FORENSIC ENGINEERING ANALYSIS OF

LOW TEMPERATURE IGNITION OF WOOD

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ABSTRACT

The phenomena of wood igniting when exposed for extended periods of time to temperatures below wood's published ignition temperature value has been of considerable interest in recent years. The interest spans the fire investigative, engineering, and fire science communities all the way to the legal system. A recent federal court ruling[1] has introduced aggravated controversy on the subject, casting doubt on the phenomena. While there are presently no scientific formulas to reliably predict the occurrence, there is substantial empirical data which demonstrates that it does in fact occur.

The purpose of this paper is to report on certain empirical case studies, research activities, and experiments undertaken which clearly demonstrate that wood will ignite when exposed for an extended period of time to temperatures well below its commonly recognized published ignition temperature of approximately 482°F (250°C). In particular, it was concluded for the conditions studied that ignition of wood occurred under exposure temperatures of as low as 256°F when exposed 12 to 16 hours per day in as little as 623 days or approximately 21 months. Data from three well-documented restaurant kitchen fires and observations of wood located behind heated wall mounted appliances in three operating restaurants, combined with laboratory and manufacturer testing are used to demonstrate that low temperature ignition of wood clearly occurs.

INTRODUCTION

The scientific community for many decades has recognized that wood can ignite under prolonged exposure to temperatures well below the published "ignition temperature". The 10th Circuit Federal Court has recently implicated that "the long-term, low-temperature ignition theory" of wood is "unreliable."[2] Burnette noted that the articles presented to the court in this case by the experts to support their opinion, were "written by some of the most respected fire scientists in the world, but those articles acknowledged that the process of pyrolysis occurred over an undefined period of time, described as 'a period of years' or 'a very long time' with no specific parameters for the timing and sequence of events involved in pyrolysis."[3] To clarify terms here, pyrolysis is a definition,[4] not a theory or a misunderstood process. The process that is being referred to and questioned in the court case at hand is actually the long-term, low-temperature ignition of wood, sometimes also referred to by some as pyrophoric carbonization as Mr. Burnette referred to it in a previous publication.[5]

Babrauskas has conducted a considerable survey and analysis of the available published short term (less than a day) ignition temperatures of wood.[6] The survey references ignition temperatures ranging anywhere from 410°F to 927°F for piloted ignition and 392°F to 950°F for autoignition. There are a number of reasons given for the wide temperature ranges. Suffice it to say, the ignition temperature of wood is not a readily definable characteristic. Wood is a complex material, and its form and condition at the time of exposure to a heat source will impact the temperature at which it ignites. In addition, the form and intensity of the heat source will influence the temperature at which wood ignites. To further complicate the matter, authors of available published literature may not distinguish between the occurrence of flaming ignition or glowing ignition when reporting temperatures. As a result, the published ignition temperatures of wood will vary widely. Babrauskas concluded in his analysis that the short term ignition temperature of wood is around 482°F.

In this present paper, we want to empirically demonstrate that wood will ignite when exposed for extended periods of time to temperatures well below the referenced short term values. In particular, it was determined that for the conditions studied, ignition of wood will occur under exposure temperatures of as little as 256°F for periods of 12 to 16 hours per day in as little as 623 days or approximately 21 months. The ignition mode under this scenario, commonly referred to as "long-term, low-temperature ignition", is via smoldering ignition. The process that initiates the smoldering ignition is best described as self-heating of thermally deteriorated wood.

Elevated exposure temperatures, typically above 170°F,[7] but below the published short-term ignition temperatures of wood, act to thermally deteriorate or "cook"[8] the wood. "Cooking wood" is heating the wood sufficiently to cause physical and chemical changes without initially causing ignition. After a period of cooking time, the wood becomes more reactive to the oxygen in the atmosphere, creating conditions favorable for self-heating to occur at low exposure temperatures.

The physical deterioration of the wood due to heat causes it to split and crack. Oxygen from the atmosphere can then more readily penetrate into the center of the wood where it reacts readily with the thermally deteriorated and chemically changed wood in an oxidation reaction. The oxidation reaction generates heat, which becomes trapped by and subsequently accumulates within the surrounding wood, driving the internal temperature of the wood up until a thermal runaway reaction occurs initiating smoldering ignition.

At the point just before smoldering ignition begins, the actual internal surface temperatures of the wood are within the range of published ignition temperature data for wood, and much higher than the exposure temperatures that initially cooked the wood and then drove the self-heating reaction. As noted by Cuzillo[9] and demonstrated in the case studies of this paper, metallic fasteners in the wood can facilitate heat transfer from a heat source into the center of the wood and subsequently enhance the process.

A RESTAURANT FIRE

On November 11, 1998 a fire destroyed a restaurant store of a popular franchise. The fire broke out and was discovered after the restaurant had closed for the night and employees had left. The free standing restaurant store, located in Clemson, South Carolina, opened for business on February 18, 1997 and had been in operation for approximately 21 months (623 days) before the fire occurred. The restaurant was open for business with cooking operations running between 12 and 16 hours per day for 7 days a week. The single story wood-framed structure was built on slab with exterior wall sheathing and roof decking of wood construction.

Investigation into the origin of the fire revealed that the fire had originated inside the kitchen wall cavity behind a wall-mounted cheese melter. Figure 1 depicts the region of fire origin with the cooking equipment removed from the wall. The wall was surfaced with five 4-foot wide sheets of 16-gauge stainless steel extending from the base tile to a height of 79 inches above the top of the base tile. Silicone construction adhesive was used to secure the stainless steel sheets to Durock® wallboard. The wallboard was supported by a 2-inch by 6-inch nominal wood stud framing with R-19 Kraft paper-backed wall insulation between the studs.

FIGURE 1
Origin area in the wall behind the cheese melter with the melter removed.

The wall was constructed with 2-inch by 12-inch nominal horizontal wood blocking between the studs for purposes of anchoring a pair of stainless steel formed cheese melter mounting brackets. Figure 2 depicts the fire damaged wall reconstructed with the mounting brackets temporarily held in place. The mounting brackets of the cheese melter were anchored to the wood blocking in the wall with 3/8-inch lag bolts as per the equipment manufacturer's specifications shown in Figure 3. The cheese melter manufacturer attached a piece of angle iron to the upper back surface of the melter running parallel to the length dimension of the unit when it was manufactured. The cheese melter was hung on the wall mounted bracket via the angle iron.

Located along the kitchen wall was the main cook line, which included, in proceeding order, a full-height refrigerator, a gas charbroiler grill, a small preparation table, an oven/range/griddle appliance, a three-basket quick-fryer, two speed fryers, a breading station, a full-height freezer, a convection double stacked oven, and at the end was a small gas hot plate with stand. The cheese melter was mounted on the wall over the charbroiler grill, preparation table and oven/range/griddle appliance. Above the entire main cook line, except the full-height refrigerator, was the main cook line exhaust hood system.

The only competent ignition source identified within the region of fire origin was excessive conduction heat transfer into the horizontal wood blocking material within the wall, particularly, though not exclusively, through the lag bolts used to anchor the cheese melter mounting bracket. The fire damage in the wall cavity behind the cheese melter exhibited characteristics of a long-term smoldering fire and potential self-heating of the wood. The wood blocking and studs were severely damaged in and around the area where the far left lag bolt of the mounting bracket was located. Figure 4 depicts the back of the cheese melter after it was removed from the wall. The pattern on the back of the cheese melter indicates a region of high temperature corresponding to the region of fire origin within the wall. Figure 5 depicts the wood blocking in the area around the far left lag bolt. An investigation into the cause of the fire was initiated.

FIGURE 2
Origin area with the wall reconstructed and the left cheese melter hanging bracket held in place.

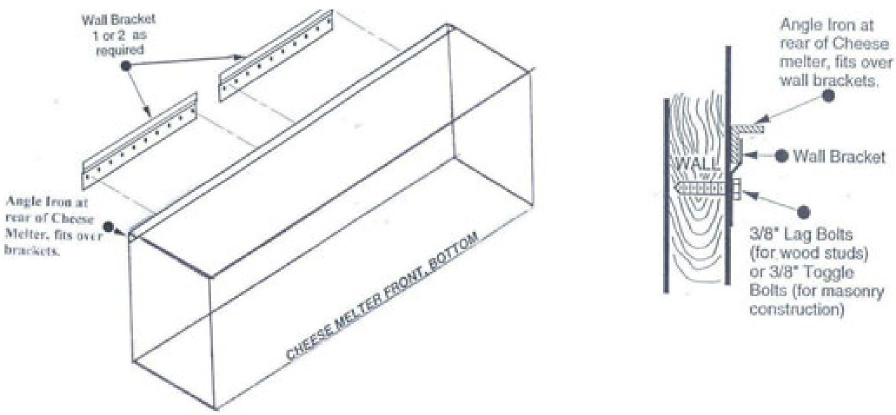

FIGURE 3
Cheese melter manufacturer's mounting instructions excerpt.

FIGURE 4
A view of the back of the cheese melter. The heat pattern on the right corresponds to the origin area within the wall.

FIGURE 5
A close up view of the origin area depicted in Fig. 1. The burned hole through the wall corresponds to the heat pattern on the back of the cheese melter.

Field Inspection of Three Exemplar Restaurants

As part of the investigation into the cause of the restaurant fire, inspections were performed at three exemplar franchise restaurants located in Trussville, Alabama, Niceville, Florida and Tullahoma, Tennessee. The stores had similar, though not exactly identical, wall construction and similar, though not exact, cooking equipment configurations. At the time of the inspections, the exemplar stores had been in operation for 907 days (30.2 months), 536 days (17.9 months), and 858 days (28.6 months), respectively. The inspections consisted of removing the cheese melter and stainless steel sheets to determine the construction and condition of the kitchen wall behind the cheese melter.

In all three restaurants, significant heat damage was observed on the wood and wallboard where the leftmost lag bolt of the cheese melter mounting bracket penetrated the wall. Figures 6, 7 and 8 respectively depict some of the heat damage observed at the Alabama, Florida and Tennessee restaurants.

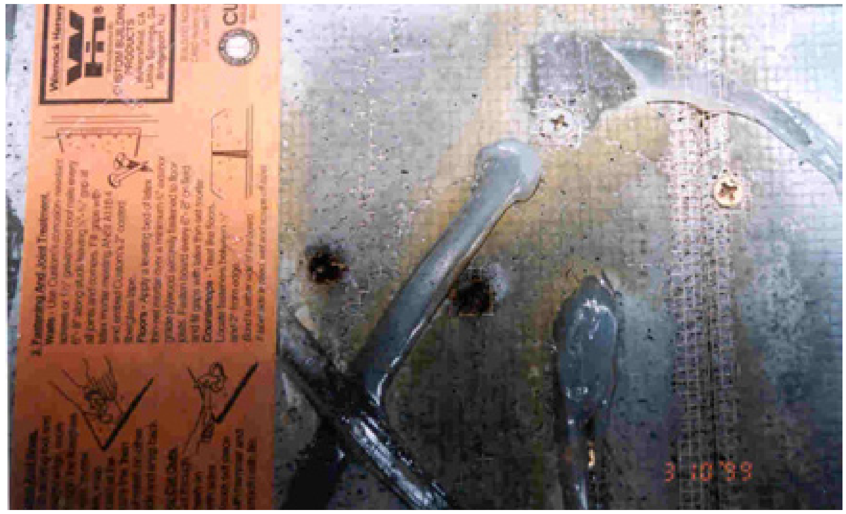

FIGURE 6
Trussville, Alabama. Heat damaged Durock® covering the wood blocking where the cheese melter hanging bracket lag bolt penetrated the wall.

FIGURE 7
Niceville, Florida. Heat damaged drywall covering the wood blocking where the cheese melter hanging bracket lag bolt penetrated the wall.

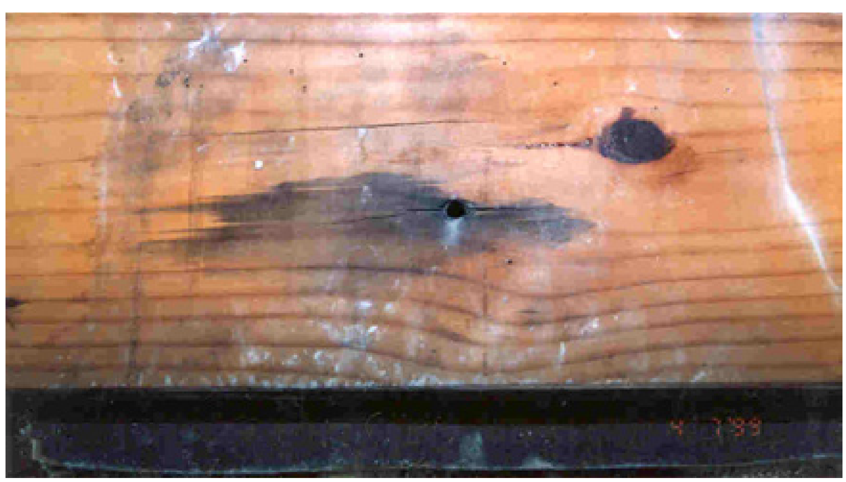

FIGURE 8
Tullahoma, Tennessee. Heat damaged wood blocking where the cheese melter bracket lag bolts penetrated the wall. Wall coverings removed.

A SECOND RESTAURANT FIRE

On April 25, 1999 a fire occurred in another of the franchise restaurant locations in Madison, Alabama. In this instance, the store was occupied and the fire quickly discovered and extinguished. Restaurant employees smelled smoke and immediately called the fire department which responded and extinguished the fire. The fire was confined to the wall cavity behind the cook line wall and particularly near the area behind the cheese melter.

Unfortunately, the authors did not have occasion to inspect and document the scene and the photographs taken by municipal investigator had been misplaced by the fire department. We did, however, interview the responding fire department personnel and their investigator. They reported that when firefighters entered the store, there was light smoke. They also reported that the source of heat appeared to be in the wall behind the cheese melter. The wall was subsequently opened, at which time "smoke poured out." The wall cavity was doused with water through the opening. Firefighters also opened the ceiling tiles and sprayed water from the top down. After the fire was extinguished, the fire department's investigator examined the wall cavity and determined that there was charring of the wood blocking "where the screws went in at the cheese melter. Charring was more intense near the cheese melter." A deep fat fryer was installed and exhausting beneath the left side of the cheese melter in this case.

This event highlights the importance of thoroughly documenting, at the very least with photographs, even the smallest of fires; however, the information obtained through the responding firefighters and their investigator is still relevant and useful to the investigation at hand. The fire was discovered and extinguished in its incipient stages being limited to the wall cavity, with extensive charring of the wood around the bolts securing the cheese melter mounting bracket to the wall. No other sources of ignition were discovered in the wall cavity.

FIGURE 9
Test wall set-up and equipment configuration for deep fat fryer and cheese melter test.

Laboratory Testing

After the exemplar stores were inspected and the second restaurant fire occurred, the franchise corporation assigned the authors to perform laboratory testing on the various cooking appliances, installed in varying configurations and operated under actual cooking conditions. The purpose of the testing was to determine if dangerously high temperatures were being generated in the kitchen walls of the restaurants during the normal operation of the cooking equipment.

A test wall was constructed and instrumented with thermocouples beneath a commercial exhaust hood in the laboratory. The test wall was constructed to the same specifications as the Clemson, SC store.

The wall was installed on castors and hinged at one end, allowing us to swing the wall out and access the back side for instrumentation, examination and to vary insulation use in the wall during the tests. Figure 9 illustrates the test wall set-up for one of the test variations run. The hood was configured to match the exhaust rate and velocity specifications of the restaurants.

The wall and the cheese melter were instrumented with 7 thermocouples along its profile at 4 different parallel locations along the wall face, for a total of 28 thermocouples. The four instrumented face locations of the wall were referenced as A, B, C and D. Figures 10 and 11 depict the location of the thermocouples in the test apparatus set-up.

Locations A and B were in insulated wall cavities. Locations C and D were in non-insulated wall cavities. Locations A and D had lag bolts securing the mounting bracket of the cheese melter to the wood blocking in the wall. The thermocouple sets for locations A and D were installed parallel to and near the lag bolt surface. Lag bolts were not installed in locations B and C. A data acquisition system was set up to collect and record the temperatures at specified incremental times during the testing. Laboratory ambient conditions were also monitored and recorded.

A total of seven tests were completed. The tests are described and the results summarized below. Note that during tests 5, 6, and 7, a third thermocouple location, referenced as Point E, was added. This thermocouple measures a single point temperature at the interface of the wood blocking and Durock wallboard at an elevation point parallel to the back surface of a free standing stand shelf assembly that was designed and added to the test apparatus to support and offset the cheese melter from the wall. The stand assembly set-up is depicted in Figure 12.

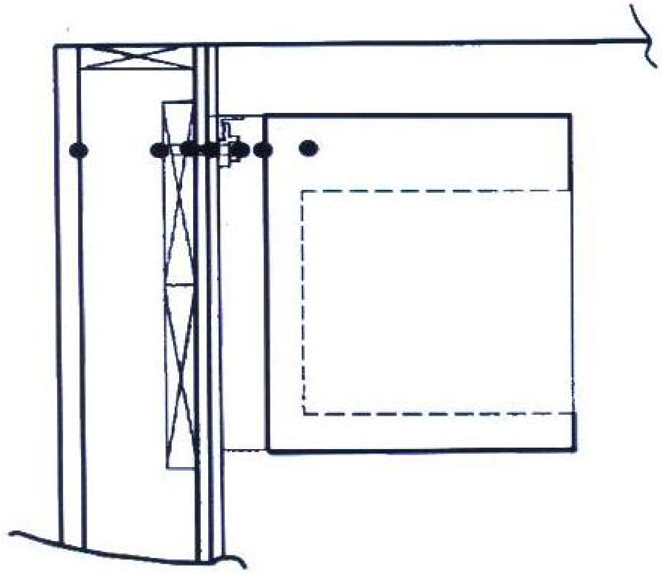

FIGURE 10
Cross-sectional view of wall and cheese melter. Thermocouples locations through the cross-section are marked by black dots. The wall and cheese melter were instrumented with 4 sets of 7 thermocouples per set.

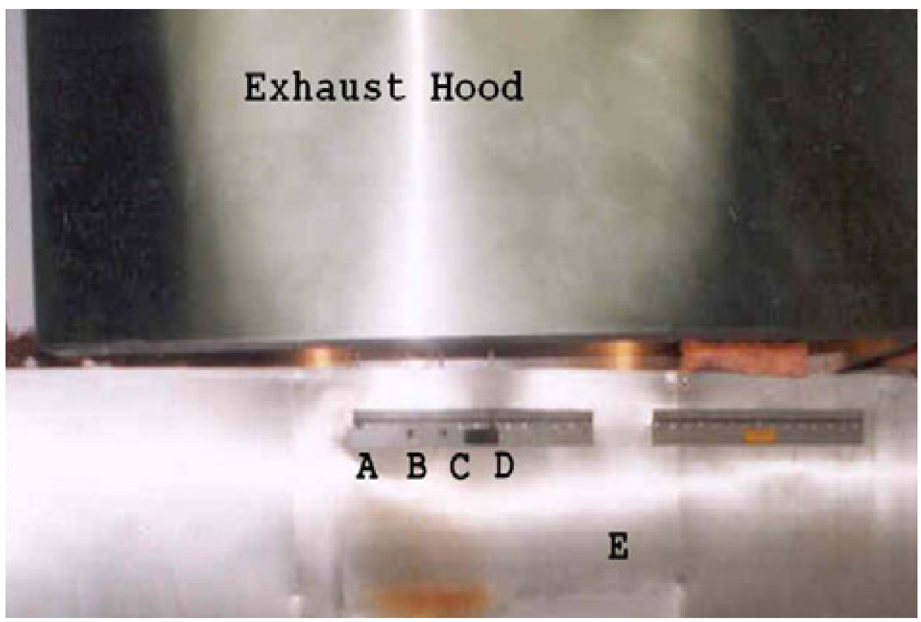

FIGURE 11
Test wall front view with mounting brackets installed and melter removed. Indicated are thermocouple set locations A, B, C, D and thermocouple elevation point location E.

Test One

Test one was conducted with the cheese melter operating alone. The angle iron on the back of the cheese melter was mounted to the bracket secured to the test wall by 3/8" diameter x 3" long lag bolts as recommended by the manufacturer. The composite wall was instrumented with thermocouples at the material interfaces as previously described.

The hood fans were turned on and the cheese melter was ignited. The cheese melter was operated at its highest temperature. Temperature data was acquired at all locations on 5-minute intervals. The test was run continuously for approximately 9 hours and 45 minutes. At this time, the maximum temperature at the front of the 2 x 12 blocking was 115°F and the temperature was increasing at a rate lower than 1°every 15 minutes. The cheese melter was turned off, the hood was left on and the wall was allowed to cool down.

Test Two

Test two was conducted with the cheese melter and steak grill operating in conjunction. The angle iron on the back of the cheese melter was mounted to a bracket secured to the test wall by 3/8" diameter by 3" long lag bolts as recommended by the manufacturer. The center of the steak grill was aligned with the left side of the cheese melter.

The hood fans were turned on and the cheese melter and steak grill were ignited. Temperature data was acquired at all locations on 5-minute intervals. The test was run from 8:15 am until 12:00 am (midnight). At 12:00 am, the cheese melter and hood were left on, but the steak grill was turned off. At 1:00 am, the hood was turned off and the cheese melter was left on until 4:00 am in an attempt to simulate conditions that probably occurred on the night of the Clemson, SC fire. At 4:00 am, the cheese melter was turned off. The hood was turned back on and the wall was left to cool off. During the test, the maximum temperature at the front of the 2 x 12 blocking was approximately 260°F, with maximum average temperatures in the blocks around the bolt at Point A equal to 256°F.

Test Three

Test three was conducted with the cheese melter and a deep fat fryer operating in conjunction. The left side of the deep fat fryer was aligned with the left side of the cheese melter. The deep fat fryer was filled with water during the test. The hood fans were turned on. The cheese melter and fryer were ignited. The water boiled at 212°F and never allowed the deep fat fryer thermostat sensor to reach its 375°F setting. Consequently, the gas burner ran continuously.

Temperature data was acquired at all locations on 5-minute intervals. The test was run continuously for 1 hour and 40 minutes, and then the fryer and cheese melter were turned off. The maximum temperature in the wall reached 370°F. It was concluded that the test with water in the fryer was creating excessively

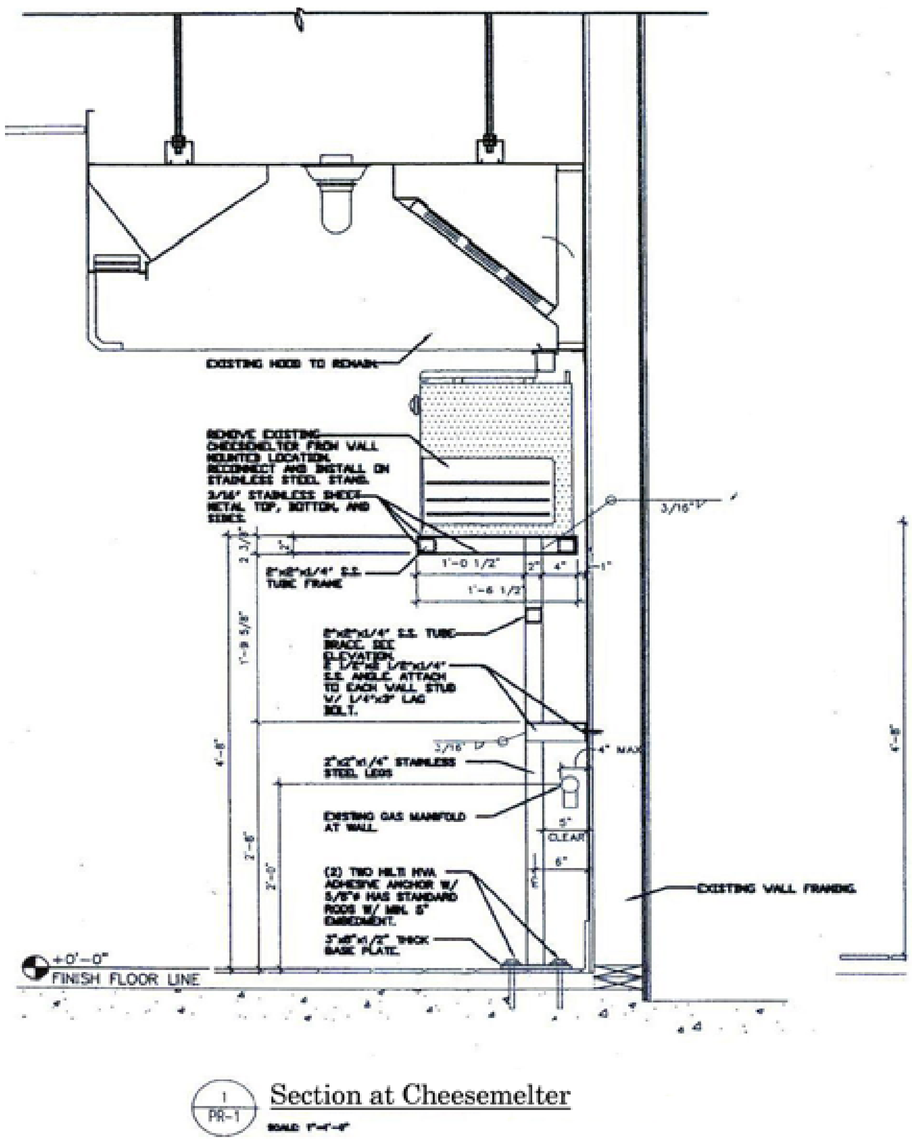

FIGURE 12
Section View. Cheese melter and stand.

high and unrealistic temperatures. The hood was left on and the back OSB panel was removed from the wall. Fans were blown on the front and back of the wall to cool it down.

Test Four

Test four was conducted with the cheese melter and a deep fat fryer operating in conjunction like Test three, except water was drained from the deep fat fryer. The deep fat fryer was filled with peanut oil and product was cooked during the test. Product included frozen chicken breasts, fish, shrimp, scallops and french fries. The test was run for about 7 hours and 5 minutes. Temperatures in the wall went up and down depending on the type of product being cooked. For example, the gas burners would have to fire more often when 2.5 lbs. of french fries were being cooked every 4 minutes than when 4 chicken breasts were being cooked over a 10 minute period, and, as a result, the wall temperatures would elevate. The maximum temperature in the wall at the front of the 2 x 12 blocking was 307°F, with a maximum average block temperature of 296°F.

Test Five

Test five was conducted with the cheese melter and deep fat fryer operating in conjunction. Prior to the testing, the cheese melter, the cheese melter bracket and the associated lag bolts were removed from the test wall. The thermocouples which formerly touched the bolt surfaces were moved .5” to the side of the previous locations but left at the same elevation. The lag-bolt holes were filled with 3-M Fire Barrier CP 25 WB+ Caulk. The stainless steel panel was rotated 180°F so that the caulked boltholes would be covered with stainless steel. The wall was instrumented at the material interfaces as in Tests one through four, except the previous bolthead and bracket thermocouples were instead installed directly to the stainless steel panel. One thermocouple was also installed between the 2 x 12 wood blocking and the Durock at the midpoint elevation of the cheese melter stand pan immediately below Point C. The elevation of the thermocouple identified as Point E was 57.125”

A free standing stand shelf was installed with a 1.75” thick spacer under the legs to raise the bottom of the cheese melter to its previously installed height of 57.5” A 2” space was left between the back of the cheese melter sides and the wall. There was, however, only a 1” gap between the back of the stand shelf and the wall. The left side of the fryer was installed adjacent to and flush with the left side of the cheese melter beneath the hood. The back of the fryer was against the stand leg and located 7” from the test wall. Previously in Test three and Test four, the back of the fryer was 6” from the test wall.

The hood fans were turned on. The cheese melter and fryer were ignited. The deep fat fryer was filled with oil and product consisting mainly of french fries was cooked during the test. Temperature data was acquired at all locations on 5 minute intervals. The test was run for 6 hours. The cheese melter and the fryer were turned off. The maximum temperature in the 2 x 12 block that occurred at Point D was 182°F, with an average temperature through the block temperature of 163°F. The temperature at Point E on the front of the 2 x 12 block directly behind the stand shelf rose to a maximum temperature of 253°F. It was concluded that removal of the lag bolts and installation of the stand had reduced the temperatures in the 2 x 12 blocking at Point D to acceptable levels, but increased the temperature to questionable levels at Point E.

Test Six

Test six was conducted with the cheese melter and steak grill operating in conjunction. The steak grill was located in the same position as in Test two, with the exception that a 7” space was between the back of the grill and the wall. The cheese melter was mounted on the stand as described in Test five. The cheese melter and steak grill were run for 10 hours 45 minutes. The maximum temperature in the wall at Point A was 237°F with a maximum average wall temperature of 225°F. The temperature at Point E was 247°F.

Test Seven

Test seven was conducted with the steak grill operating alone. The steak grill was left in the same positions as in Tests two and six. The cheese melter and stand were removed. The hood fans were turned on and the steak grill was ignited. Temperatures were acquired for 8 hours 35 minutes. The maximum temperature in the wall at Point A was 206°F with a maximum average wall temperature of 189°F. The temperature at Point E was 163°F.

TEST RESULTS

Table 1 provides a comparison of the maximum average temperatures developed across the 2 x 12 wood blocking at Points A and D for each test. In addition, Table 1 provides the maximum temperatures developed on the front of the wood blocking at Point E for tests five, six and seven. The maximum average temperatures in Table 1 are calculated by summing the maximum front and back of the 2 x 12 wood blocking temperatures and dividing by 2.

For each of the test, maximum temperatures occurred at different times. Figure 13 provides a graph of the temperatures on the front of the 2 x 12 wood blocking for point A during Tests one through four compared to the elapsed time. The temperature at the front of the wood blocking at Point E was only measured for Tests five, six and seven. Point A and Point D have lag bolts installed in Tests one through four only.

Test two, simulating the Clemson, SC store, indicates that the temperature on the front surface of the 2 x 12 wood blocking where the far left bolt was installed reached as much as 265°F with an average wood block temperature of 256°F when the cheese melter was operated in conjunction with the charbroiler.

Test four indicates that the temperature on the front surface of the 2 x 12 wood blocking where the far left bolt was installed reached as much as 307°F with an average of 296°F when the cheese melter was operated in conjunction with the deep fat fryer. Note, however, that the temperatures fluctuate up and down more with the fryer than with the charbroiler, which has a more continuous operation and uniform distribution of heat on the wall.

The steel lag bolts have a relatively high thermal conductivity (approximately 350 times that of wood) and will therefore readily transfer heat from the exterior wall surface into the wood components of the wall. The wood blocking materials have a relatively low thermal conductivity and essentially act as an insulator, trapping the conducted heat. As a result, the temperature of the wood near the lag bolts can be expected to rise to a temperature near that of the bolts.

The manufacturer specified installation of the cheese melter on the mounting bracket produced only a gap of 3 inches between the back of the cheese melter and the wall for hot gases produced by cooking appliances beneath it to pass through and into the hood above.

TABLE 1 Maximum Average Temperatures °F Developed Across Wood Blocking at Points A & D,[1] Maximum Temperatures °F Developed on Front of Wood Blocking at Point E[2]

Test No.	Test Description	POINT A With Insulation[3]	POINT D No Insulation[3]	POINT E No Insulation
1	Cheesemelter / Bracket / Operating Alone	115.0	111.5	N/A
2	Cheesemelter / Bracket / Operating with Steak Grill	256.0	216.5	N/A
3	Cheesemelter / Bracket / Operating with Fryer & Water	287.5	355.0	N/A
4	Cheesemelter / Bracket / Operating with Fryer & Product	295.5	271.5	N/A
5	Cheesemelter / Stand / Operating with Fryer & Product	122.0	163.0	253.0
6	Cheesemelter / Stand / Operating with Steak Grill	224.5	198.5	247.0
7	Steak Grill Operating Alone	199.0	154.0	164.0

(1) Maximum average temperatures calculated by summing the maximum front and back of 2 x 12 block temperatures and dividing by 2. Fore each test, maximum temperatures occurred at different times. A graph of the maximum temperature distribution through the wall is shown in Figures 6 and 9.

(2) Temperatures at the front of wood blocks at Point E only measured for Test five and Test six.

(3) Point A and Point D have lag bolts installed in Tests one through four.

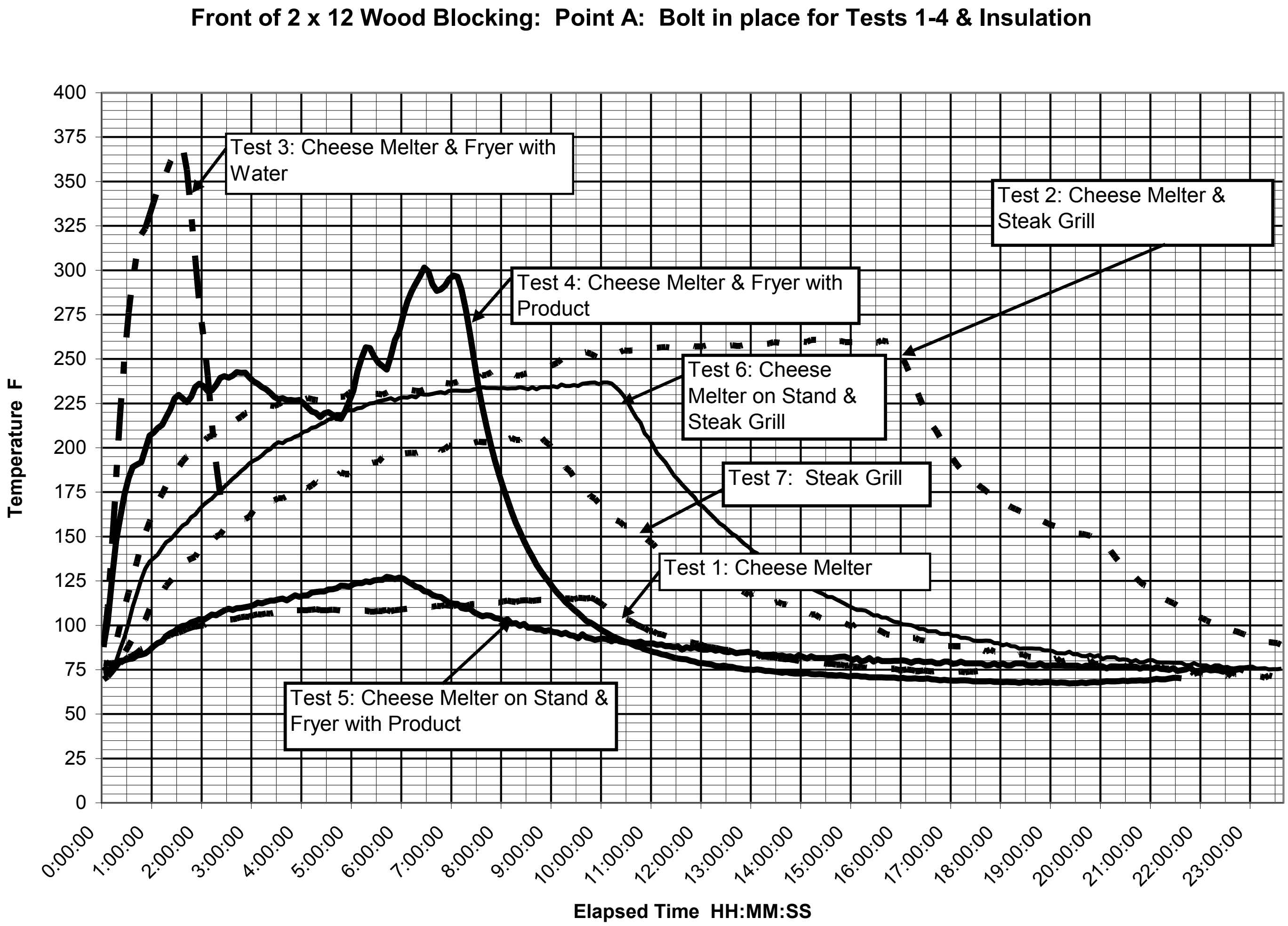

FIGURE 13
Time vs. Temperature Graph at front of wood blocking – Point A

The normal flow of hot exhaust gases from the charbroiler and the fat fryer were constricted in the small gap. The constricted flow of hot gases elevated the temperatures in the gap and increased the heat transfer into the wall, particularly through the lag bolts, and subsequently increased the wall temperature.

Prior to the time of the testing (1999) a number of research documents were surveyed to obtain information on the critical temperatures above which combustion might be deemed a problem for the wood components in the wall. Based on a review of those documents, it was concluded that regulations on maximum temperatures for wood considered about 212°F as the maximum allowable safe temperature for wood under prolonged exposure to heat.[8,10,11] As noted however in the beginning of this paper, a more recent survey of the research literature indicates a maximum temperature of 170°F as the maximum allowable safe temperature.

The temperatures generated in the wall during the testing, particularly at the lag bolt locations, well exceeded the 212°F temperature and therefore were considered a serious fire hazard. Because of the long operating hours of the restaurant, it is probable that the temperatures for the wall in question well exceeded the 212°F temperature multiple times throughout each day that the restaurant was operating. In particular, the temperatures of the wall would well exceed the 212°F temperature during peak operating times of the day.

Correlations and studies were also made based on the heat generation and output of the various cooking equipment configurations being operated in conjunction with the cheese melter; however, that is a topic for another discussion.

As a result of the testing, the franchise completely redesigned the kitchen cook line wall for all new construction. Combustible materials would no longer be utilized in the construction of the kitchen cook line wall. For existing construction, the mounting bracket and lag bolts would be removed and the holes sealed. A freestanding stand to support and offset the cheese melter from the wall to provide a sufficient air gap to cool the wall would be installed.

During product development, the manufacturer of the cheese melter had conducted laboratory performance testing on the melter and had measured the temperatures within the wall during operation of the unit. However, the manufacture had only conducted testing with the melter operating alone and not in conjunction with cooking equipment that was known to be installed beneath it. The melter manufacturer intentionally designed the unit to be installed above and knew it would be operated in conjunction with other cooking equipment however they failed to evaluate and test these operating conditions. The Clemson case being investigated was also eventually litigated and settled prior to trial after expert deposition testimony was given and investigative and testing results presented.

AND YET A THIRD RESTAURANT FIRE

On February 16, 2003, a third fire occurred at another of the franchise restaurants, this time located in Sebring, Florida. As a result of the fire, the structure was destroyed. The store in question had been in operation for approximately 1275 days (42.5 months), and research indicated that it was the first new restaurant constructed after the wall design changes were directed. The fire once again was determined to have originated in the wall cavity behind the cheese melter where the bracket bolts penetrated the wall. The fire patterns were practically identical to those of the Clemson, SC restaurant fire. So what happened?

The authors were not involved in the field investigation and were contacted to work on the investigation sometime after the matter was already in litigation and the scene was no longer available. Figure 14 depicts the kitchen wall as it was sectioned and removed from the kitchen intact and preserved as evidence. The wall had a classic v-pattern associated with it. A copy of the construction plans were obtained and a scaled transparent overlay of the kitchen equipment was made from the plans and placed over a scaled photograph of the wall to illustrate the location of the v-pattern relative to the cheese melter. Figure 15 depicts the overlay.

In the case of the Sebring restaurant, the contractor grossly failed to follow the construction plans in building the wall. The plans included multiple detailed drawings clearly illustrating and stating how the wall was to be constructed with metal studs and a metal header to mount the cheese melter bracket to it, as well as noncombustible Durock sheathing. Instead, the contractor

FIGURE 14
A view of the cookline wall being lifted from the restaurant. Note the typical v-pattern on the wall where the cheese melter had been located.

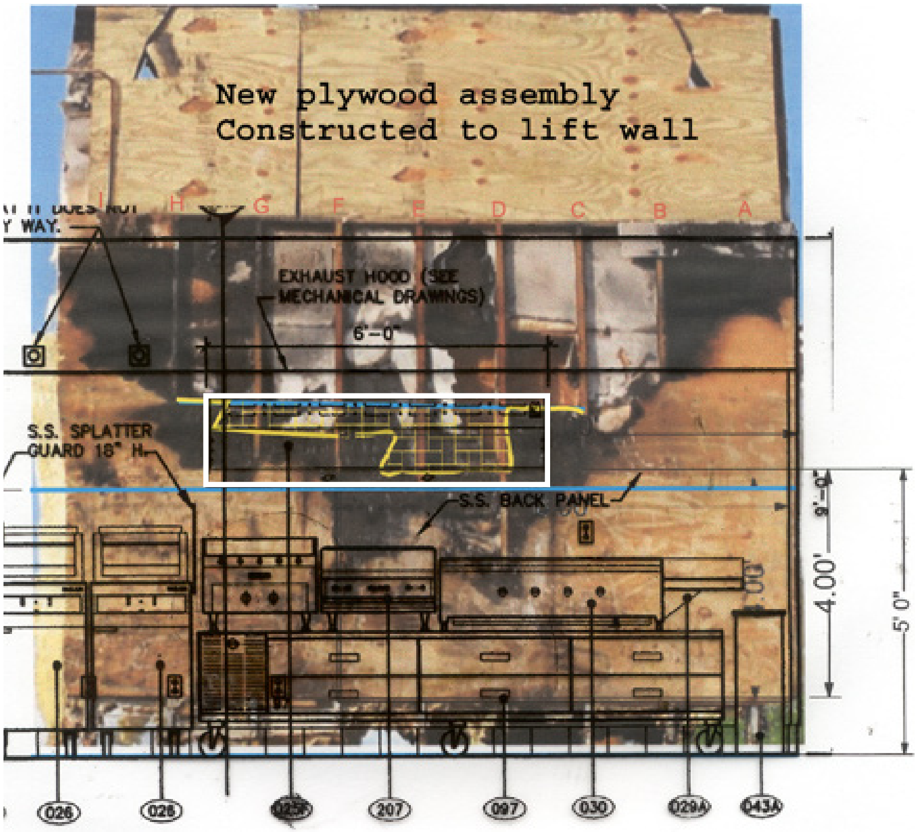

FIGURE 15
Cookline wall with scaled transparency overlay of the cooking equipment.
The cheese melter location is outlined in white.

used 2 x 12 wood blocking between metal studs, covered the wall with plywood sheathing and lag bolted the bracket to the wall as per the cheese melter manufacturer's installation instructions. At several points in the wall where the bolts penetrated into the wood blocking, the blocking was totally consumed.

The same cheese melter manufacturer was involved in the litigation for the Clemson, SC fire. Even after that litigation, the manufacturer continued to provide the same installation instructions for lag bolting the cheese melter to wood blocking in the wall. As previously discussed, the manufacturer had failed to test the operation of the cheese melter in conjunction with any other cooking equipment that was known to be installed and operated underneath it.

Although the Clemson, SC store fire litigation made the cheese melter manufacturer acutely aware of the problem, the manufacturer never changed its installation instructions, never provided any warnings associated with mounting the cheese melter to a combustible wall and operating other cooking equipment beneath it, and never issued any technical bulletins to their distributors and customers related to the fire hazards represented.

Manufacturer's Laboratory Experiments

During the Sebring, Florida restaurant fire litigation, the manufacturer of the cheese melter initiated their independent testing of the cheesmelter with other cooking equipment operating in conjunction with and beneath it. The testing data along with deposition testimony of the manufacturer's product development personnel was obtained during discovery proceedings. In one of their tests, the wall at the bracket lag bolt reportedly ignited to smoldering ignition at temperatures recorded around 298°F in just 30 minutes. Other testing also produced temperatures in the wood blocking around the lag bolts of around 254°F. Their conclusions were that operating the melter in conjunction with other equipment beneath it can create dangerously high temperatures in the wall.

In the Sebring case, a detailed analysis was performed and an expert report was prepared. The analysis and report included the testing and exemplar inspection data developed during the Clemson, SC restaurant matter. As a result, the case was settled prior to trial and without the need of expert deposition testimony.

CONCLUSIONS

The phenomenon of long-term low-temperature ignition of wood is real and with absolute certainty does occur. The three restaurant fires which occurred are real world tests and combined with laboratory testing confirm that when temperatures in the 2 x 12 wood blocking materials in the cook line wall reach an average of 256°F over a prolonged period of time fires occur.

Empirical data related to this phenomenon should continue to be collected and analyzed for all the various conditions under which it occurs. In particular, investigators should carefully document and publish their findings on this subject matter in order to establish a comprehensive record under the various conditions that it occurs.

Although laboratory testing should be pursued, full scale long-term testing would be both tedious and expensive to complete. Furthermore, there is a wide range of real world conditions under which low temperature ignition of wood may occur. At present, the real world offers the best laboratory conditions for studying, testing and gathering data on the subject.

Finally, a thorough investigation and a clear and proper presentation of the data and research are the most effective tools an engineer has for helping to resolve litigation matters. In the Clemson, South Carolina and the Sebring, Florida cases reviewed in this paper, both cases were resolved favorably without the need for trial.

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