Title	Calorimetry-Eighteen Cardboard Boxes		
Test Type	Custom		
Lab Number	NTSB-3	**Author**	Justin L. Rowe
Test dates	8/8/11, 8/9/11, 8/10/11	**No. Tests**	4

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NOTE: All dimensional measurements were taken in English units and were later converted to metric units. Any inconsistencies between the two units are due to rounding errors when the English units were converted to metric.

Introduction

Four calorimetry tests were conducted to determine the fire growth rate and energy released from a stack of cardboard boxes and to examine the affect of the ignition scenario on fire development. Eighteen cardboard boxes containing shredded paper were configured in a 3x3x2 array, as shown in Figure 1. The fire was started either by using an open flame ignition source or heating a cartridge heater to simulate thermal runaway of a lithium-ion battery inside the array of boxes. Instrumentation was installed to measure the heat flux, fire plume temperature, smoke production, and heat release rate of the fire. Video and photos were taken to document the test series. The test series was conducted using the 4 MW calorimeter in the Medium Burn Room (MBR) of the Bureau of Alcohol, Tobacco, Firearm, and Explosives (ATF) Fire Research Laboratory (FRL) in Beltsville, MD.

Figure 1. General layout of fuel load (6548_200240.JPG)

Test Set Up

General

Eighteen 0.46 x 0.46 x 0.46 m (18 x 18 x 18 inch) cardboard boxes were stacked in a 3x3x2 array and placed on one layer of 13 mm (0.5 inch) thick Durock cement board in an open laboratory environment, as shown in Figure 1. The top and bottom of each box was closed by alternating the flaps. There was a 0.05 m (2 inch) separation between adjacent boxes on each layer but there was no separation between the top and bottom layer. Each box contained 1.13 kg (2.5 lbs) of shredded paper, shown in Figure 2, for a total of 20.4 kg (45 lbs) of paper. The width of the paper was 4 mm (0.16 inch).

Figure 2. Shredded paper in cardboard box (6548_200255.JPG)

Test 1 (Exp ID. 6548) and Test 2 (Exp ID. 6549)

In Test 1 and Test 2, modifications were made to the middle box on the bottom layer to facilitate airflow to the ignition device. Two 25 mm (1 inch) diameter vents were made on each side of the box at a distance of 50 mm (2 inch) from the top and bottom edge and 0.23 m (9 inch) from the sides, as shown in Figure 3.

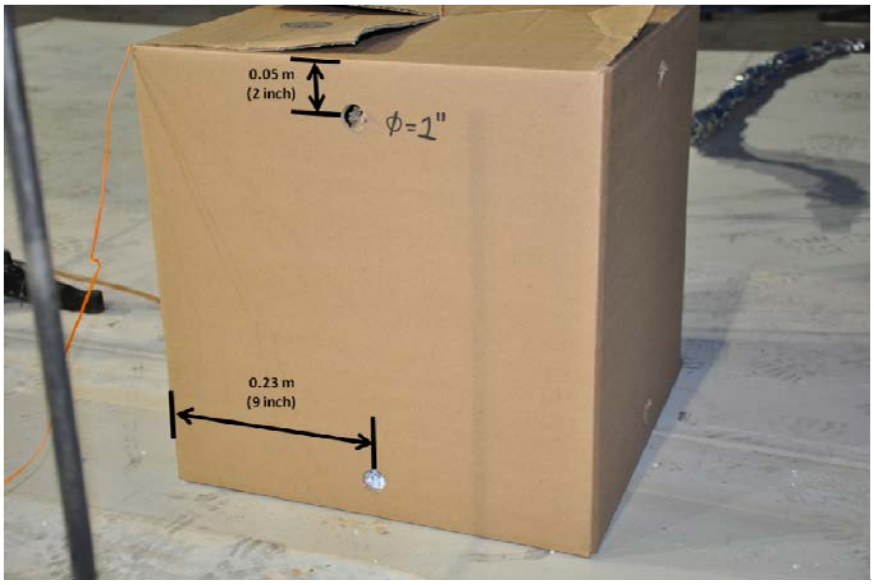

Figure 3. Ignition box (6548_212765.JPG)

Test 3 (Exp ID. 6557) and Test 4 (Exp ID. 6558)

In Test 3 and Test 4, a 0.22 x 0.20 x 0.06 m (8.5 x 8 x 2.5 inch) cardboard container filled with 100 rechargeable lithium-ion batteries (Manufacturer: LG Chem; Model: 18650) was added to the test configuration. The batteries were stacked vertically in a single layer, separated by cardboard inserts as shown in Figure 4. The batteries had a 3.7 Volt, 2600 mAmp-hour rating.

In Test 3, the battery container was located in the middle of the cardboard box configuration between the top and bottom layer, as shown in Figure 5. The battery container was mounted in a 0.48 m (19 inch) high metal stand to keep the batteries supported during the fire.

In Test 4, the battery container was placed on the metal stand within the middle box on the top layer, as shown in Figure 6, and then covered with the shredded paper, as shown in Figure 7. The metal stand was installed through the boxes to provide additional support during the fire. Vents identical to those in Test 1 and Test 2 were also made, as shown in Figure 6.

Figure 4. Configuration of batteries (6557_200849.JPG)

Figure 5. Configuration of batteries in Test 3 (6557_200843.JPG)

Figure 6. Configuration of batteries in Test 4 (6558_200978.JPG)

Figure 7. Configuration of fuel load in ignition box in Test 4 (6558_200977.JPG)

Experiment Details

Ignition Scenario

Test 1 (Exp ID. 6548) and Test 2 (Exp ID. 6549)

An open flame ignition source was used to ignite the shredded paper inside the middle box on the bottom layer. The ignition device consisted of fifteen large kitchen matches (Manufacturer: Diamond) wrapped around an electric igniter, as shown in Figure 8, and connected to a 6 VDC battery. The ignition device was placed vertically near the top surface of the shredded paper. A small fire starter packet was placed adjacent to the ignition device as shown in Figure 9.

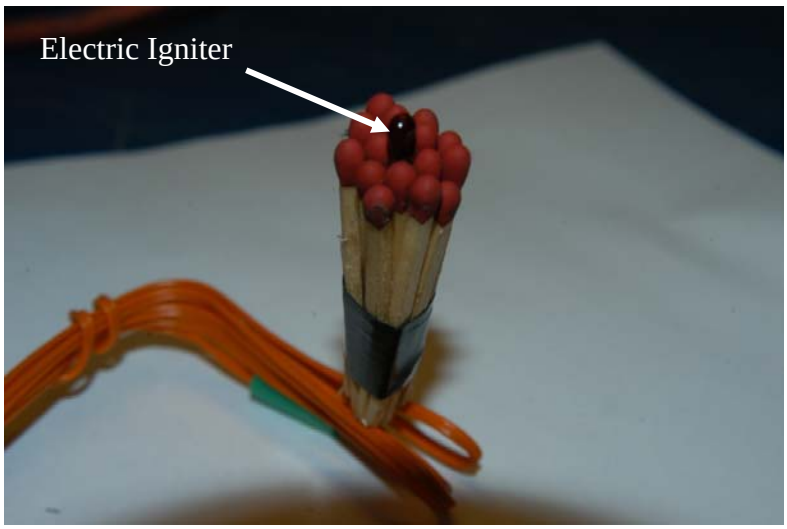

Figure 8. Ignition device (6548_212774.JPG)

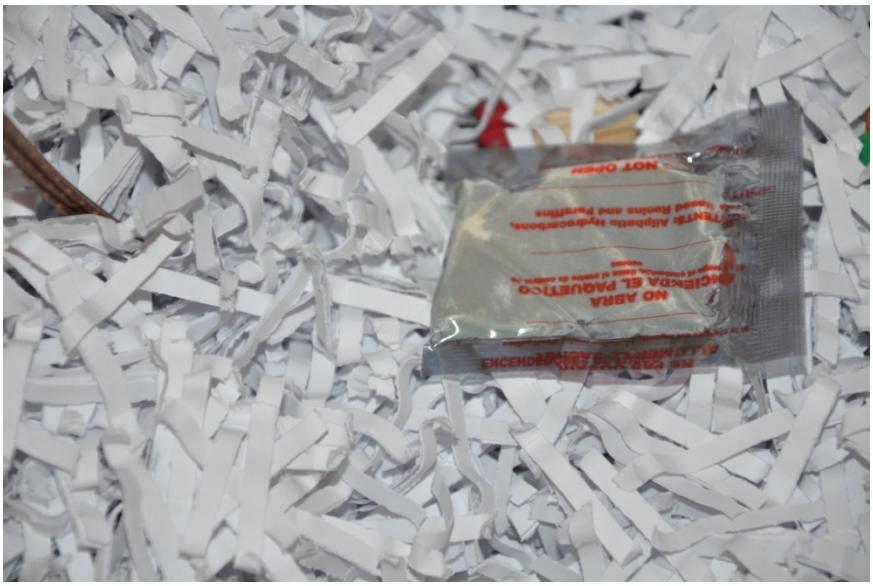

Figure 9. Fire starter packet (6548_200253.JPG)

Test 3 (Exp ID. 6557) and Test 4 (Exp ID. 6558)

A cartridge heater, shown in Figure 10, was used as the primary ignition device to simulate thermal runaway of a rechargeable lithium-ion battery. The cartridge heater was positioned in the box of batteries as shown in Figure 11.

At the start of the test, power was supplied to the cartridge heater, using a variable transformer connected to a 115 VAC power supply.

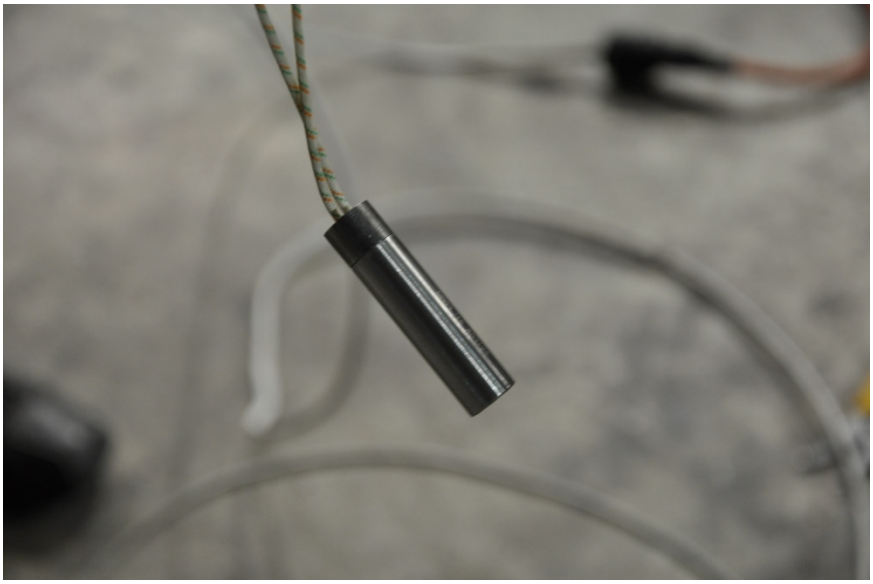

Figure 10. Cartridge heater (6557_200845.JPG)

Figure 11. Cartridge heater location in battery array (6557_200855.JPG)

Instrumentation

The test series was conducted under FRL's 4 MW calorimeter. The calorimeter used in this test series was equipped with instrumentation to measure the following fire properties: total heat release rate, convective heat release rate, and combustion gas production rates.

Other instrumentation included one thermocouple tree and four heat flux gauges. The thermocouple tree was used to measure a vertical temperature profile along the plume centerline. The tree consisted of five thermocouples starting at the center of the top surface of the array of boxes and extending 1.22m (48 inch) above the boxes at 0.30 m (12 inch) intervals. An additional thermocouple was placed at each of the heat flux gage locations.

The heat flux gauges were used to measure the total energy transfer per unit area. The gauges were centered parallel to each side of the box array at a distance of 1.52m (60 inch) at a height of 0.46 m (18 inch) for Test 1 and a height of 0.91 m (36 inch) for Test 2 through Test 4.

Elevation distances described in the body of this report are relative to the z-axis defined in Figure 12.

Figure 12. Instrumentation setup (6557_200823.JPG)

Laboratory Conditions

The ambient laboratory temperature, barometric pressure, and relative humidity were measured during the experiment(s). The laboratory conditions were measured using an industrial probe and microserver. The probe measures the ambient conditions using capacitive digital sensors. The sensor probe has surface mounted circuitry which responds to changes in the environment and outputs a digital signal. The Laboratory Conditions were measured in accordance with the method defined in FRL Laboratory Instruction "LI017 Laboratory Conditions" [1].

The following table provides a description of the instrumentation used to collect the ambient laboratory conditions measurements during the experiments.

Table 1. Lab Conditions Description

Description	Manufacturer	Model
MBR_01	OMEGA	IBTHX-D

Thermocouples

Thermocouples are temperature measurement sensors that consist of two dissimilar metals joined at one end (a junction) that produces a small thermo-electrical voltage when the wire is heated. The change in voltage is interpreted as a change in temperature [2]. There are many configurations of thermocouples which affect the temperature range, ruggedness, and response time. The information required to identify these factors for the thermocouples that were used during the experiment(s) conducted for this test series is provided in the "Thermocouple Measurement Description" table. Thermocouples used during this test series were used in accordance with the method defined in FRL laboratory instruction "LI001 Thermocouple" [3].

The following table provides a description of the instrumentation used to collect the temperature measurements during the experiments. The "Description" column describes the location of the temperature measurement. The "Z" location is the height of the thermocouple above the floor. The "Thermocouple Type" describes the characteristics of the thermocouple used.

Table 2. Thermocouple Measurement Description

Description	Location Z (m)	Thermocouple type
Center_48	1.22	Type K, Glass Ins., 24 AWG wire
Center_60	1.52	Type K, Glass Ins., 24 AWG wire
Center_72	1.83	Type K, Glass Ins., 24 AWG wire
Center_84	2.13	Type K, Glass Ins., 24 AWG wire
Center_Top of box	0.91	Type K, Glass Ins., 24 AWG wire
East	0.46	Type K, Glass Ins., 24 AWG wire
Near igniter	0.46	Type K, Glass Ins., 24 AWG wire
North	0.46	Type K, Glass Ins., 24 AWG wire
South	0.46	Type K, Glass Ins., 24 AWG wire
West	0.46	Type K, Glass Ins., 24 AWG wire

Heat Flux Transducers

A heat flux transducer is a device that measures the rate of absorbed incident energy, and expresses it on a per unit area basis. The operating principle of the Schmidt-Boelter heat flux transducer(s) used during this test series is based on one-dimensional heat conduction through a solid. Temperature sensors are placed on a thin, thermally conductive sensor element, and applying heat establishes a temperature gradient across the element. The heat flux is proportional to the temperature difference across the element according to Fourier's Law [4].

There are many configurations of heat flux transducers which affect range, size, mode and sensitivity. The information required to identify these factors for the heat flux transducer(s) that were used during the experiment(s) conducted for this test series is provided in the "Heat Flux Measurement Description" table. Heat flux transducers were used in accordance with the method defined in FRL laboratory instruction "LI002 Heat Flux Transducer" [5].

The following table provides a description of the transducer used to collect heat flux measurements during the experiment(s). The "Description" column typically describes the location of the heat flux transducer. Heat flux mode indicates whether the total heat flux was measured or just the radiation fraction. Heat flux over range is the maximum measured value reported for this transducer.

Table 3. Heat Flux Measurement Description

Description	Heat Flux Mode	Heat Flux Max Range (kW/m²)
East	Total	75.00
North	Total	75.00
South	Total	75.00
West	Total	75.00

Fire Product Collectors

Fire product collectors, also called heat release calorimeters, are used in fire experiments to measure several characteristics of fires based upon the measured properties of the fire plume. Fire Product collectors consist of a collection hood connected to an exhaust duct placed over a fire as shown in Figure 13. Instrumentation in the exhaust duct measures the properties of the effluent. The fire characteristics that are often calculated from fire products collectors are total heat release rate (HRR), convective heat release rate (CHRR), smoke production rate (SPR), and yield rates of gas species such as carbon monoxide and carbon dioxide.

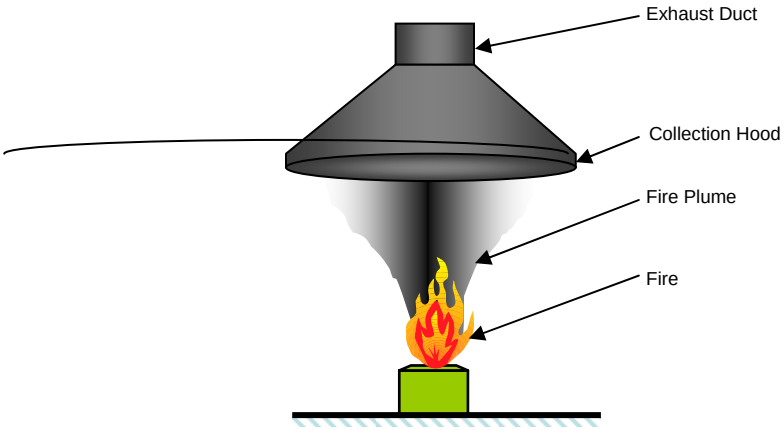

Figure 13. Typical products collector hood

Photographs

Digital Cameras are used within the FRL to record digital still photographs during experiments. Digital Cameras used during this test series were used in accordance with the method defined in FRL Laboratory Instruction "LI003 Digital Cameras" [6].

Results for Test 1 (Exp. ID 6548)

The following table provides a summary of the ambient laboratory temperature during the experiment.

Table 4. Ambient Laboratory Temperature Summary

Description	Initial Value (C)	Minimum (C)	Maximum (C)	Average (C)	Final Value (C)
MBR_01	27.5	27.4	27.6	27.5	27.6

The following table provides a summary of the ambient laboratory pressure during the experiment.

Table 5. Ambient Laboratory Pressure Summary

Description	Initial Value (kPa)	Minimum (kPa)	Maximum (kPa)	Average (kPa)	Final Value (kPa)
MBR_01	99.81	99.78	99.82	99.80	99.79

The following table provides a summary of the ambient laboratory relative humidity during the experiment.

Table 6. Ambient Laboratory Relative Humidity Summary

Description	Initial Value (%)	Minimum (%)	Maximum (%)	Average (%)	Final Value (%)
MBR_01	60.8	60.3	61.0	60.6	60.4

The following table provides a summary of the temperature results. The "Initial Temperature" column provides the measured temperature at the beginning of the test. The maximum temperature recorded during the test is provided in the "Maximum" column. The remaining columns provide the calculated maximum average temperatures.

Table 7. Temperature Value Result Summary

Description	Initial (C)	Maximum (C)	30 second maximum average (C)	60 second maximum average (C)	300 second maximum average (C)	600 second maximum average (C)
Center_48	27	976	911	833	515	282
Center_60	27	971	921	871	495	273
Center_72	27	925	890	845	461	257
Center_84	28	846	810	751	424	238
Center_Top of box	28	851	781	686	502	273

The following table shows which thermocouple(s) were taken out of service during the experiment.

Table 8. Out of Service Times

Description	Time out of service (s)	Out of service reason
Center_48	618	TC Damage
Center_60	618	TC Damage
Center_72	618	TC Damage
Center_84	618	TC Damage
Center_Top of box	618	TC Damage

The following chart(s) present a time-dependent representation of the instantaneous temperatures measured during the experiment.

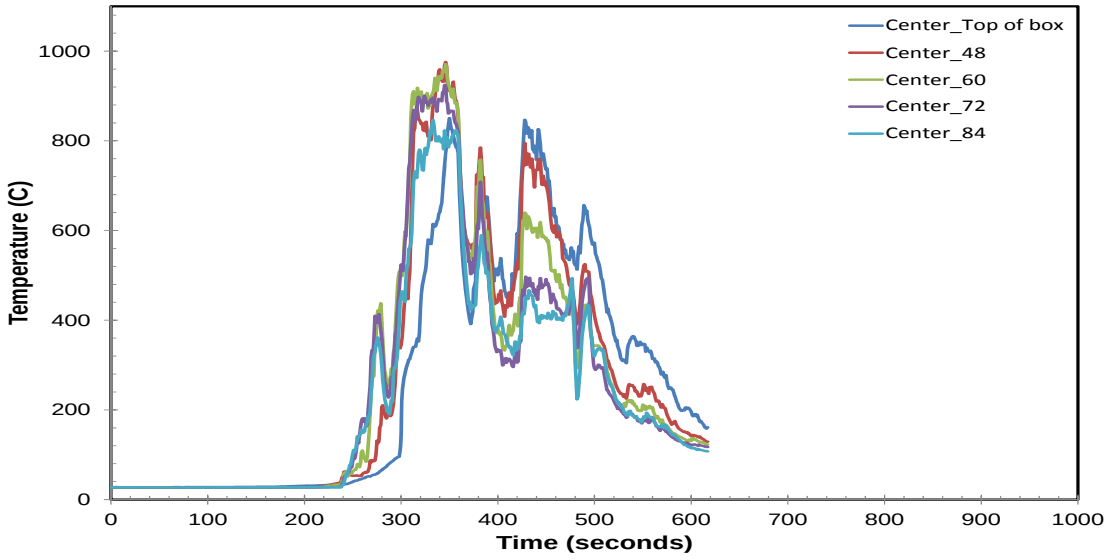

Figure 14. Temperature

The following table provides a summary of the heat flux results. The "Description" column typically describes the location of the heat flux transducer. The time at which the heat flux first changes by a pre-determined amount is provided in the "Time of Initial Change" column. The maximum heat flux recorded during the test is provided in the "Maximum" column. The "Maximum Average" columns are calculated over four pre-determined time spans.

Table 9. Heat Flux Result Summary

Description	Time of Initial Change (s)	Maximum (kW/m²)	30 second maximum average (kW/m²)	60 second maximum average (kW/m²)	300 second maximum average (kW/m²)	600 second maximum average (kW/m²)
East	1	3.3	3.1	3.0	2.5	1.7
North	1	3.6	3.5	3.5	2.8	1.8
South	1	4.6	4.3	4.1	2.9	1.7
West	1	3.5	3.0	2.9	2.4	1.6

The following chart shows a time dependent representation of the instantaneous heat flux measured during the experiment.

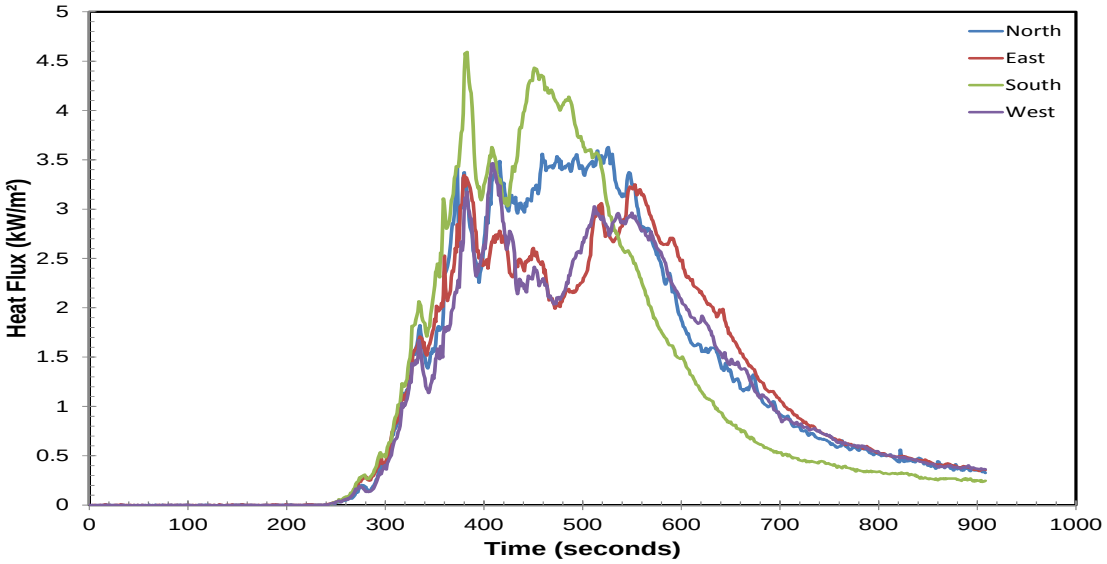

Figure 15. Heat Flux

The following chart provides a time history of the concentration of carbon monoxide and carbon dioxide measured in the exhaust duct during the fire.

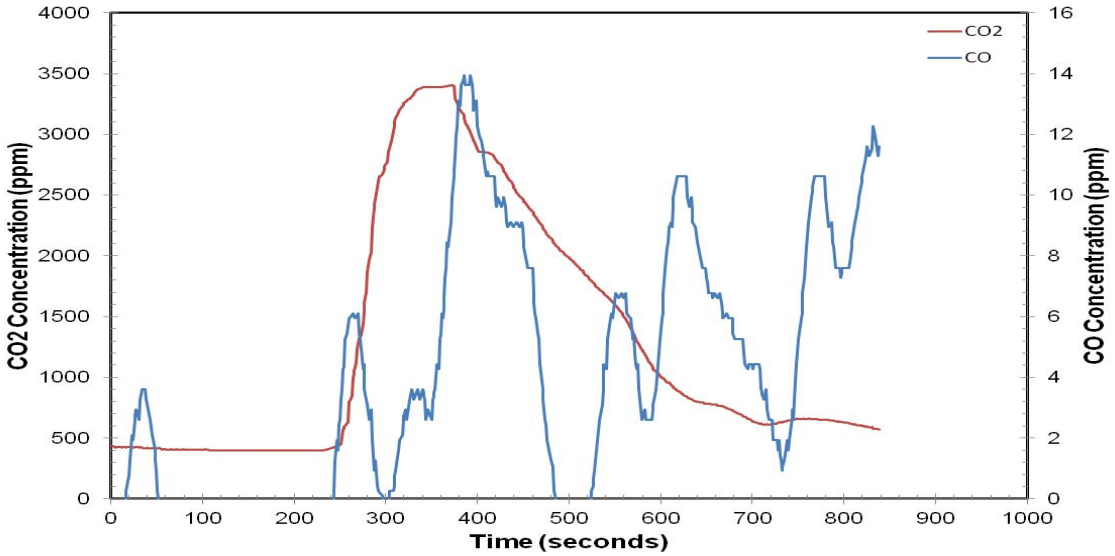

Figure 16. Carbon monoxide and carbon dioxide concentrations

The following chart provides a time history of the concentration of oxygen measured in the exhaust duct during the fire.

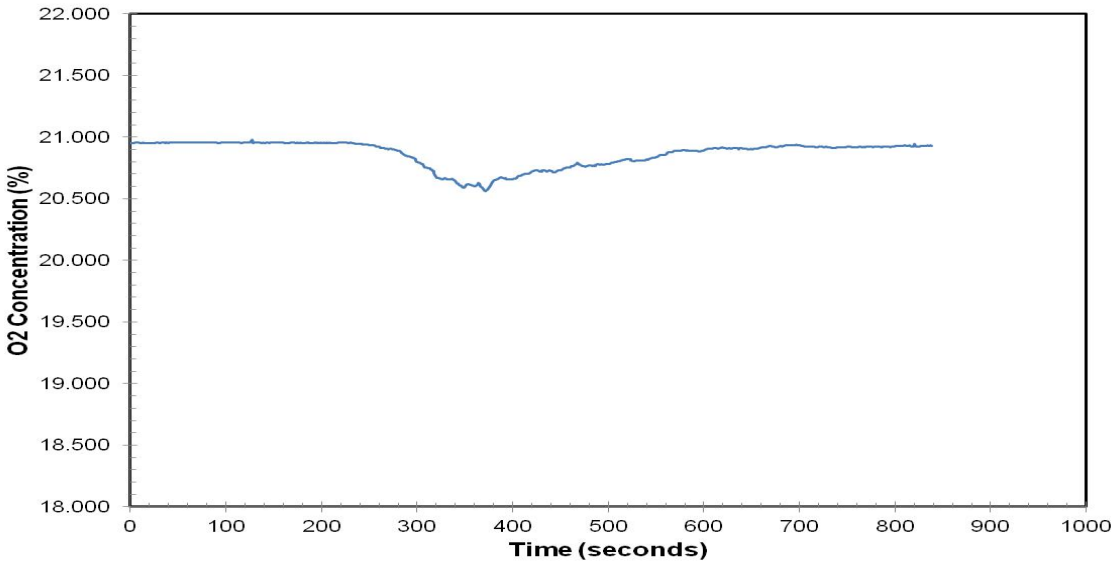

Figure 17. Oxygen Concentration

The following table provides a summary of the heat release rate (HRR) test results. The maximum HRR recorded during the test is provided in the "Maximum" column. The "maximum average" values are calculated from average values of heat release rate over specified time periods. The maximum average values provide a means to compare the severity of different fires over these time spans. The "Total heat released" is calculated from the area under the curve for the duration of the test.

Table 10. Heat Release Rate Result Summary

Maximum (kW)	30 second maximum average (kW)	1 minute maximum average (kW)	5 minute maximum average (kW)	10 minute maximum average (kW)	Total Heat Release (kJ)
1428	1307	1264	1307	474	286542

The following chart provides a time history of the heat release rate from the fire.

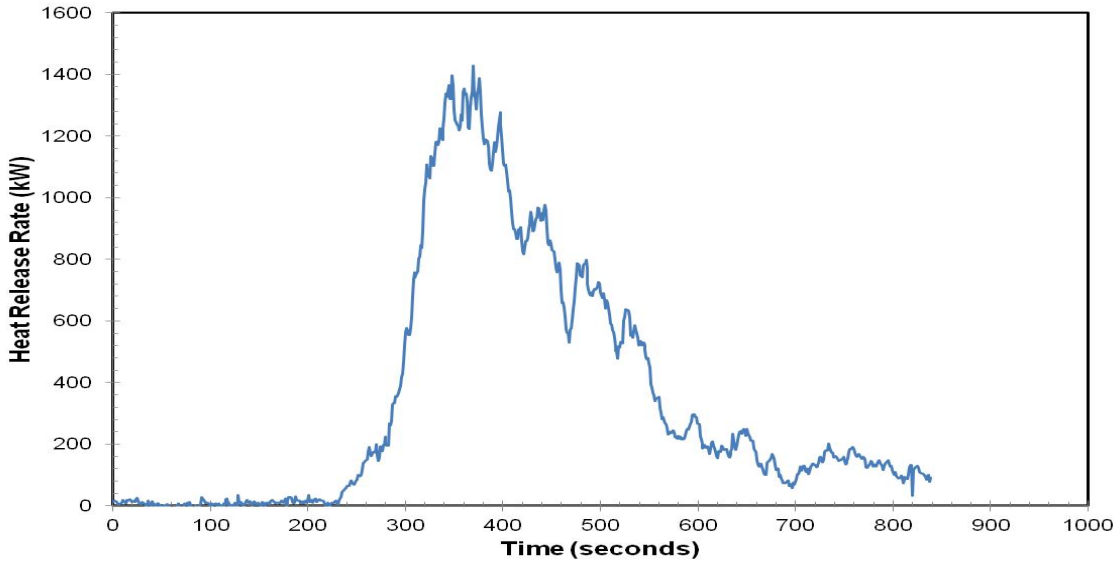

Figure 18. Heat Release Rate

The following table provides a summary of the convective heat release rate (CHRR) test results.

Table 11. Convective Heat Release Rate Result Summary

Maximum (kW)	30 second maximum average (kW)	Peak 60 sec avg (kW)	5 minute maximum average (kW)	Peak 600 sec avg (kW)
914	787	740	491	295

The following chart provides a time history of the convective heat release rate from the fire.

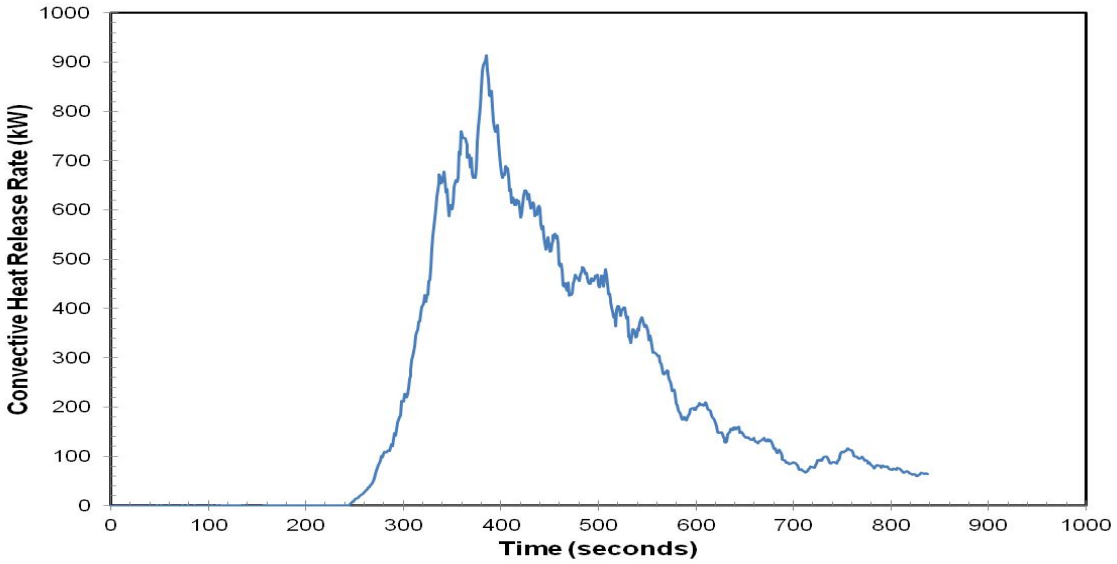

Figure 19. Convective Heat Release Rate

The following chart displays the production rates of CO and CO2.

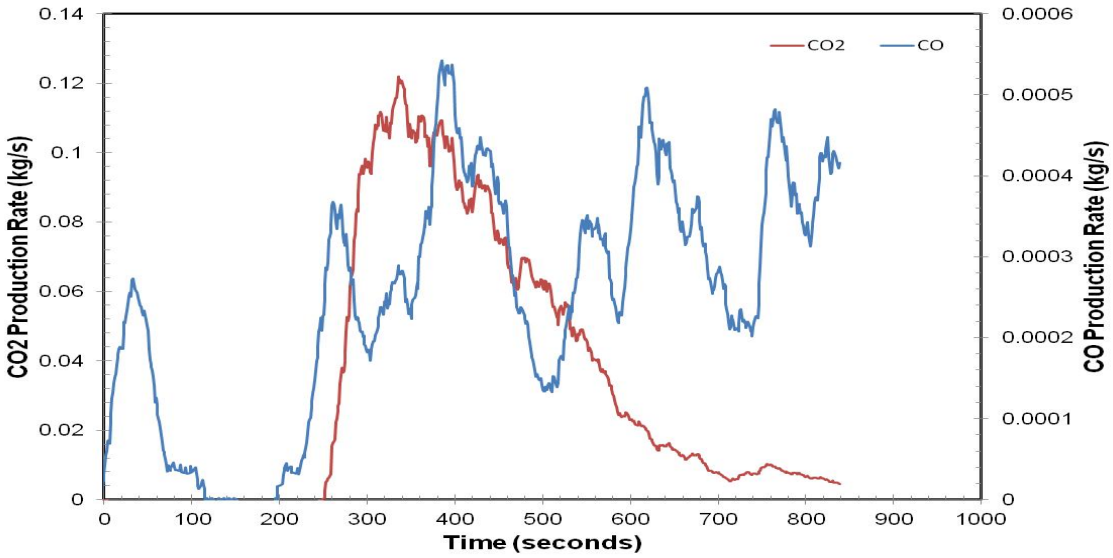

Figure 20. CO and CO2 production rates

The following table provides a description of the video(s) taken during this experiment.

Table 12. Video Log

Description	Start Time	Duration (s)	Filename
1	13:58:32	932	6548_20110808_135832_1.mp4
2	13:58:33	932	6548_20110808_135833_2.mp4
3	13:58:35	932	6548_20110808_135835_3.mp4

The following figures show all of the still photographs uploaded into the FireTOSS system. The caption below each figure provides the picture's filename as well as any description and elapsed test time associated with the picture.

Figure 21. Pre test 4:15 hr:min, 6548_212765.jpg

Figure 22. Pre test 33 minutes, 6548_200255.jpg

Figure 23. Pre test 33 minutes, 6548_200254.jpg

Figure 24. Pre test 32 minutes, 6548_200253.jpg

Figure 25. Pre test 30 minutes, 6548_200252.jpg

Figure 26. Pre test 30 minutes, 6548_200251.jpg

Figure 27. Pre test 29 minutes, 6548_200250.jpg

Figure 28. Pre test 29 minutes, 6548_200249.jpg

Figure 29. Pre test 28 minutes, 6548_200248.jpg

Figure 30. Pre test 28 minutes, 6548_200247.jpg

Figure 31. Pre test 27 minutes, 6548_200246.jpg

Figure 32. Pre test 27 minutes, 6548_200245.jpg

Figure 33. Pre test 27 minutes, 6548_200244.jpg

Figure 34. Pre test 27 minutes, 6548_200243.jpg

Figure 35. Pre test 27 minutes, 6548_200242.jpg

Figure 36. Pre test 27 minutes, 6548_200241.jpg

Figure 37. Pre test 26 minutes, 6548_200240.jpg

Figure 38. Pre test 26 minutes, 6548_200239.jpg

Figure 39. Pre test 26 minutes, 6548_200238.jpg

Figure 40. Pre test 26 minutes, 6548_200237.jpg

Figure 41. Pre test 26 minutes, 6548_200236.jpg

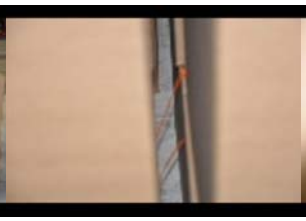

Figure 42. Pre test 26 minutes, 6548_200235.jpg

Figure 43. Pre test 26 minutes, 6548_200234.jpg

Figure 44. Pre test 20 minutes, 6548_200233.jpg

Figure 45. Pre test 20 minutes, 6548_200232.jpg

Figure 46. Pre test 18 minutes, 6548_200231.jpg

Figure 47. Pre test 11 minutes, 6548_200230.jpg

Figure 48. Pre test 10 minutes, 6548_200229.jpg

Figure 49. 48 seconds, 6548_200228.jpg

Figure 50. 94 seconds, 6548_200227.jpg

Figure 51. 153 seconds, 6548_200226.jpg

Figure 52. 162 seconds, 6548_200225.jpg

Figure 53. 165 seconds, 6548_200224.jpg

Figure 54. 179 seconds, 6548_200223.jpg

Figure 55. 218 seconds, 6548_200222.jpg

Figure 56. 221 seconds, 6548_200221.jpg

Figure 57. 224 seconds, 6548_200220.jpg

Figure 58. 227 seconds, 6548_200219.jpg

Figure 59. 240 seconds, 6548_200218.jpg

Figure 60. 242 seconds, 6548_200217.jpg

Figure 61. 245 seconds, 6548_200216.jpg

Figure 62. 246 seconds, 6548_200215.jpg

Figure 63. 248 seconds, 6548_200214.jpg

Figure 64. 249 seconds, 6548_200213.jpg

Figure 65. 260 seconds, 6548_200212.jpg

Figure 66. 267 seconds, 6548_200211.jpg

Figure 67. 269 seconds, 6548_200210.jpg

Figure 68. 276 seconds, 6548_200209.jpg

Figure 69. 287 seconds, 6548_200208.jpg

Figure 70. 289 seconds, 6548_200207.jpg

Figure 71. 306 seconds, 6548_200206.jpg

Figure 72. 310 seconds, 6548_200205.jpg

Figure 73. 313 seconds, 6548_200204.jpg

Figure 74. 316 seconds, 6548_200203.jpg

Figure 75. 322 seconds, 6548_200202.jpg

Figure 76. 332 seconds, 6548_200201.jpg

Figure 77. 336 seconds, 6548_200200.jpg

Figure 78. 348 seconds, 6548_200199.jpg

Figure 79. 355 seconds, 6548_200198.jpg

Figure 80. 360 seconds, 6548_200197.jpg

Figure 81. 365 seconds, 6548_200196.jpg

Figure 82. 366 seconds, 6548_200195.jpg

Figure 83. 376 seconds, 6548_200194.jpg

Figure 84. 378 seconds, 6548_200193.jpg

Figure 85. 386 seconds, 6548_200192.jpg

Figure 86. 389 seconds, 6548_200191.jpg

Figure 87. 394 seconds, 6548_200190.jpg

Figure 88. 398 seconds, 6548_200189.jpg

Figure 89. 410 seconds, 6548_200188.jpg

Figure 90. 430 seconds, 6548_200187.jpg

Figure 91. 432 seconds, 6548_200186.jpg

Figure 92. 436 seconds, 6548_200185.jpg

Figure 93. 440 seconds, 6548_200184.jpg

Figure 94. 447 seconds, 6548_200183.jpg

Figure 95. 452 seconds, 6548_200181.jpg

Figure 96. 452 seconds, 6548_200182.jpg

Figure 97. 469 seconds, 6548_200180.jpg

Figure 98. 472 seconds, 6548_200179.jpg

Figure 99. 477 seconds, 6548_200178.jpg

Figure 100. 498 seconds, 6548_200177.jpg

Figure 101. 501 seconds, 6548_200176.jpg

Figure 102. 512 seconds, 6548_200175.jpg

Figure 103. 516 seconds, 6548_200174.jpg

Figure 104. 535 seconds, 6548_200173.jpg

Figure 105. 543 seconds, 6548_200172.jpg

Figure 106. 580 seconds, 6548_200171.jpg

Figure 107. 582 seconds, 6548_200170.jpg

Figure 108. 585 seconds, 6548_200169.jpg

Figure 109. 590 seconds, 6548_200168.jpg

Figure 110. 595 seconds, 6548_200167.jpg

Figure 111. 607 seconds, 6548_200166.jpg

Figure 112. 611 seconds, 6548_200165.jpg

Figure 113. 850 seconds, 6548_200164.jpg

Figure 114. 853 seconds, 6548_200163.jpg

Figure 115. Post test 0 minutes, 6548_200162.jpg

Figure 116. Post test 0 minutes, 6548_200161.jpg

Figure 117. Post test 0 minutes, 6548_200160.jpg

Figure 118. Post test 0 minutes, 6548_200159.jpg

Figure 119. Post test 0 minutes, 6548_200158.jpg

Figure 120. Post test 0 minutes, 6548_200157.jpg

Figure 121. Post test 0 minutes, 6548_200156.jpg

Figure 122. Post test 0 minutes, 6548_200155.jpg

Figure 123. 6548_212774.jpg

Results for Test 2 (Exp. ID 6549)

The following table provides a summary of the ambient laboratory temperature during the experiment.

Table 13. Ambient Laboratory Temperature Summary

Description	Initial Value (C)	Minimum (C)	Maximum (C)	Average (C)	Final Value (C)
MBR_01	27.7	27.7	27.7	27.7	27.7

The following table provides a summary of the ambient laboratory pressure during the experiment.

Table 14. Ambient Laboratory Pressure Summary

Description	Initial Value (kPa)	Minimum (kPa)	Maximum (kPa)	Average (kPa)	Final Value (kPa)
MBR_01	99.75	99.73	99.77	99.75	99.73

The following table provides a summary of the ambient laboratory relative humidity during the experiment.

Table 15. Ambient Laboratory Relative Humidity Summary

Description	Initial Value (%)	Minimum (%)	Maximum (%)	Average (%)	Final Value (%)
MBR_01	59.4	59.0	59.5	59.3	59.1

The following table provides a summary of the temperature results. The "Initial Temperature" column provides the measured temperature at the beginning of the test. The maximum temperature recorded during the test is provided in the "Maximum" column. The remaining columns provide the calculated maximum average temperatures.

Table 16. Temperature Value Result Summary

Description	Initial (C)	Maximum (C)	30 second maximum average (C)	60 second maximum average (C)	300 second maximum average (C)	600 second maximum average (C)
Center_48	28	893	833	735	551	344
Center_60	28	963	839	721	515	328
Center_72	28	956	882	752	534	348
Center_84	28	915	810	685	496	326
Center_Top of box	28	932	856	761	497	303

The following chart(s) present a time-dependent representation of the instantaneous temperatures measured during the experiment.

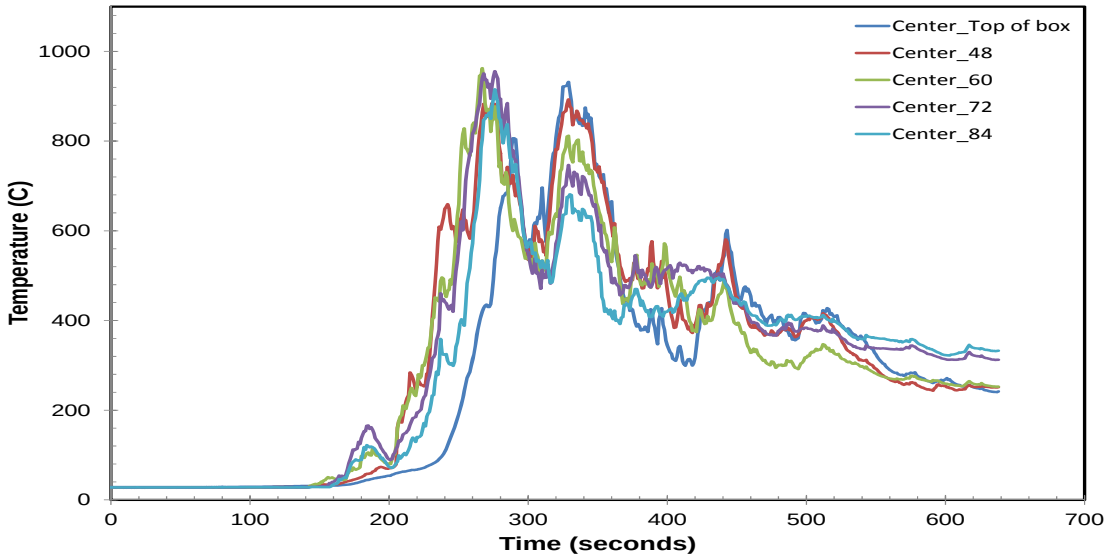

Figure 124. Temperature

The following table provides a summary of the heat flux results. The "Description" column typically describes the location of the heat flux transducer. The time at which the heat flux first changes by a pre-determined amount is provided in the "Time of Initial Change" column. The maximum heat flux recorded during the test is provided in the "Maximum" column. The "Maximum Average" columns are calculated over four pre-determined time spans.

Table 17. Heat Flux Result Summary

Description	Time of Initial Change (s)	Maximum (kW/m²)	30 second maximum average (kW/m²)	60 second maximum average (kW/m²)	300 second maximum average (kW/m²)	600 second maximum average (kW/m²)
East	1	5.3	4.8	4.4	3.4	1.9
North	1	6.2	5.7	5.5	3.7	2.0
South	1	4.9	4.5	4.4	3.2	1.8
West	1	6.9	6.5	6.3	3.9	2.1

The following chart shows a time dependent representation of the instantaneous heat flux measured during the experiment.

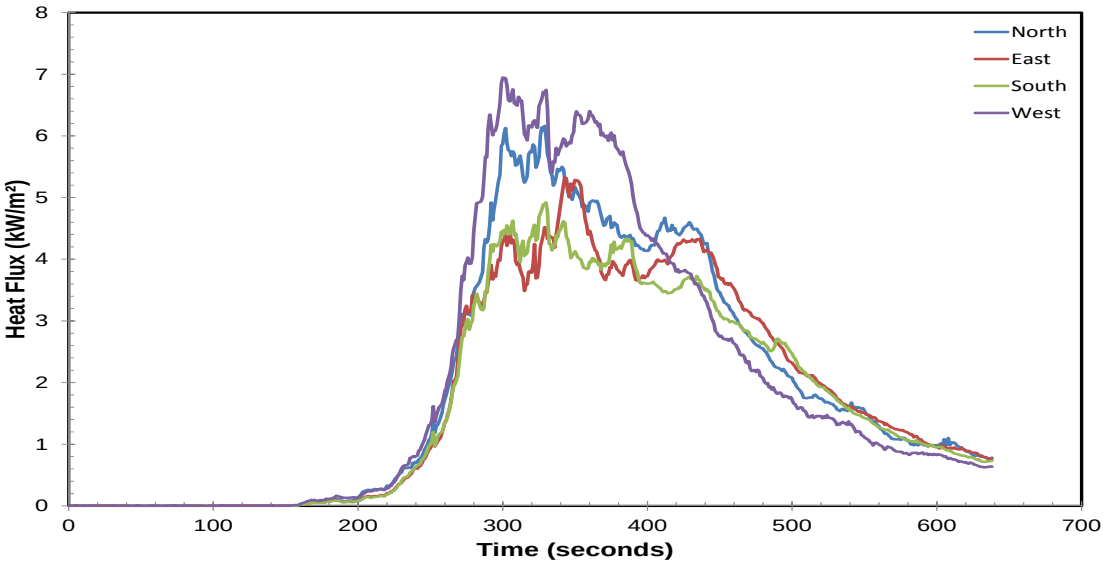

Figure 125. Heat Flux

The following chart provides a time history of the concentration of carbon monoxide and carbon dioxide measured in the exhaust duct during the fire.

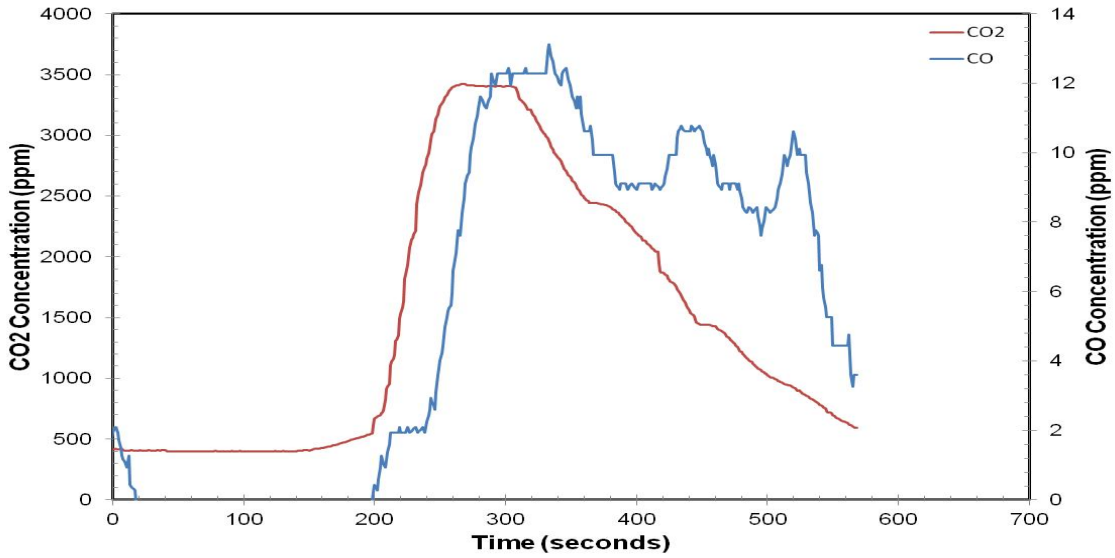

Figure 126. Carbon monoxide and carbon dioxide concentrations

The following chart provides a time history of the concentration of oxygen measured in the exhaust duct during the fire.

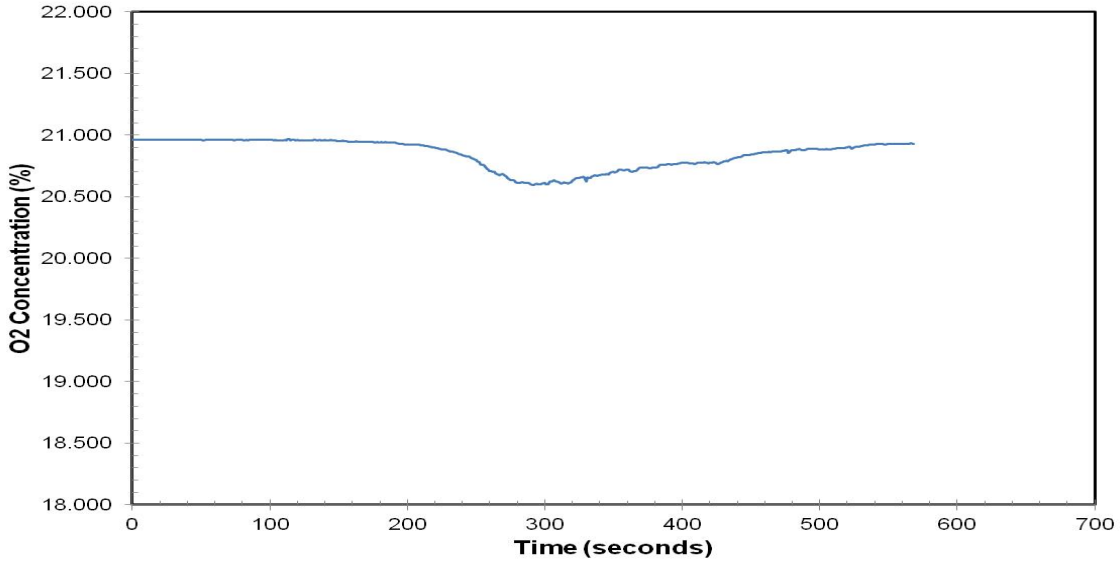

Figure 127. Oxygen Concentration

The following table provides a summary of the heat release rate (HRR) test results. The maximum HRR recorded during the test is provided in the "Maximum" column. The "maximum average" values are calculated from average values of heat release rate over specified time periods. The maximum average values provide a means to compare the severity of different fires over these time spans. The "Total heat released" is calculated from the area under the curve for the duration of the test.

Table 18. Heat Release Rate Result Summary

Maximum (kW)	30 second maximum average (kW)	1 minute maximum average (kW)	5 minute maximum average (kW)	10 minute maximum average (kW)	Total Heat Release (kJ)
1783	1660	1544	1660	483	289335

The following chart provides a time history of the heat release rate from the fire.

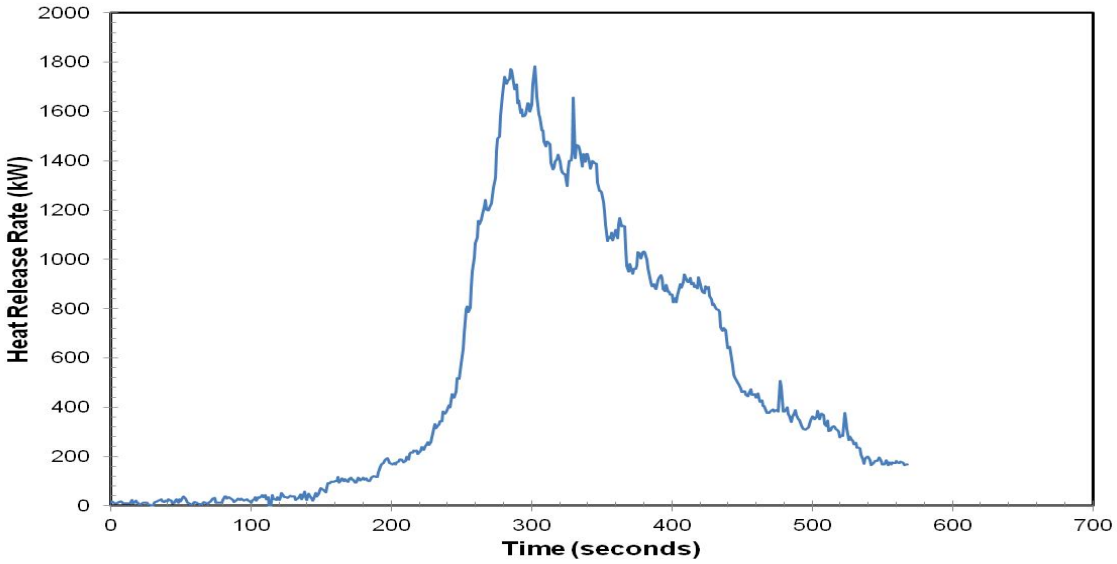

Figure 128. Heat Release Rate

The following table provides a summary of the convective heat release rate (CHRR) test results.

Table 19. Convective Heat Release Rate Result Summary

Maximum (kW)	30 second maximum average (kW)	Peak 60 sec avg (kW)	5 minute maximum average (kW)	Peak 600 sec avg (kW)
993	887	877	515	271

The following chart provides a time history of the convective heat release rate from the fire.

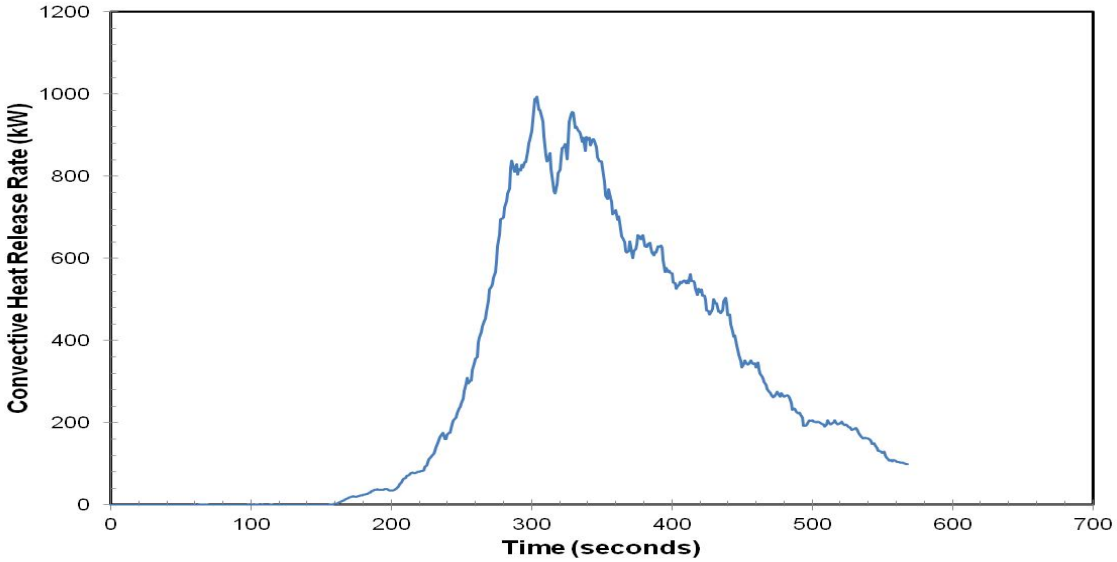

Figure 129. Convective Heat Release Rate

The following chart displays the production rates of CO and CO2.

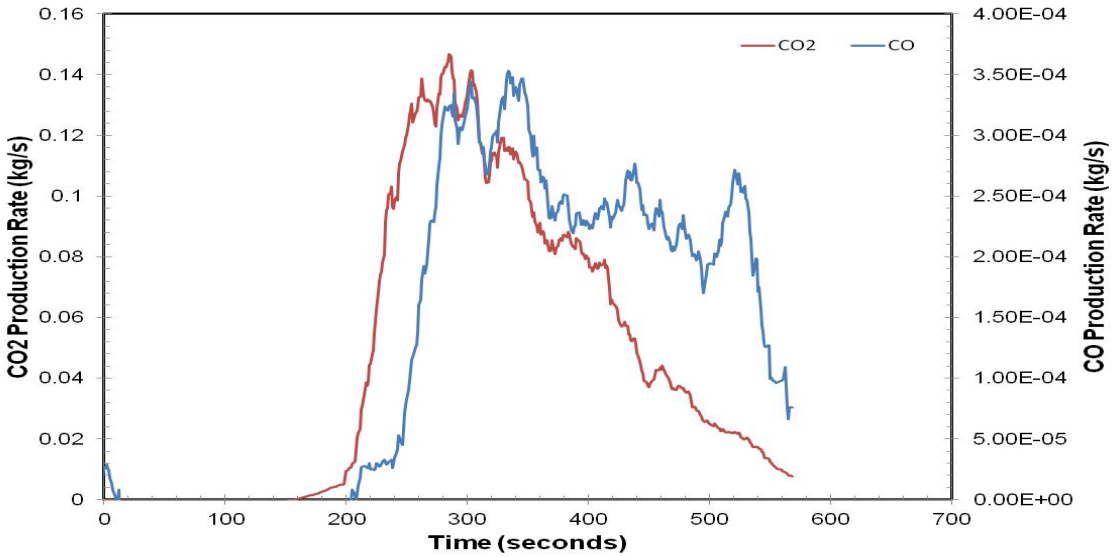

Figure 130. CO and CO2 production rates

The following table provides a description of the video(s) taken during this experiment.

Table 20. Video Log

Description	Start Time	Duration (s)	Filename
1	15:13:59	672	6549_20110808_151359_1.mp4
2	15:14:00	672	6549_20110808_151400_2.mp4
3	15:14:09	664	6549_20110808_151409_3.mp4

The following figures show all of the still photographs uploaded into the FireTOSS system. The caption below each figure provides the picture's filename as well as any description and elapsed test time associated with the picture.

Figure 131. Pre test 7 minutes, 6549_200364.jpg

Figure 132. Pre test 7 minutes, 6549_200363.jpg

Figure 133. Pre test 7 minutes, 6549_200362.jpg

Figure 134. Pre test 7 minutes, 6549_200361.jpg

Figure 135. Pre test 6 minutes, 6549_200360.jpg

Figure 136. Pre test 6 minutes, 6549_200359.jpg

Figure 137. Pre test 6 minutes, 6549_200358.jpg

Figure 138. 64 seconds, 6549_200357.jpg

Figure 139. 68 seconds, 6549_200356.jpg

Figure 140. 81 seconds, 6549_200355.jpg

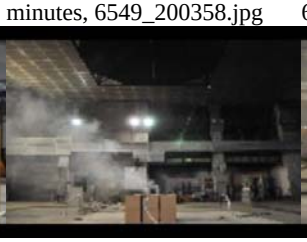

Figure 141. 116 seconds, 6549_200354.jpg

Figure 142. 141 seconds, 6549_200353.jpg

Figure 143. 147 seconds, 6549_200352.jpg

Figure 144. 151 seconds, 6549_200351.jpg

Figure 145. 154 seconds, 6549_200350.jpg

Figure 146. 158 seconds, 6549_200349.jpg

Figure 147. 160 seconds, 6549_200348.jpg

Figure 148. 162 seconds, 6549_200347.jpg

Figure 149. 167 seconds, 6549_200346.jpg

Figure 150. 170 seconds, 6549_200345.jpg

Figure 151. 175 seconds, 6549_200344.jpg

Figure 152. 178 seconds, 6549_200343.jpg

Figure 153. 191 seconds, 6549_200342.jpg

Figure 154. 199 seconds, 6549_200341.jpg

Figure 155. 207 seconds, 6549_200340.jpg

Figure 156. 210 seconds, 6549_200339.jpg

Figure 157. 218 seconds, 6549_200338.jpg

Figure 158. 228 seconds, 6549_200337.jpg

Figure 159. 232 seconds, 6549_200336.jpg

Figure 160. 235 seconds, 6549_200335.jpg

Figure 161. 240 seconds, 6549_200334.jpg

Figure 162. 251 seconds, 6549_200333.jpg

Figure 163. 256 seconds, 6549_200332.jpg

Figure 164. 261 seconds, 6549_200331.jpg

Figure 165. 267 seconds, 6549_200330.jpg

Figure 166. 272 seconds, 6549_200329.jpg

Figure 167. 274 seconds, 6549_200328.jpg

Figure 168. 277 seconds, 6549_200327.jpg

Figure 169. 280 seconds, 6549_200326.jpg

Figure 170. 285 seconds, 6549_200325.jpg

Figure 171. 288 seconds, 6549_200324.jpg

Figure 172. 293 seconds, 6549_200323.jpg

Figure 173. 296 seconds, 6549_200322.jpg

Figure 174. 306 seconds, 6549_200321.jpg

Figure 175. 311 seconds, 6549_200320.jpg

Figure 176. 319 seconds, 6549_200319.jpg

Figure 177. 324 seconds, 6549_200318.jpg

Figure 178. 328 seconds, 6549_200317.jpg

Figure 179. 332 seconds, 6549_200316.jpg

Figure 180. 347 seconds, 6549_200315.jpg

Figure 181. 354 seconds, 6549_200313.jpg

Figure 182. 354 seconds, 6549_200314.jpg

Figure 183. 356 seconds, 6549_200312.jpg

Figure 184. 362 seconds, 6549_200311.jpg

Figure 185. 367 seconds, 6549_200310.jpg

Figure 186. 371 seconds, 6549_200309.jpg

Figure 187. 388 seconds, 6549_200308.jpg

Figure 188. 395 seconds, 6549_200307.jpg

Figure 189. 399 seconds, 6549_200306.jpg

Figure 190. 412 seconds, 6549_200305.jpg

Figure 191. 416 seconds, 6549_200304.jpg

Figure 192. 428 seconds, 6549_200303.jpg

Figure 193. 430 seconds, 6549_200302.jpg

Figure 194. 452 seconds, 6549_200301.jpg

Figure 195. 454 seconds, 6549_200300.jpg

Figure 196. 458 seconds, 6549_200299.jpg

Figure 197. 460 seconds, 6549_200298.jpg

Figure 198. 478 seconds, 6549_200297.jpg

Figure 199. 487 seconds, 6549_200296.jpg

Figure 200. 497 seconds, 6549_200295.jpg

Figure 201. 500 seconds, 6549_200294.jpg

Figure 202. 505 seconds, 6549_200293.jpg

Figure 203. 527 seconds, 6549_200292.jpg

Figure 204. 534 seconds, 6549_200291.jpg

Figure 205. 538 seconds, 6549_200290.jpg

Figure 206. 540 seconds, 6549_200289.jpg

Figure 207. 543 seconds, 6549_200288.jpg

Figure 208. 546 seconds, 6549_200287.jpg

Figure 209. 548 seconds, 6549_200286.jpg

Figure 210. 550 seconds, 6549_200285.jpg

Figure 211. Post test 0 minutes, 6549_200284.jpg

Figure 212. Post test 0 minutes, 6549_200283.jpg

Figure 213. Post test 0 minutes, 6549_200282.jpg

Figure 214. Post test 0 minutes, 6549_200281.jpg

Figure 215. Post test 0 minutes, 6549_200280.jpg

Figure 216. Post test 0 minutes, 6549_200279.jpg

Figure 217. Post test 0 minutes, 6549_200278.jpg

Figure 218. Post test 0 minutes, 6549_200277.jpg

Figure 219. Post test 1 minutes, 6549_200276.jpg

Figure 220. Post test 1 minutes, 6549_200275.jpg

Figure 221. Post test 1 minutes, 6549_200274.jpg

Results for Test 3 (Exp. ID 6557)

The following table provides a summary of the ambient laboratory temperature during the experiment.

Table 21. Ambient Laboratory Temperature Summary

Description	Initial Value (C)	Minimum (C)	Maximum (C)	Average (C)	Final Value (C)
MBR_01	27.7	27.7	27.8	27.7	27.8

The following table provides a summary of the ambient laboratory pressure during the experiment.

Table 22. Ambient Laboratory Pressure Summary

Description	Initial Value (kPa)	Minimum (kPa)	Maximum (kPa)	Average (kPa)	Final Value (kPa)
MBR_01	99.42	99.35	99.43	99.40	99.37

The following table provides a summary of the ambient laboratory relative humidity during the experiment.

Table 23. Ambient Laboratory Relative Humidity Summary

Description	Initial Value (%)	Minimum (%)	Maximum (%)	Average (%)	Final Value (%)
MBR_01	62.7	62.1	63.2	62.9	62.3

The following table provides a summary of the temperature results. The "Initial Temperature" column provides the measured temperature at the beginning of the test. The maximum temperature recorded during the test is provided in the "Maximum" column. The remaining columns provide the calculated maximum average temperatures.

Table 24. Temperature Value Result Summary

Description	Initial (C)	Maximum (C)	30 second maximum average (C)	60 second maximum average (C)	300 second maximum average (C)	600 second maximum average (C)
Center_48	27	995	958	924	817	585
Center_60	27	1009	915	899	801	574
Center_72	27	928	883	865	805	599
Center_84	28	924	886	865	793	591
Center_Top of box	28	1005	946	932	804	557
Near igniter	29	850	813	792	696	632

The following table shows which thermocouple(s) were taken out of service during the experiment.

Table 25. Out of Service Times

Description	Time out of service (s)	Out of service reason
Center_48	2524	TC damage
Center_60	2524	TC damage
Center_72	2524	TC damage
Center_84	2524	TC damage
Center_Top of box	2524	TC damage
Near igniter	2524	TC damage

The following chart(s) present a time-dependent representation of the instantaneous temperatures measured during the experiment.

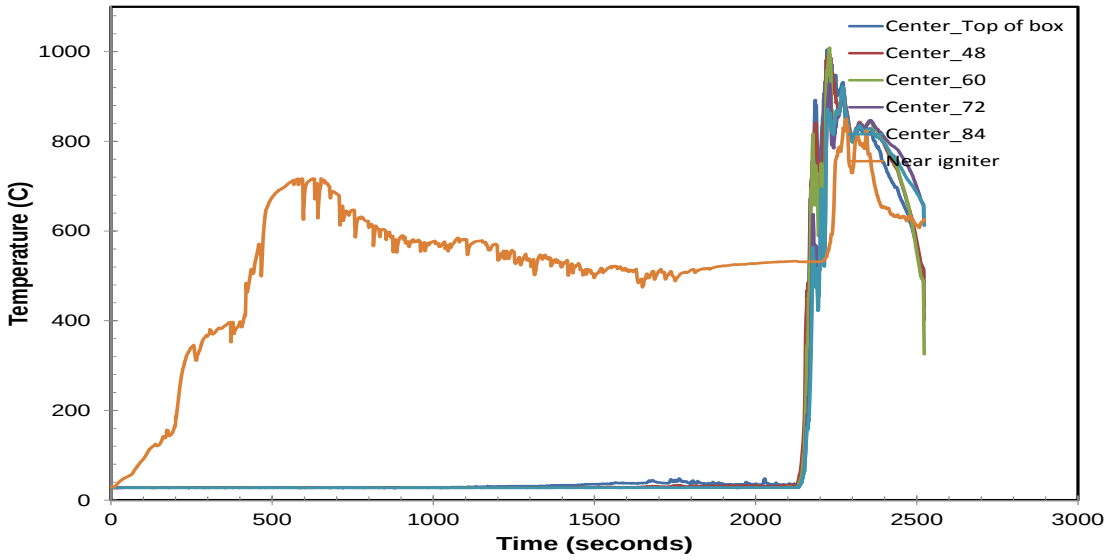

Figure 222. Temperature

The following table provides a summary of the heat flux results. The "Description" column typically describes the location of the heat flux transducer. The time at which the heat flux first changes by a pre-determined amount is provided in the "Time of Initial Change" column. The maximum heat flux recorded during the test is provided in the "Maximum" column. The "Maximum Average" columns are calculated over four pre-determined time spans.

Table 26. Heat Flux Result Summary

Description	Time of Initial Change (s)	Maximum (kW/m²)	30 second maximum average (kW/m²)	60 second maximum average (kW/m²)	300 second maximum average (kW/m²)	600 second maximum average (kW/m²)
East	1	5.6	5.2	4.7	3.6	2.2
North	1	6.6	6.1	5.5	3.9	2.4
South	1	5.9	5.5	5.0	3.6	2.3
West	1	7.6	7.0	6.5	4.6	2.9

The following chart shows a time dependent representation of the instantaneous heat flux measured during the experiment.

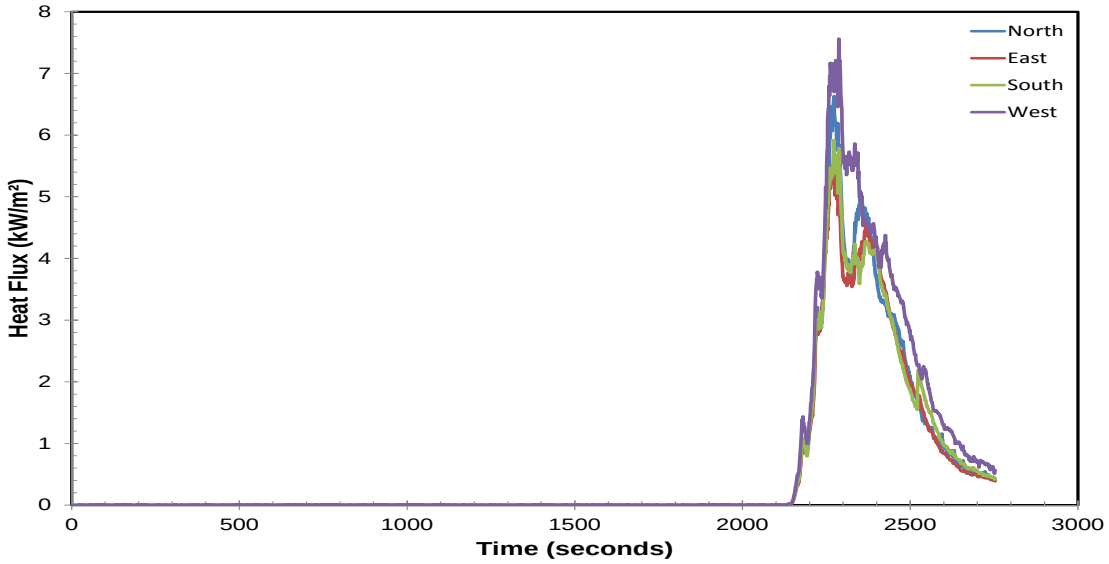

Figure 223. Heat Flux

The following chart provides a time history of the concentration of carbon monoxide and carbon dioxide measured in the exhaust duct during the fire.

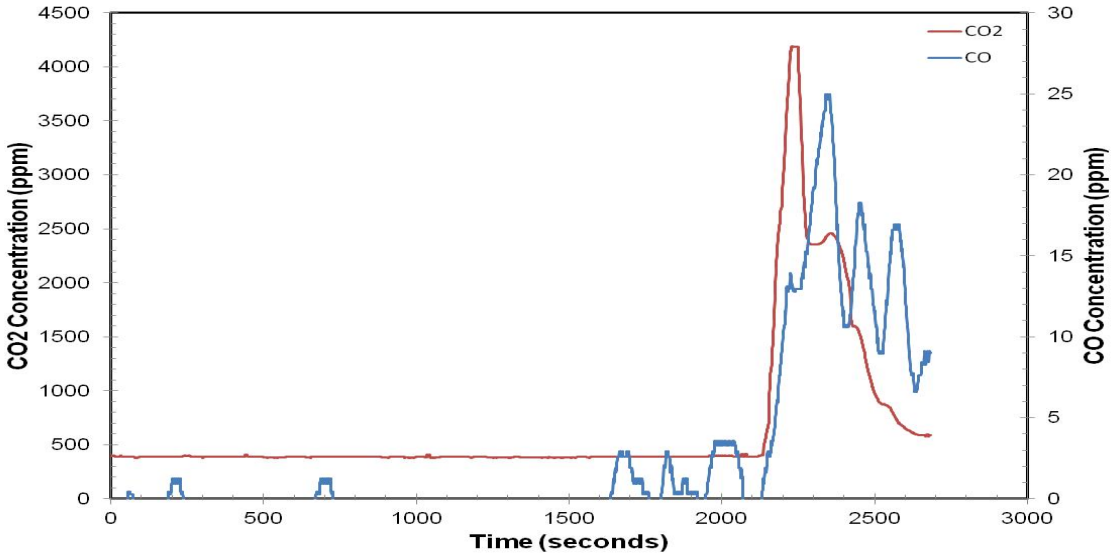

Figure 224. Carbon monoxide and carbon dioxide concentrations

The following chart provides a time history of the concentration of oxygen measured in the exhaust duct during the fire.

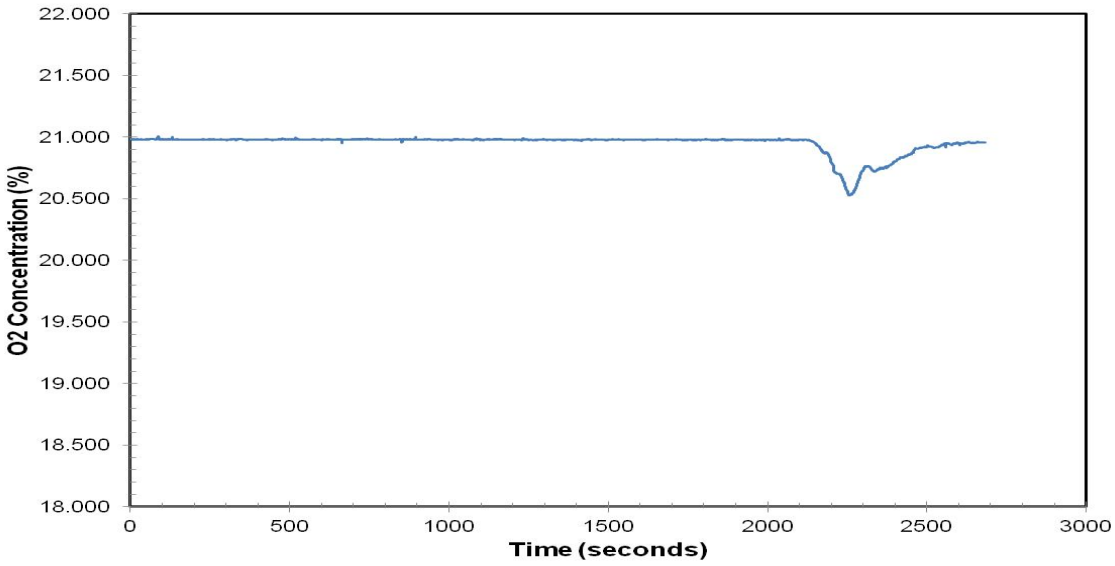

Figure 225. Oxygen Concentration

The following table provides a summary of the heat release rate (HRR) test results. The maximum HRR recorded during the test is provided in the "Maximum" column. The "maximum average" values are calculated from average values of heat release rate over specified time periods. The maximum average values provide a means to compare the severity of different fires over these time spans. The "Total heat released" is calculated from the area under the curve for the duration of the test.

Table 27. Heat Release Rate Result Summary

Maximum (kW)	30 second maximum average (kW)	1 minute maximum average (kW)	5 minute maximum average (kW)	10 minute maximum average (kW)	Total Heat Release (kJ)
1906	1765	1521	1765	509	305725

The following text and chart have not been reviewed

The following chart provides a time history of the heat release rate from the fire.

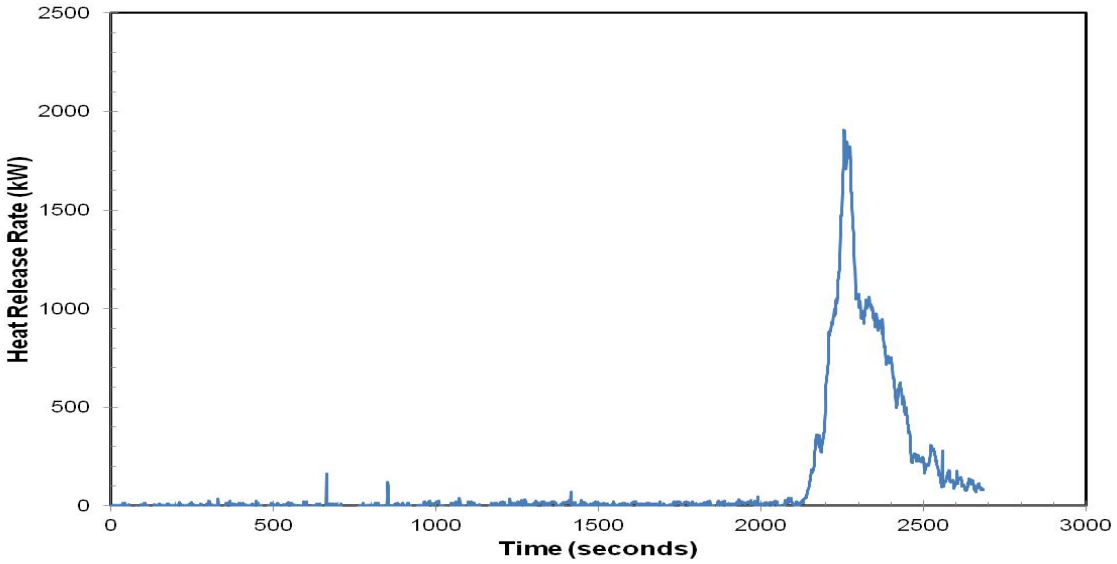

Figure 226. Heat Release Rate

The following table provides a summary of the convective heat release rate (CHRR) test results.

Table 28. Convective Heat Release Rate Result Summary

Maximum (kW)	30 second maximum average (kW)	Peak 60 sec avg (kW)	5 minute maximum average (kW)	Peak 600 sec avg (kW)
1024	924	860	536	318

The following chart provides a time history of the convective heat release rate from the fire.

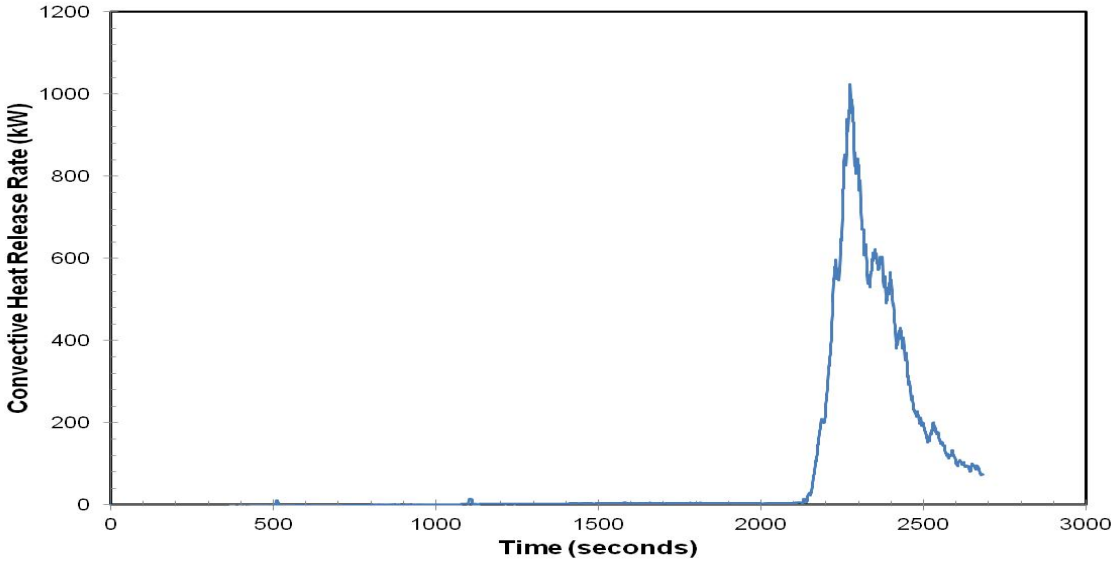

Figure 227. Convective Heat Release Rate

The following chart displays the production rates of CO and CO2.

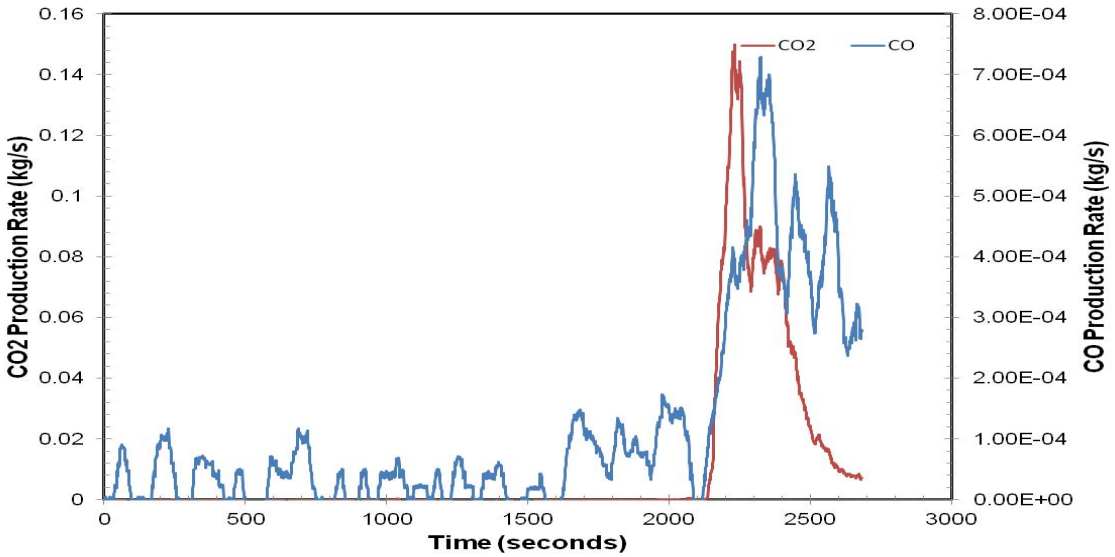

Figure 228. CO and CO2 production rates

The following table provides a description of the video(s) taken during this experiment.

Table 29. Video Log

Description	Start Time	Duration (s)	Filename
1	13:54:15	2795	6557_20110809_135415_1.mp4
2	13:54:16	2795	6557_20110809_135416_2.mp4
3	13:54:18	2794	6557_20110809_135418_3.mp4

The following figures show all of the still photographs uploaded into the FireTOSS system. The caption below each figure provides the picture's filename as well as any description and elapsed test time associated with the picture.

Figure 229. Pre test 27 minutes, 6557_200856.jpg

Figure 230. Pre test 27 minutes, 6557_200855.jpg

Figure 231. Pre test 27 minutes, 6557_200854.jpg

Figure 232. Pre test 26 minutes, 6557_200853.jpg

Figure 233. Pre test 24 minutes, 6557_200852.jpg

Figure 234. Pre test 24 minutes, 6557_200851.jpg

Figure 235. Pre test 23 minutes, 6557_200850.jpg

Figure 236. Pre test 23 minutes, 6557_200849.jpg

Figure 237. Pre test 23 minutes, 6557_200848.jpg

Figure 238. Pre test 23 minutes, 6557_200847.jpg

Figure 239. Pre test 23 minutes, 6557_200846.jpg

Figure 240. Pre test 21 minutes, 6557_200845.jpg

Figure 241. Pre test 15 minutes, 6557_200844.jpg

Figure 242. Pre test 15 minutes, 6557_200843.jpg

Figure 243. Pre test 15 minutes, 6557_200842.jpg

Figure 244. Pre test 15 minutes, 6557_200841.jpg

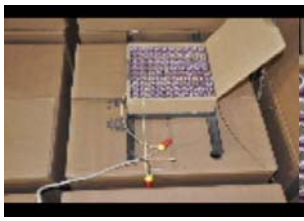

Figure 245. Pre test 15 minutes, 6557_200840.jpg

Figure 246. Pre test 15 minutes, 6557_200839.jpg

Figure 247. Pre test 15 minutes, 6557_200838.jpg

Figure 248. Pre test 14 minutes, 6557_200837.jpg

Figure 249. Pre test 14 minutes, 6557_200836.jpg

Figure 250. Pre test 14 minutes, 6557_200835.jpg

Figure 251. Pre test 14 minutes, 6557_200834.jpg

Figure 252. Pre test 13 minutes, 6557_200833.jpg

Figure 253. Pre test 13 minutes, 6557_200832.jpg

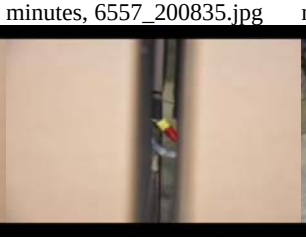

Figure 254. Pre test 13 minutes, 6557_200831.jpg

Figure 255. Pre test 13 minutes, 6557_200830.jpg

Figure 256. Pre test 13 minutes, 6557_200829.jpg

Figure 257. Pre test 13 minutes, 6557_200828.jpg

Figure 258. Pre test 12 minutes, 6557_200827.jpg

Figure 259. Pre test 12 minutes, 6557_200826.jpg

Figure 260. Pre test 12 minutes, 6557_200825.jpg

Figure 261. Pre test 12 minutes, 6557_200824.jpg

Figure 262. Pre test 34 seconds, 6557_200823.jpg

Figure 263. Pre test 6 seconds, 6557_200822.jpg

Figure 264. 19 seconds, 6557_200821.jpg

Figure 265. 23 seconds, 6557_200820.jpg

Figure 266. 39 seconds, 6557_200819.jpg

Figure 267. 113 seconds, 6557_200818.jpg

Figure 268. 145 seconds, 6557_200817.jpg

Figure 269. 182 seconds, 6557_200816.jpg

Figure 270. 209 seconds, 6557_200815.jpg

Figure 271. 212 seconds, 6557_200814.jpg

Figure 272. 218 seconds, 6557_200813.jpg

Figure 273. 222 seconds, 6557_200812.jpg

Figure 274. 239 seconds, 6557_200811.jpg

Figure 275. 242 seconds, 6557_200810.jpg

Figure 276. 317 seconds, 6557_200809.jpg

Figure 277. 337 seconds, 6557_200808.jpg

Figure 278. 399 seconds, 6557_200807.jpg

Figure 279. 420 seconds, 6557_200806.jpg

Figure 280. 424 seconds, 6557_200805.jpg

Figure 281. 427 seconds, 6557_200804.jpg

Figure 282. 460 seconds, 6557_200803.jpg

Figure 283. 469 seconds, 6557_200802.jpg

Figure 284. 475 seconds, 6557_200801.jpg

Figure 285. 479 seconds, 6557_200800.jpg

Figure 286. 501 seconds, 6557_200799.jpg

Figure 287. 532 seconds, 6557_200798.jpg

Figure 288. 605 seconds, 6557_200797.jpg

Figure 289. 621 seconds, 6557_200796.jpg

Figure 290. 644 seconds, 6557_200795.jpg

Figure 291. 650 seconds, 6557_200794.jpg

Figure 292. 672 seconds, 6557_200793.jpg

Figure 293. 711 seconds, 6557_200792.jpg

Figure 294. 714 seconds, 6557_200791.jpg

Figure 295. 723 seconds, 6557_200790.jpg

Figure 296. 737 seconds, 6557_200789.jpg

Figure 297. 765 seconds, 6557_200788.jpg

Figure 298. 768 seconds, 6557_200787.jpg

Figure 299. 771 seconds, 6557_200786.jpg

Figure 300. 809 seconds, 6557_200785.jpg

Figure 301. 830 seconds, 6557_200784.jpg

Figure 302. 866 seconds, 6557_200783.jpg

Figure 303. 893 seconds, 6557_200782.jpg

Figure 304. 902 seconds, 6557_200781.jpg

Figure 305. 963 seconds, 6557_200780.jpg

Figure 306. 964 seconds, 6557_200779.jpg

Figure 307. 994 seconds, 6557_200778.jpg

Figure 308. 1001 seconds, 6557_200777.jpg

Figure 309. 1038 seconds, 6557_200776.jpg

Figure 310. 1041 seconds, 6557_200775.jpg

Figure 311. 1066 seconds, 6557_200774.jpg

Figure 312. 1116 seconds, 6557_200773.jpg

Figure 313. 1118 seconds, 6557_200772.jpg

Figure 314. 1140 seconds, 6557_200771.jpg

Figure 315. 1220 seconds, 6557_200770.jpg

Figure 316. 1263 seconds, 6557_200769.jpg

Figure 317. 1431 seconds, 6557_200768.jpg

Figure 318. 1497 seconds, 6557_200767.jpg

Figure 319. 1505 seconds, 6557_200766.jpg

Figure 320. 1510 seconds, 6557_200765.jpg

Figure 321. 1760 seconds, 6557_200764.jpg

Figure 322. 1765 seconds, 6557_200763.jpg

Figure 323. 1773 seconds, 6557_200762.jpg

Figure 324. 1778 seconds, 6557_200761.jpg

Figure 325. 1804 seconds, 6557_200760.jpg

Figure 326. 1825 seconds, 6557_200759.jpg

Figure 327. 2157 seconds, 6557_200758.jpg

Figure 328. 2163 seconds, 6557_200757.jpg

Figure 329. 2179 seconds, 6557_200756.jpg

Figure 330. 2220 seconds, 6557_200755.jpg

Figure 331. 2223 seconds, 6557_200754.jpg

Figure 332. 2252 seconds, 6557_200753.jpg

Figure 333. 2297 seconds, 6557_200752.jpg

Figure 334. 2326 seconds, 6557_200751.jpg

Figure 335. 2350 seconds, 6557_200750.jpg

Figure 336. 2367 seconds, 6557_200749.jpg

Figure 337. 2370 seconds, 6557_200748.jpg

Figure 338. 2436 seconds, 6557_200747.jpg

Figure 339. 2474 seconds, 6557_200746.jpg

Figure 340. 2531 seconds, 6557_200745.jpg

Figure 341. 2536 seconds, 6557_200744.jpg

Figure 342. 2622 seconds, 6557_200743.jpg

Figure 343. 2719 seconds, 6557_200742.jpg

Figure 344. Post test 0 minutes, 6557_200741.jpg

Figure 345. Post test 2 minutes, 6557_200740.jpg

Figure 346. Post test 3 minutes, 6557_200739.jpg

Figure 347. Post test 3 minutes, 6557_200738.jpg

Figure 348. Post test 3 minutes, 6557_200737.jpg

Figure 349. Post test 3 minutes, 6557_200736.jpg

Results for Test 4 (Exp. ID 6558)

The following table provides a summary of the ambient laboratory temperature during the experiment.

Table 30. Ambient Laboratory Temperature Summary

Description	Initial Value (C)	Minimum (C)	Maximum (C)	Average (C)	Final Value (C)
MBR_01	27.3	27.3	27.5	27.3	27.4

The following table provides a summary of the ambient laboratory pressure during the experiment.

Table 31. Ambient Laboratory Pressure Summary

Description	Initial Value (kPa)	Minimum (kPa)	Maximum (kPa)	Average (kPa)	Final Value (kPa)
MBR_01	99.88	99.85	99.90	99.88	99.86

The following table provides a summary of the ambient laboratory relative humidity during the experiment.

Table 32. Ambient Laboratory Relative Humidity Summary

Description	Initial Value (%)	Minimum (%)	Maximum (%)	Average (%)	Final Value (%)
MBR_01	55.4	54.6	55.9	55.2	54.7

The following table provides a summary of the temperature results. The "Initial Temperature" column provides the measured temperature at the beginning of the test. The maximum temperature recorded during the test is provided in the "Maximum" column. The remaining columns provide the calculated maximum average temperatures.

Table 33. Temperature Value Result Summary

Description	Initial (C)	Maximum (C)	30 second maximum average (C)	60 second maximum average (C)	300 second maximum average (C)	600 second maximum average (C)
Center_48	27	1017	960	888	769	760
Center_60	27	920	830	795	775	773
Center_72	27	818	810	808	783	777
Center_84	27	865	825	809	715	537
Center_Top of box	27	1052	945	905	773	755
East	27	47	46	45	42	38
Near igniter	27	954	872	843	763	679
North	27	43	42	41	40	37
South	27	48	47	46	41	37
West	26	43	41	39	37	33

The following chart(s) present a time-dependent representation of the instantaneous temperatures measured during the experiment.

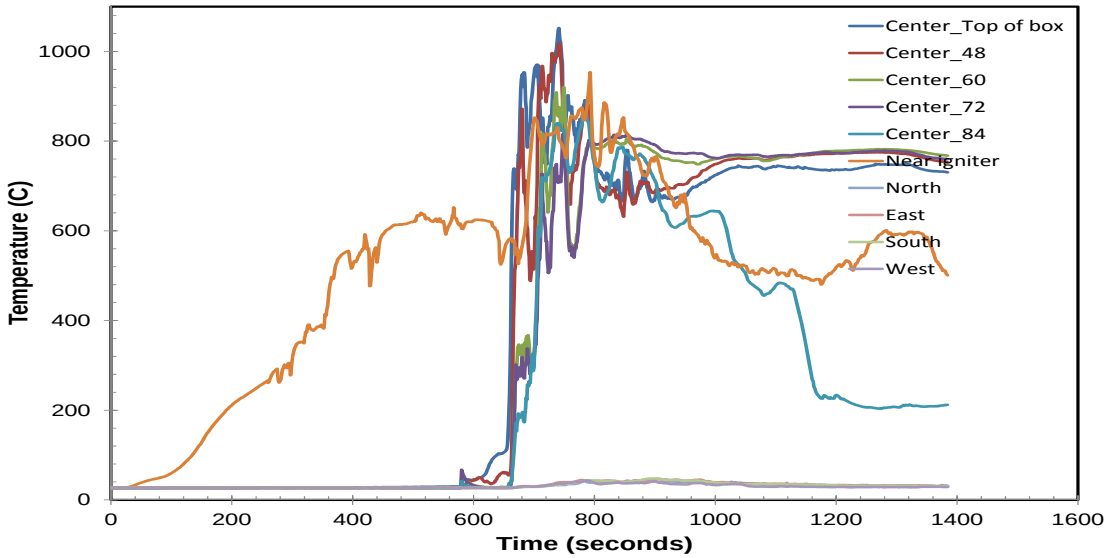

Figure 350. Temperature

The following table provides a summary of the heat flux results. The "Description" column typically describes the location of the heat flux transducer. The time at which the heat flux first changes by a pre-determined amount is provided in the "Time of Initial Change" column. The maximum heat flux recorded during the test is provided in the "Maximum" column. The "Maximum Average" columns are calculated over four pre-determined time spans.

Table 34. Heat Flux Result Summary

Description	Time of Initial Change (s)	Maximum (kW/m²)	30 second maximum average (kW/m²)	60 second maximum average (kW/m²)	300 second maximum average (kW/m²)	600 second maximum average (kW/m²)
East	1	6.3	5.5	5.0	3.6	2.2
North	1	5.6	5.0	4.5	3.2	2.1
South	1	5.7	5.2	4.7	3.5	2.1
West	1	5.5	5.0	4.5	3.4	2.1

The following chart shows a time dependent representation of the instantaneous heat flux measured during the experiment.

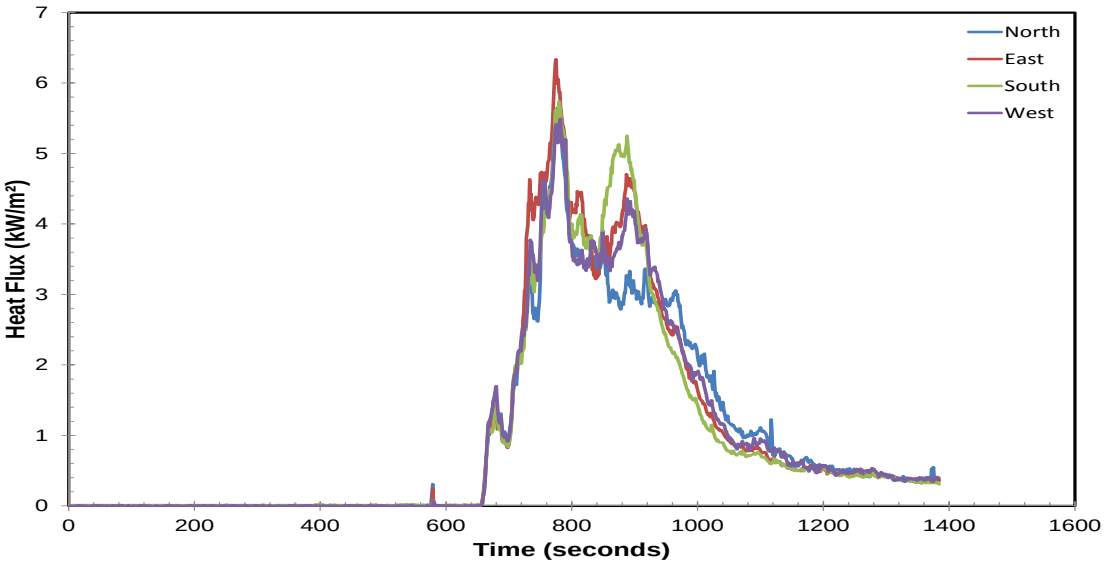

Figure 351. Heat Flux

The following chart provides a time history of the concentration of carbon monoxide and carbon dioxide measured in the exhaust duct during the fire.

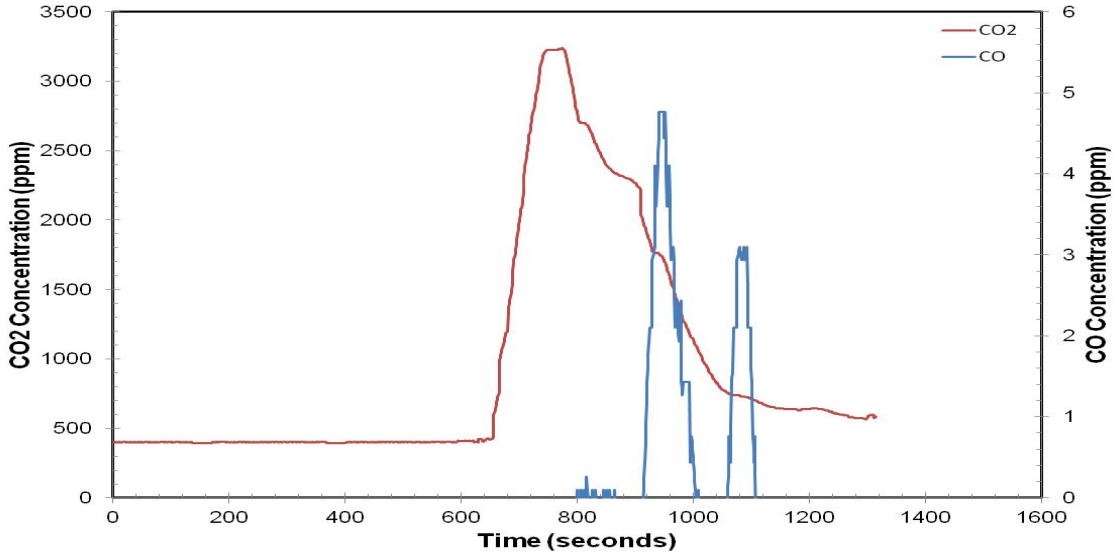

Figure 352. Carbon monoxide and carbon dioxide concentrations

The following chart provides a time history of the concentration of oxygen measured in the exhaust duct during the fire.

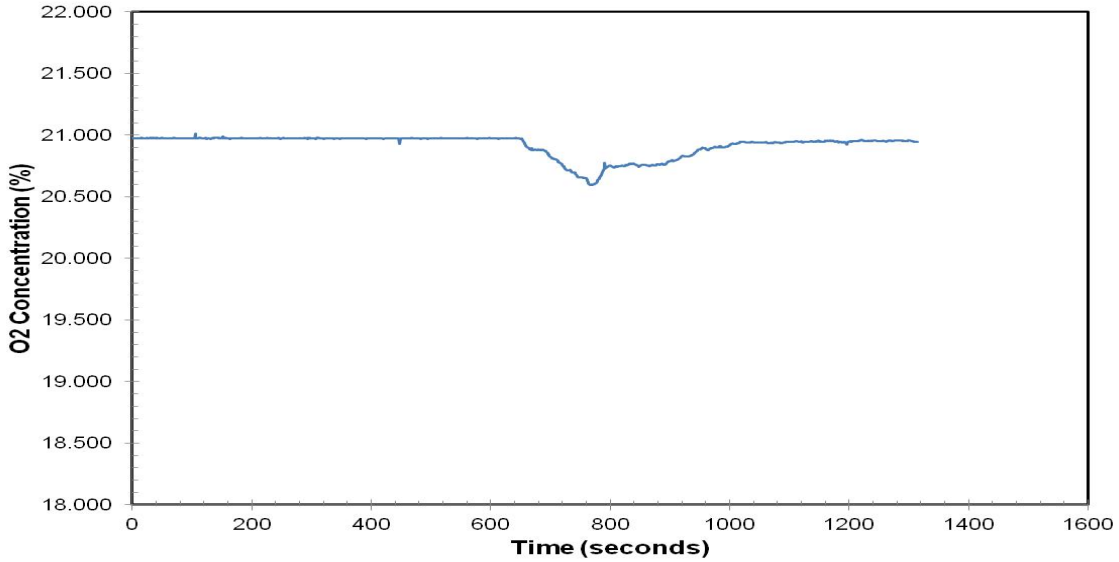

Figure 353. Oxygen Concentration

The following table provides a summary of the heat release rate (HRR) test results. The maximum HRR recorded during the test is provided in the "Maximum" column. The "maximum average" values are calculated from average values of heat release rate over specified time periods. The maximum average values provide a means to compare the severity of different fires over these time spans. The "Total heat released" is calculated from the area under the curve for the duration of the test.

Table 35. Heat Release Rate Result Summary

Maximum (kW)	30 second maximum average (kW)	1 minute maximum average (kW)	5 minute maximum average (kW)	10 minute maximum average (kW)	Total Heat Release (kJ)
1508	1329	1207	1329	461	290126

The following chart provides a time history of the heat release rate from the fire.

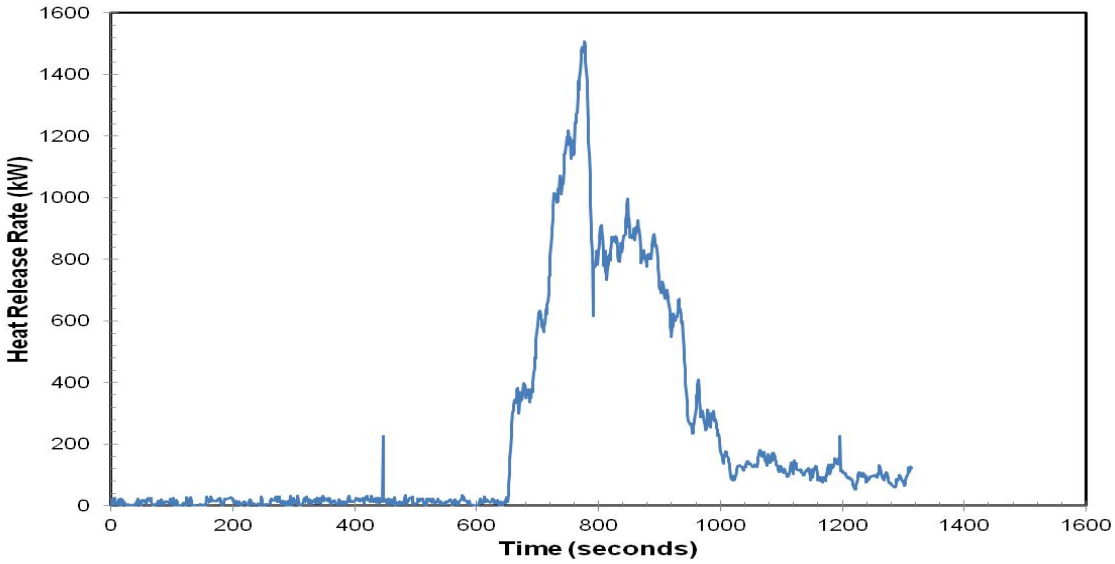

Figure 354. Heat Release Rate

The following table provides a summary of the convective heat release rate (CHRR) test results.

Table 36. Convective Heat Release Rate Result Summary

Maximum (kW)	30 second maximum average (kW)	Peak 60 sec avg (kW)	5 minute maximum average (kW)	Peak 600 sec avg (kW)
874	734	659	461	280

The following chart provides a time history of the convective heat release rate from the fire.

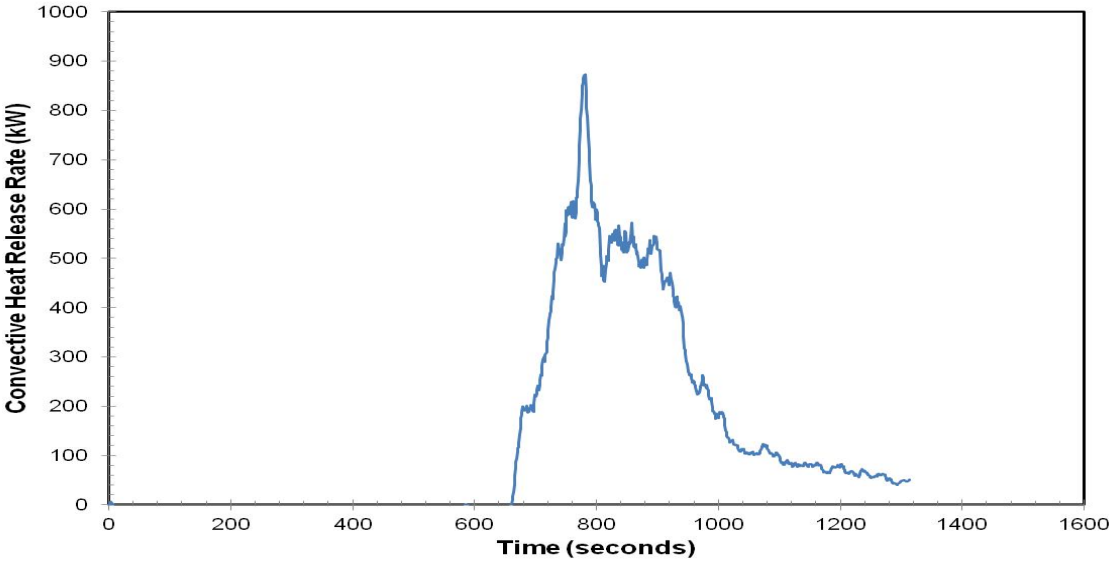

Figure 355. Convective Heat Release Rate

The following chart displays the production rates of CO and CO2.

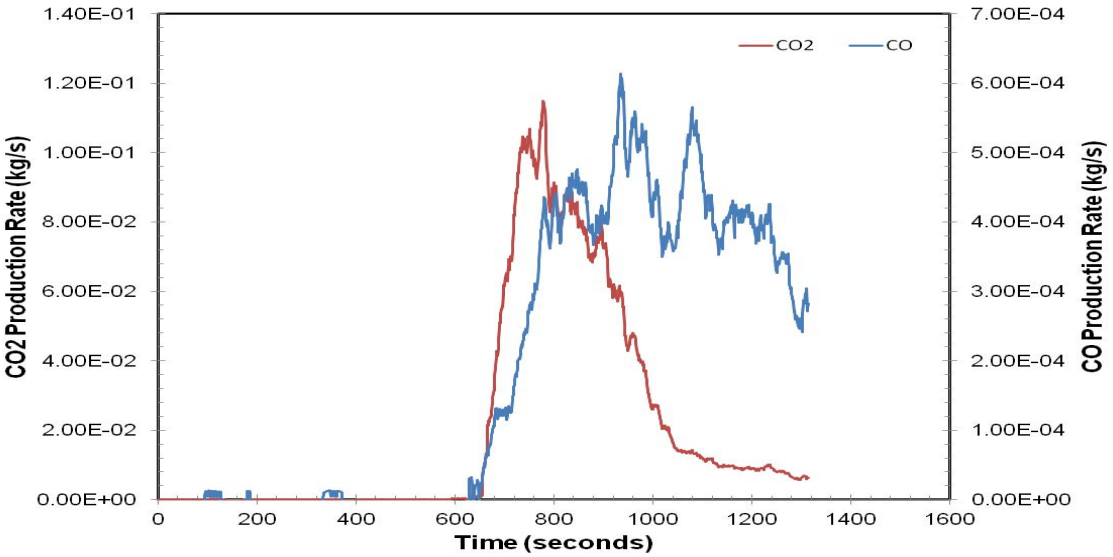

Figure 356. CO and CO2 production rates

The following table provides a description of the video(s) taken during this experiment.

Table 37. Video Log

Description	Start Time	Duration (s)	Filename
1	09:05:31	1479	6558_20110810_090531_1.mp4
2	09:05:33	1478	6558_20110810_090533_2.mp4
3	09:05:35	1477	6558_20110810_090535_3.mp4

The following figures show all of the still photographs uploaded into the FireTOSS system. The caption below each figure provides the picture's filename as well as any description and elapsed test time associated with the picture.

Figure 357. Pre test 26 minutes, 6558_200980.jpg

Figure 358. Pre test 26 minutes, 6558_200979.jpg

Figure 359. Pre test 25 minutes, 6558_200978.jpg

Figure 360. Pre test 25 minutes, 6558_200977.jpg

Figure 361. Pre test 24 minutes, 6558_200976.jpg

Figure 362. Pre test 24 minutes, 6558_200975.jpg

Figure 363. Pre test 20 minutes, 6558_200974.jpg

Figure 364. Pre test 19 minutes, 6558_200973.jpg

Figure 365. Pre test 19 minutes, 6558_200972.jpg

Figure 366. Pre test 10 minutes, 6558_200971.jpg

Figure 367. Pre test 9 minutes, 6558_200970.jpg

Figure 368. Pre test 9 minutes, 6558_200969.jpg

Figure 369. Pre test 9 minutes, 6558_200968.jpg

Figure 370. Pre test 8 minutes, 6558_200967.jpg

Figure 371. Pre test 3 minutes, 6558_200966.jpg

Figure 372. Pre test 3 minutes, 6558_200965.jpg

Figure 373. Pre test 76 seconds, 6558_200964.jpg

Figure 374. 7 seconds, 6558_200963.jpg

Figure 375. 10 seconds, 6558_200962.jpg

Figure 376. 14 seconds, 6558_200961.jpg

Figure 377. 73 seconds, 6558_200960.jpg

Figure 378. 140 seconds, 6558_200959.jpg

Figure 379. 214 seconds, 6558_200958.jpg

Figure 380. 257 seconds, 6558_200957.jpg

Figure 381. 367 seconds, 6558_200956.jpg

Figure 382. 371 seconds, 6558_200955.jpg

Figure 383. 384 seconds, 6558_200954.jpg

Figure 384. 397 seconds, 6558_200953.jpg

Figure 385. 404 seconds, 6558_200952.jpg

Figure 386. 441 seconds, 6558_200951.jpg

Figure 387. 503 seconds, 6558_200950.jpg

Figure 388. 508 seconds, 6558_200949.jpg

Figure 389. 570 seconds, 6558_200948.jpg

Figure 390. 573 seconds, 6558_200947.jpg

Figure 391. 581 seconds, 6558_200946.jpg

Figure 392. 608 seconds, 6558_200945.jpg

Figure 393. 620 seconds, 6558_200944.jpg

Figure 394. 639 seconds, 6558_200943.jpg

Figure 395. 653 seconds, 6558_200942.jpg

Figure 396. 656 seconds, 6558_200941.jpg

Figure 397. 661 seconds, 6558_200940.jpg

Figure 398. 666 seconds, 6558_200939.jpg

Figure 399. 673 seconds, 6558_200938.jpg

Figure 400. 679 seconds, 6558_200937.jpg

Figure 401. 687 seconds, 6558_200936.jpg

Figure 402. 715 seconds, 6558_200935.jpg

Figure 403. 724 seconds, 6558_200933.jpg

Figure 404. 773 seconds, 6558_200916.jpg

Figure 405. 811 seconds, 6558_200915.jpg

Figure 406. 819 seconds, 6558_200914.jpg

Figure 407. 822 seconds, 6558_200913.jpg

Figure 408. 852 seconds, 6558_200912.jpg

Figure 409. 878 seconds, 6558_200911.jpg

Figure 410. 883 seconds, 6558_200910.jpg

Figure 411. 915 seconds, 6558_200909.jpg

Figure 412. 935 seconds, 6558_200908.jpg

Figure 413. 954 seconds, 6558_200907.jpg

Figure 414. 979 seconds, 6558_200906.jpg

Figure 415. 981 seconds, 6558_200905.jpg

Figure 416. 982 seconds, 6558_200904.jpg

Figure 417. 984 seconds, 6558_200903.jpg

Figure 418. 1002 seconds, 6558_200902.jpg

Figure 419. 1008 seconds, 6558_200901.jpg

Figure 420. 1028 seconds, 6558_200900.jpg

Figure 421. 1034 seconds, 6558_200899.jpg

Figure 422. 1065 seconds, 6558_200898.jpg

Figure 423. 1069 seconds, 6558_200897.jpg

Figure 424. 1119 seconds, 6558_200896.jpg

Figure 425. 1125 seconds, 6558_200895.jpg

Figure 426. 1160 seconds, 6558_200894.jpg

Figure 427. 1211 seconds, 6558_200893.jpg

Figure 428. 1214 seconds, 6558_200892.jpg

Figure 429. 1267 seconds, 6558_200891.jpg

Figure 430. 1314 seconds, 6558_200890.jpg

Figure 431. 1340 seconds, 6558_200889.jpg

Figure 432. 1345 seconds, 6558_200888.jpg

Figure 433. Post test 0 minutes, 6558_200887.jpg

Figure 434. Post test 0 minutes, 6558_200886.jpg

Figure 435. Post test 0 minutes, 6558_200885.jpg

Figure 436. Post test 0 minutes, 6558_200884.jpg

Figure 437. Post test 8 minutes, 6558_200883.jpg

Figure 438. Post test 8 minutes, 6558_200882.jpg

Figure 439. Post test 8 minutes, 6558_200881.jpg

Figure 440. Post test 8 minutes, 6558_200880.jpg

Figure 441. Post test 9 minutes, 6558_200879.jpg

Figure 442. Post test 9 minutes, 6558_200878.jpg

Figure 443. Post test 9 minutes, 6558_200877.jpg

References

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2. The Temperature Handbook, 2nd edition, Omega Engineering, Stamford, CT, 2000.
3. Laboratory Instruction LI001 - Thermocouple, Bureau of Alcohol, Tobacco, Firearms and Explosives – Fire Research Laboratory, Beltsville, MD.
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