second coal dust experiment

Figure 45 depicts the rise in temperature until the apparatus reaches steady state. In this test 92.5 grams of coal dust were used.

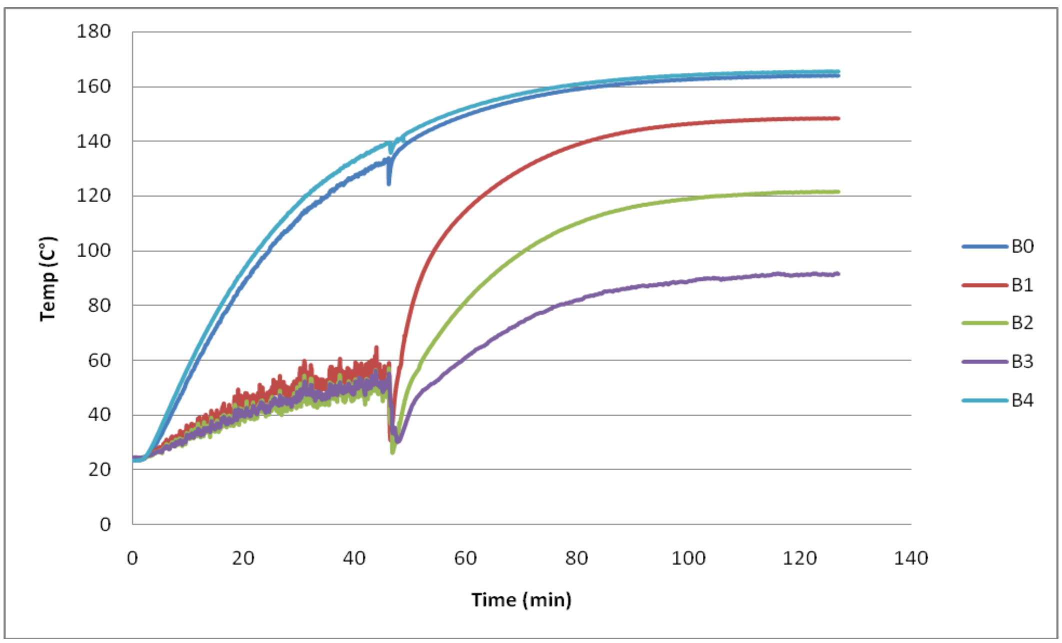


Figure 45: Non-ignition of 1 inch coal dust

6.2 Heating of coal dust with Ignition

In this test the desired temperature of the surface of the hot plate was 160 degrees Celsius. The temperature controller was first set to 175 degrees Celsius and this only resulted in a temperature on the surface of the hot plate of 122 degrees Celsius. To try and reach the desired surface temperature the temperature of the temperature controller was raised to 200 degrees Celsius. After slightly over 91 minutes the surface of the hot plate was hovering right below 160 degrees Celsius. At this time the coal dust was added and packed down into the apparatus. The apparatus was entirely filled with coal dust.

After approximately 161 minutes the temperature at thermocouple A2 began to rise rapidly indicating an ignition of the coal dust. This can be seen in Figure 46. An image of the test setup before and after the experiment was run can be seen in Figure 48 and 49. In Figure 49 the change in the makeup of the material can be seen. The original material is a fine black power with no lumps. Figure 50 provides an image of the location of the thermocouples in the coal dust experiments. The bottom location in Figure 47 is centered in the apparatus and is located .2632 inches from the bottom of the "V". The middle one is located .2632 inches above the bottom and the top one is a further .2632 inches above.

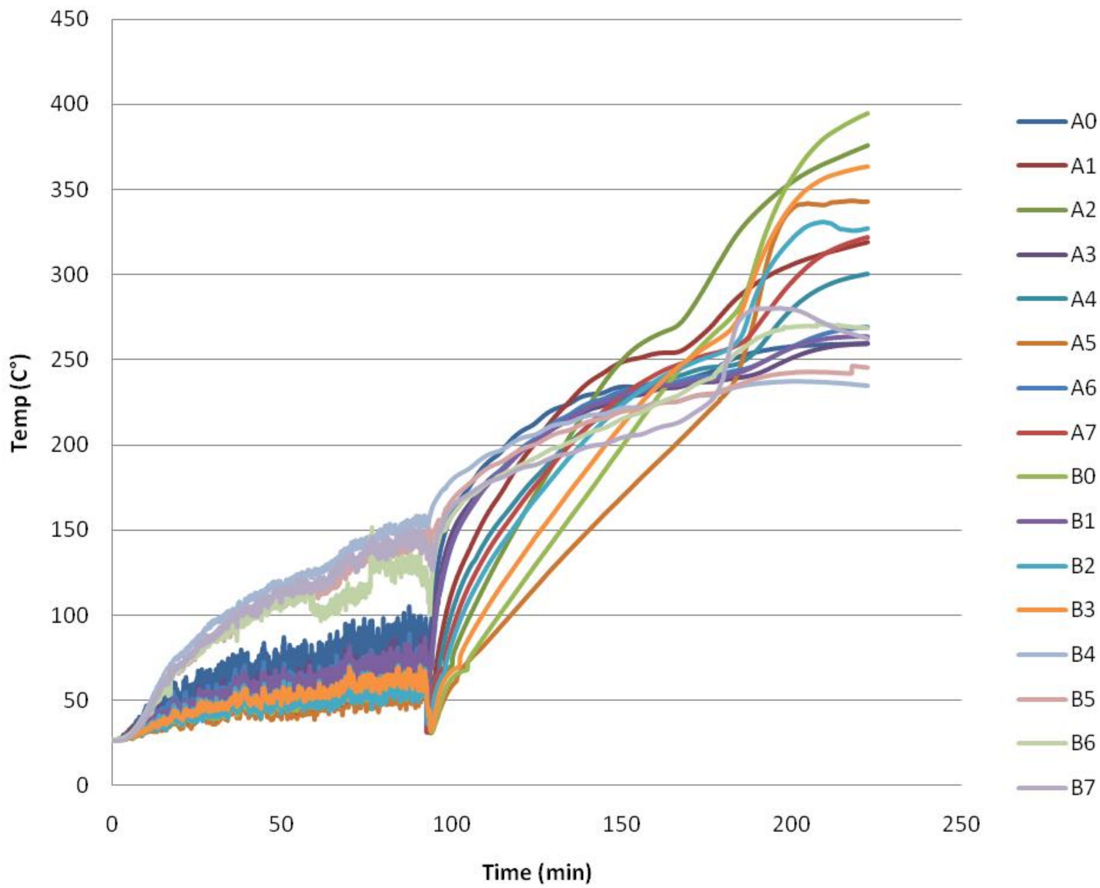


Figure 46: Ignition of coal dust

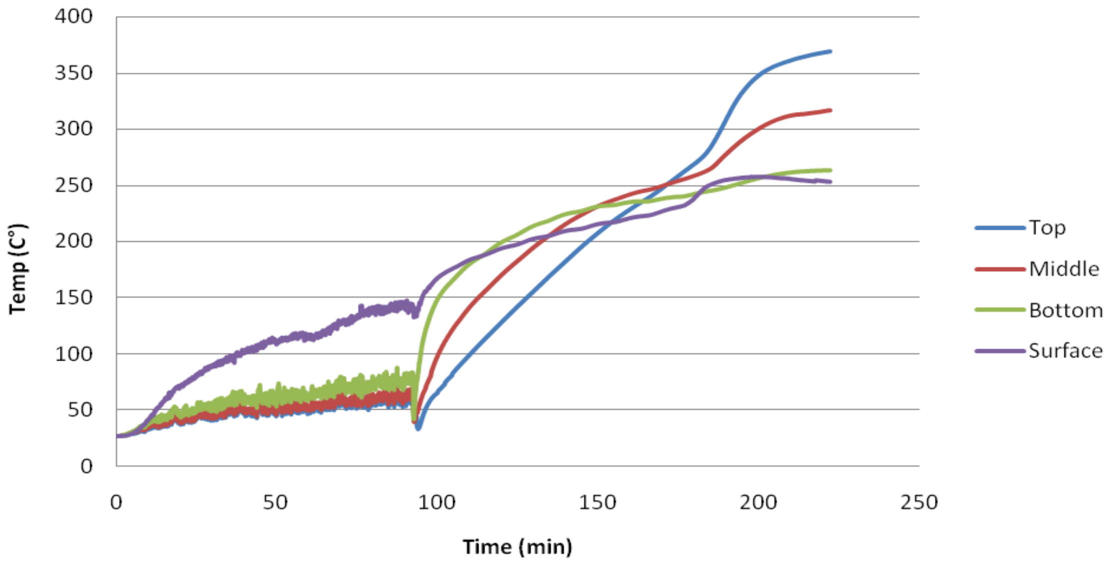


Figure 47: Averaged temperature

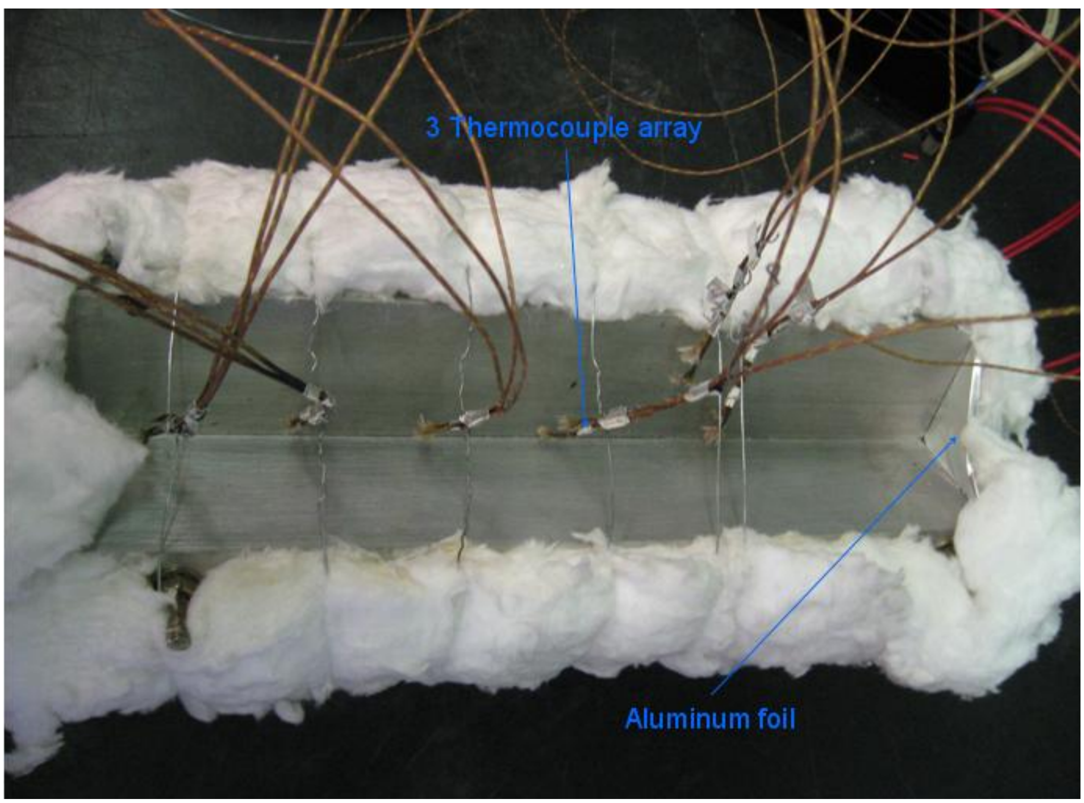


Figure 48: Thermocouples before coal dust was added

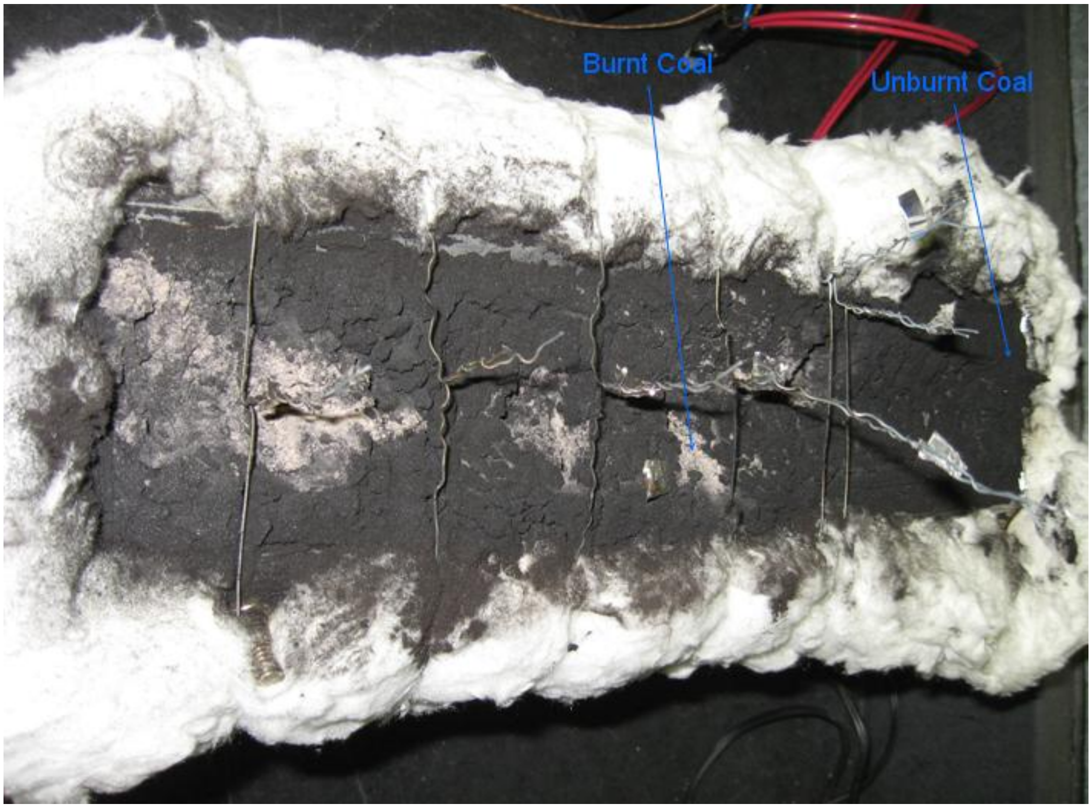


Figure 49: Coal Dust after ignition

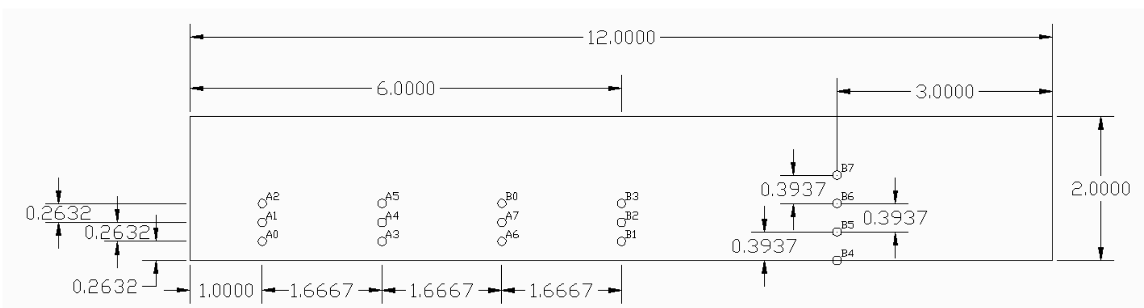


Figure 50: Location of thermopiles in coal dust experiments

The next test was done with an inch of coal dust added. The inch was measure vertically from the bottom on the “V”. The temperature controller was set to 230 degrees Celsius to insure that the coal dust would ignite. The temperatures of the different locations can be seen in Figure 51 and the location of the thermocouples can be seen in Figure 52. In this test 99.7 grams of coal dust were used. The surface of the apparatus reached 186 degrees Celsius at steady state. Ignition of the coal dust according to ASTM standards E 2021-01 occurs when the temperature of the coal exceed the temperature of the hotplate surface by 50 degrees, which in this case was 236 degrees Celsius.

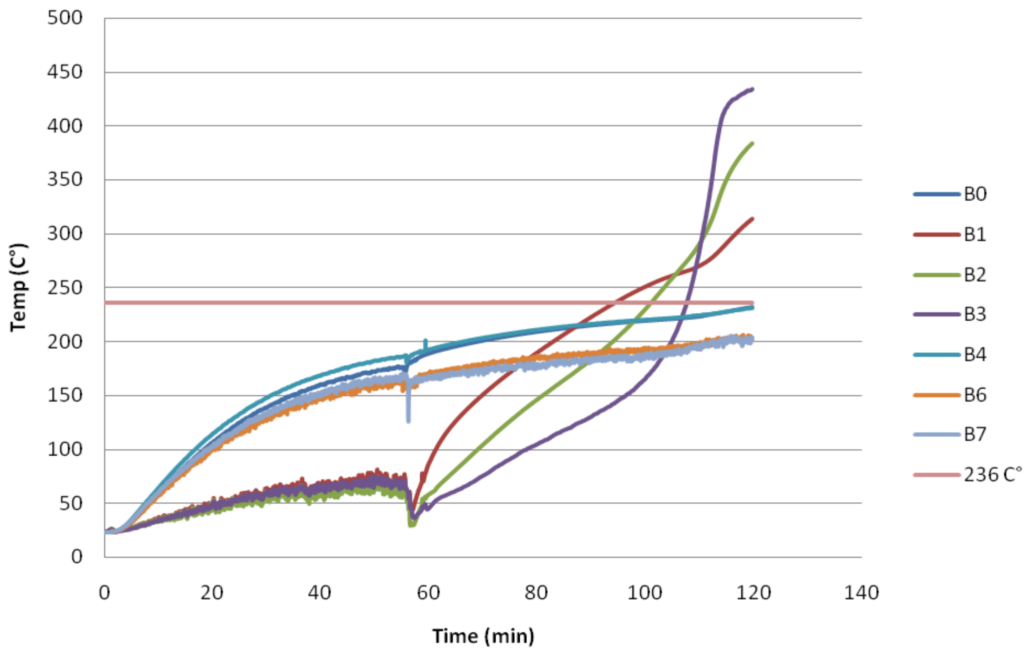


Figure 51: Ignition with 1 inch of coal

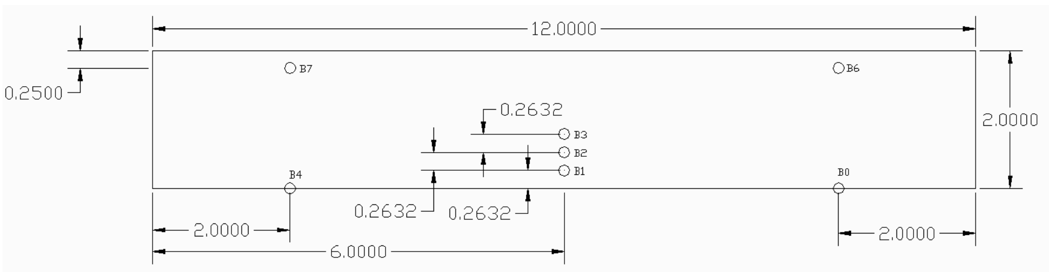


Figure 52: Location of thermocouples in second coal dust experiment

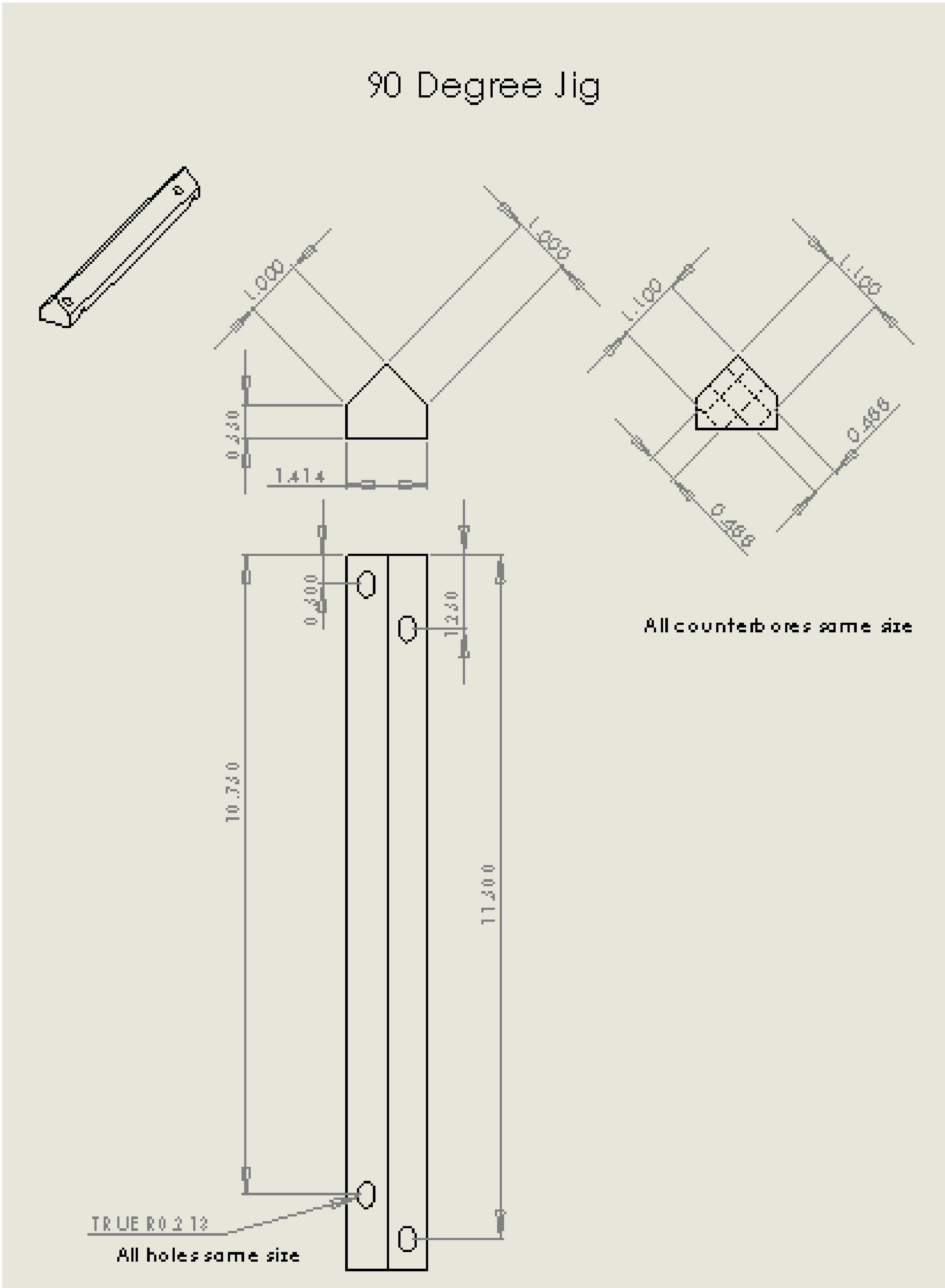
7 Conclusion

The primary goal of this project was to design, build, and test a hot plate in the shape of a “V” that could be used for ignition testing of a variety of different dusts. The hot plate is capable being set at three different angles. When comparing the temperature across the surface of the flat hot plate configuration to the temperature across the surface of the hot plate used for previous testing of coal dust the temperature were in a comparable range. When the apparatus was assembled the temperature across the surface of one side of the apparatus in the vertical direction varied. It was concluded that there was a temperature gradient because of the geometry of the apparatus. Through our testing we determined that the cause of the gradient was largely due to the mass of the bottom jig. Therefore we reduced the mass of the bottom jig of the apparatus. When the temperatures were compared along the centerline of the apparatus it was decided that the difference in temperature along the length of the apparatus along the bottom was within the range of ±3 degrees Celsius. This range is comparable to the hot plate used for previous testing even though it is only in one dimension, along the length of the apparatus, the shape of our apparatus dictates that it will not heat uniformly in the other dimension. This apparatus can be used for doing comparative testing, between different orientations in regards to different hot plate surface and ignition temperatures of various dusts.

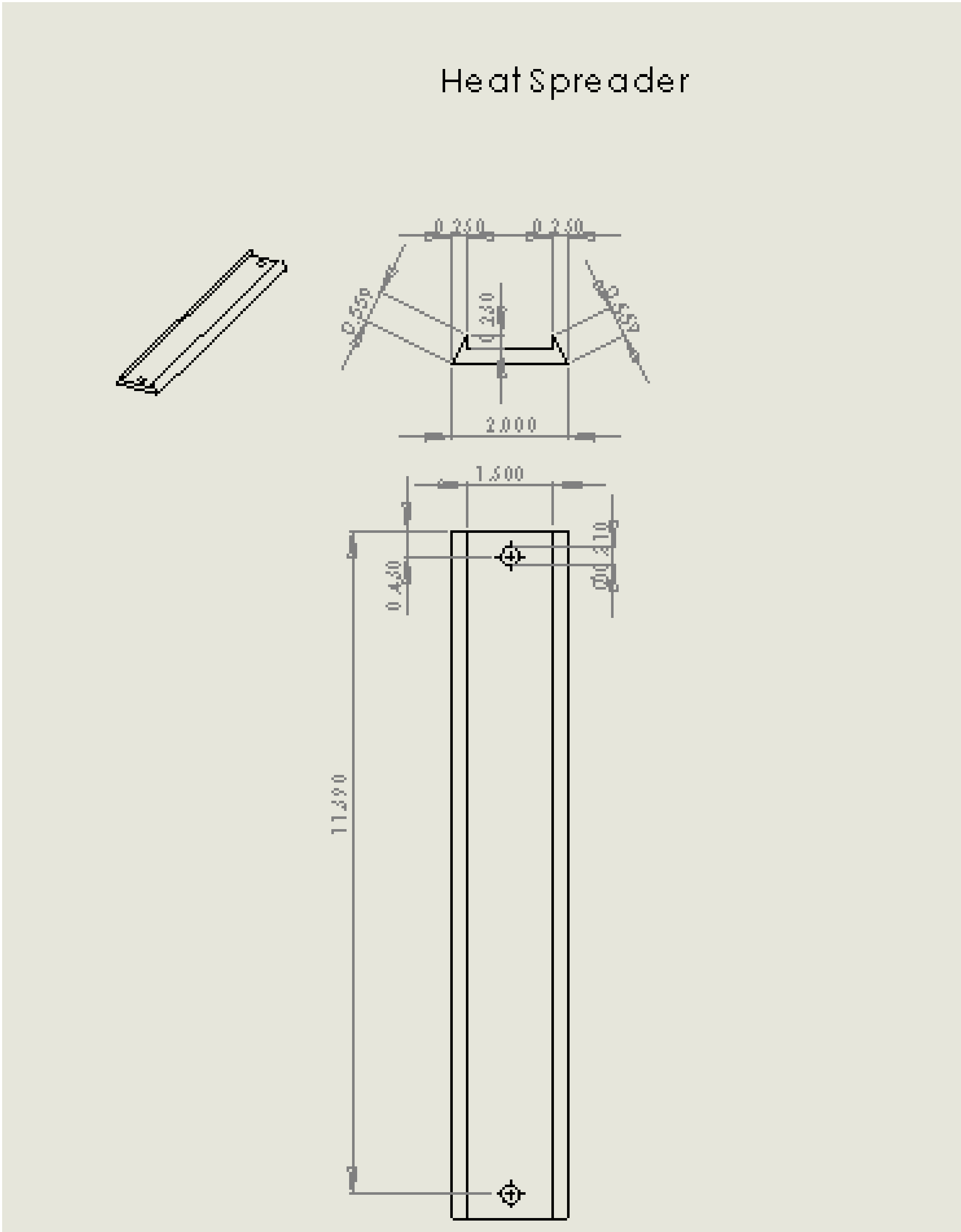
8 References

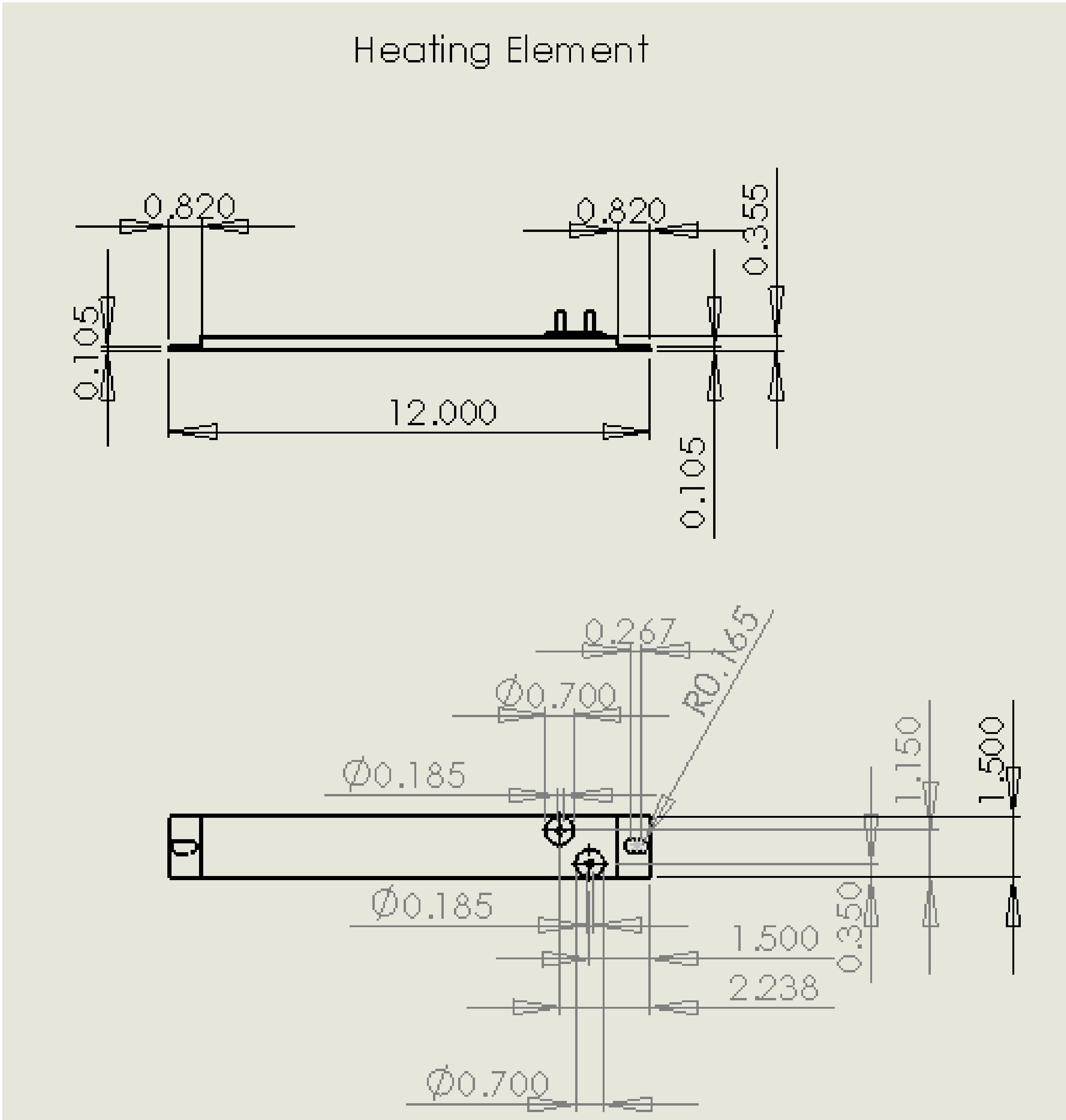
1. ASTM Standard E2021-01, 1999 (2002), "Standard Test Method for Hot-Surface Ignition Temperature of Dust Layers," ASTM International, West Conshohocken, PA, 2002, DOI: 10.1520/E2021-06, www.astm.org

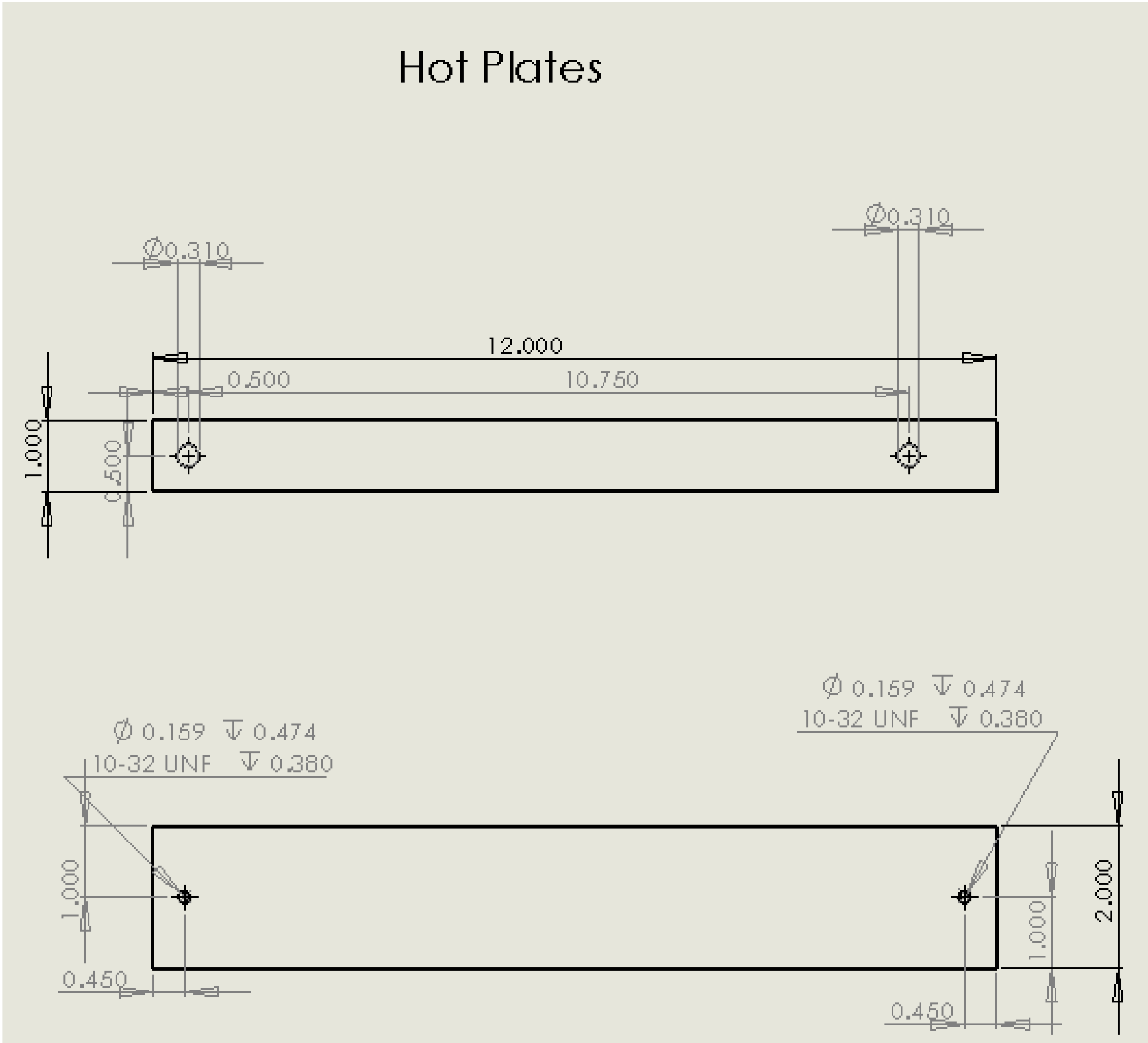
Appendix A



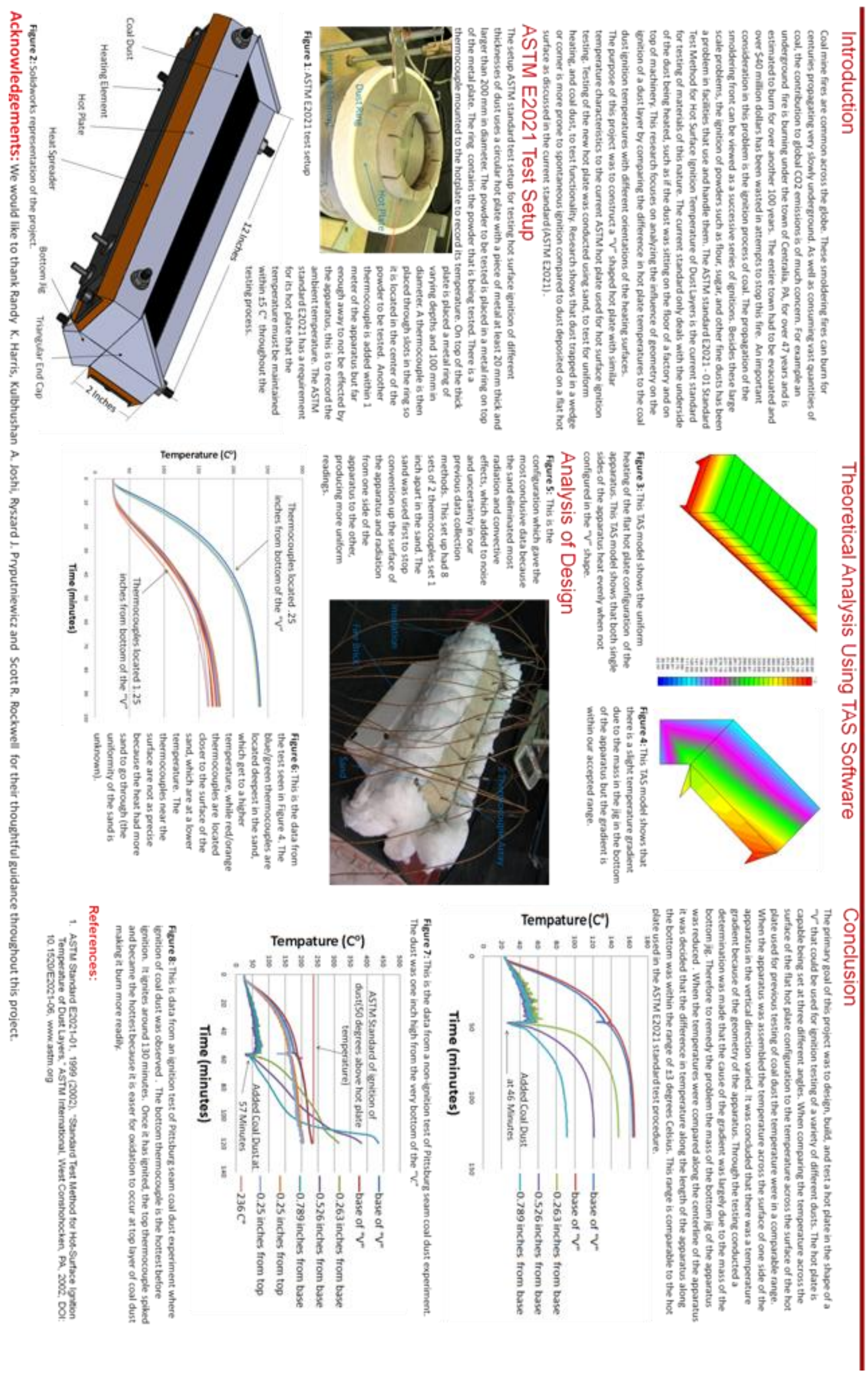
90 Degree Jig
1.000
1.000
1.100
1.100
0.250
1.414
0.488
0.488
0.500
1.250
10.750
11.500
All counterbores same size
TRUE R0.213
All holes same size


Heat Spreader
0.250
0.250
0.559
0.250
0.559
2.000
1.500
0.430
Ø0.210
11.590


Heating Element
0.820
0.820
0.355
0.105
12.000
0.105
0.267
R0.165
Ø0.700
Ø0.185
1.150
1.500
Ø0.185
1.500
0.350
2.238
Ø0.700


Hot Plates
Ø0.310
Ø0.310
12.000
0.500
10.750
1.000
0.500
Ø 0.159 ⊽ 0.474
10-32 UNF ⊽ 0.380
Ø 0.159 ⊽ 0.474
10-32 UNF ⊽ 0.380
1.000
0.450
1.000
2.000
0.450

Appendix B



Coal Dust Ignition
Departments: Mechanical Engineering & Fire Protection Engineering
Alexander S. Andrews & John D. Desrosier
Advisor: Professor Ali S. Rangwala
Introduction
Coal mine fires are common across the globe. These smoldering fires can burn for centuries propagating very slowly underground. As well as consuming vast quantities of coal, the contribution to global CO2 emissions is of much concern. For example an underground fire is burning under the town of Centralia, PA, for over 47 years and is estimated to burn for over another 100 years. The entire town had to be evacuated and over $40 million dollars has been wasted in attempts to stop this fire. An important consideration in this problem is the ignition process of coal. The propagation of the smoldering front can be viewed as a successive series of ignitions. Besides these large scale problems, the ignition of powders such as flour, sugar, and other fine dusts has been a problem in facilities that use and handle them. The ASTM standard E2021 - 01 Standard Test Method for Hot Surface Ignition Temperature of Dust Layers is the current standard for testing of materials of this nature. The current standard only deals with the underside of the dust being heated, such as if the dust was sitting on the floor of a factory and on top of machinery. This research focuses on analyzing the influence of geometry on the ignition of a dust layer by comparing the difference in hot plate temperatures to the coal dust ignition temperatures with different orientations of the heating surfaces.
The purpose of this project was to construct a "V" shaped hot plate with similar temperature characteristics to the current ASTM hot plate used for hot surface ignition testing. Testing of the new hot plate was conducted using sand, to test for uniform heating, and coal dust, to test functionality. Research shows that dust trapped in a wedge or corner is more prone to spontaneous ignition compared to dust deposited on a flat hot surface as discussed in the current standard(ASTM E2021).
ASTM E2021 Test Setup
The setup ASTM standard test setup for testing hot surface ignition of different thicknesses of dust uses a circular hot plate with a piece of metal at least 20 mm thick and larger than 200 mm in diameter. The powder to be tested is placed in a metal ring on top of the metal plate. The ring contains the powder that is being tested. There is a thermocouple mounted to the hotplate to record its temperature. On top of the thick plate is placed a metal ring of varying depths and 100 mm in diameter. A thermocouple is then placed through slots in the ring so it is located in the center of the powder to be tested. Another thermocouple is added within 1 meter of the apparatus but far enough away to not be effected by the apparatus, this is to record the ambient temperature. The ASTM standard E2021 has a requirement for its hot plate that the temperature must be maintained within ±5 C° throughout the testing process.
Hot Plate
Dust Ring
Heating Element
Figure 1: ASTM E2021 test setup
12 Inches
2 Inches
Coal Dust
Heating Element
Hot Plate
Heat Spreader
Bottom Jig
Triangular End Cap
Figure 2: Solidworks representation of the project.
Theoretical Analysis Using TAS Software
Figure 3: This TAS model shows the uniform heating of the flat hot plate configuration of the apparatus. This TAS model shows that both single sides of the apparatus heat evenly when not configured in the "V" shape.
Figure 4: This TAS model shows that there is a slight temperature gradient due to the mass in the jig in the bottom of the apparatus but the gradient is within our accepted range.
Analysis of Design
Figure 5: This is the configuration which gave the most conclusive data because the sand eliminated most radiation and convective effects, which added to noise and uncertainty in our previous data collection methods. This set up had 8 sets of 2 thermocouples set 1 inch apart in the sand. The sand was used first to stop convention up the surface of the apparatus and radiation from one side of the apparatus to the other, producing more uniform readings.
2 Thermocouple Array
Insulation
Fire Brick
Sand
Thermocouples located .25 inches from bottom of the "V"
Thermocouples located 1.25 inches from bottom of the "V"
Temperature (C°)
Time (minutes)
Figure 6: This is the data from the test seen in Figure 4. The blue/green thermocouples are located deepest in the sand, which get to a higher temperature, while red/orange thermocouples are located closer to the surface of the sand, which are at a lower temperature. The thermocouples near the surface are not as precise because the heat had more sand to go through (the uniformity of the sand is unknown).
Conclusion
The primary goal of this project was to design, build, and test a hot plate in the shape of a "V" that could be used for ignition testing of a variety of different dusts. The hot plate is capable being set at three different angles. When comparing the temperature across the surface of the flat hot plate configuration to the temperature across the surface of the hot plate used for previous testing of coal dust the temperature were in a comparable range. When the apparatus was assembled the temperature across the surface of one side of the apparatus in the vertical direction varied. It was concluded that there was a temperature gradient because of the geometry of the apparatus. Through the testing conducted a determination was made that the cause of the gradient was largely due to the mass of the bottom jig. Therefore to remedy the problem the mass of the bottom jig of the apparatus was reduced . When the temperatures were compared along the centerline of the apparatus it was decided that the difference in temperature along the length of the apparatus along the bottom was within the range of ±3 degrees Celsius. This range is comparable to the hot plate used in the ASTM E2021 standard test procedure.
Tempature (C°)
Time (minutes)
Added Coal Dust at 46 Minutes
base of "V"
base of "V"
0.263 inches from base
0.526 inches from base
0.789 inches from base
Figure 7: This is the data from a non-ignition test of Pittsburg seam coal dust experiment. The dust was one inch high from the very bottom of the "V."
Tempature (C°)
Time (minutes)
ASTM Standard of ignition of dust(50 degrees above hot plate temperature)
Added Coal Dust at 57 Minutes
base of "V"
base of "V"
0.263 inches from base
0.526 inches from base
0.789 inches from base
0.25 inches from top
0.25 inches from top
236 C°
Figure 8: This is data from an ignition test of Pittsburg seam coal dust experiment where ignition of coal dust was observed . The bottom thermocouple is the hottest before ignition. It ignites around 130 minutes. Once it has ignited, the top thermocouple spiked and became the hottest because it is easer for oxidation to occur at top layer of coal dust making it burn more readily.
References:
1. ASTM Standard E2021-01, 1999 (2002), "Standard Test Method for Hot-Surface Ignition Temperature of Dust Layers," ASTM International, West Conshohocken, PA, 2002, DOI: 10.1520/E2021-06, www.astm.org
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