Using Smoke Obscuration to Warn of Pre-Ignition Conditions of Unattended Cooking Fires

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Abstract

A series of 21 experiments was conducted to examine the potential to use kitchen-installed photoelectric smoke detection devices to warn of approaching ignition of food during unattended cooking. An electric range, range hood, and cabinets were installed in a mock-up kitchen. Research smoke meters and standard off-the-shelf photoelectric smoke detectors were installed above the food, on the ceiling, and on the upper wall. In addition to smoke meter and smoke detector outputs, pan and food temperatures along with digital videos of the experiments were recorded. Cooking oils and bacon were heated to ignition in frying pans on the range top. The standard-threshold smoke alarms activated minutes before ignition. Typically, smoke production reached alarm levels at least 2 min before ignition. Frying hamburger tests were also conducted to compare smoke levels from attended, but smoky, cooking to the unattended cooking smoke levels. Analysis indicates that there is an extensive time window of elevated smoke obscuration during the unattended cooking above smoky attended cooking and prior to ignition sufficient to allow warning that would either alert the cook to return and de-energize the range or to interface with an automatic de-energizing device connected to the range.

Keywords: kitchen fires, photoelectric smoke detection, unattended cooking, cooking fire prevention, pre-ignition warning

Introduction

In the United States from 2009 to 2013, cooking caused 45 % of home structure fires, 17 % of the associated deaths, 42 % of the injuries, and 16 % of the property damage. [1]. Ranges and cooktops were involved in most each of these losses and account for over 300 deaths and 4000 injuries per year. About half of cooking fires result from the equipment being unattended. Unattended cooking fires remain a leading cause of fire incidents, injuries, property loss, and deaths even though efforts to research the issue and develop technology to impact the problem have been ongoing for over 20 years. As one of the leading causes of residential fires, unattended cooking fires remain a high priority fire problem requiring solutions.

The National Institute of Standards and Technology (NIST), the Consumer Product Safety Commission (CPSC), Underwriters Laboratories (UL), the National Fire Protection Association's (NFPA) Fire Protection Research Foundation (FPRF), and contractors to these organizations have researched engineering solutions to address unattended cooking fires for nearly 20 years. Most devices conceived for this purpose are thermal and expected to warn of approaching ignition temperatures. Recent work by Dinaburg and Gottuk at Jensen Hughes and sponsored by the FPRF and NIST developed recommendation for a test standard for cooking pre-ignition detection devices [2]. In 2015, the Association of Home Appliance Manufacturers (AHAM), in cooperation with Underwriters Laboratories (UL), proposed a modification to the 16th edition of UL 858 standard Cooking Oil Ignition Test for electric ranges [3] which has been adopted and will be effective April 4, 2019. The revised standard considers and tests any built-in device designed to prevent ignition of food on the range.

For most studies of this problem, the focus on detecting approaching ignition has been range-centric; i.e., the solution needed to be connected to the range to interrupt the heating process during unattended cooking to prevent ignition [4, 5, 6]. However, NIST's recommendation in 1996 was to explore smoke as the most reliable and early warning of approaching ignition [7]. Due to nuisance alarms, smoke alarms have not typically been deployed in kitchens and are not listed for such use. Detection and alarming of smoke levels would necessarily need to be external from the range, probably on the ceiling, and would need to interface with a range to shut it down in the event of approaching ignition. NIST recently decided to revisit the potential for using smoke to enable warning of approaching ignition. To be effective, a time window needed to be found between normal cooking smoke levels and approaching-ignition smoke levels generated by unattended cooking. A smoke level threshold could then be set which allowed for sufficient time for the homeowner to hear an alarm and respond or for automatic range shutdown to be initiated prior to ignition.

Experimental Description

Experiments were designed to explore the smoke produced by unattended cooking of various foods. The foods and pan sizes and materials were selected based partly on the experiments performed by Dinaburg and Gottuk [2] and the results generated by particular combinations. The presence and operation of a range hood was also added to this effort. The goal of the experiments was to generate data that could be analyzed to establish the relationship between smoke and time before ignition for fire prevention. Relatively smoky normal cooking was also needed to determine if it could be differentiated from the unattended cooking smoke levels.

The experiments were conducted at NIST in a room 3.0 m wide x 2.45 m tall x 3.2 m deep with a 9.1 m wide and 2.0 m tall opening and a 0.44 m soffit which allows the smoke to be exhausted out of the test area and thought the exhaust duct. A room diagram is shown in **Fehler! Verweisquelle konnte nicht gefunden werden.**. A kitchen mockup was built using cement board cabinets and a built-in range and a range hood. A residential electric (coil burner) range was purchased and installed. A large front burner on the range with a 1.95 kW rating was used. The range hood exhausted above the false ceiling to the room exhaust and operated at 104 L/min (220 ft^3/min). NIST used the same 25 cm (10 in) diameter stainless steel pans Jensen Hughes determined led to fastest ignition [2].

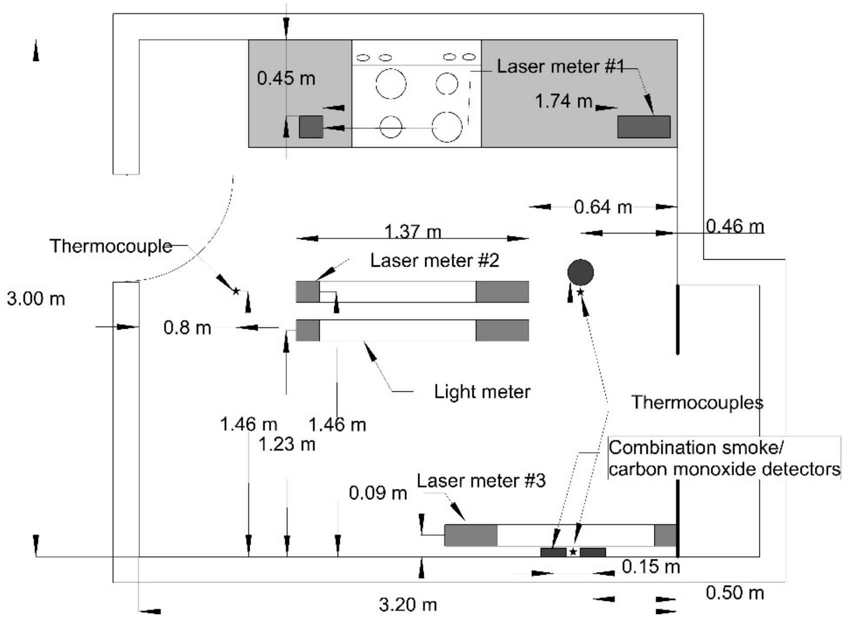

Fig. 1. Top view of the instrument layout in the test room.

Measurements included power and current used by the range, smoke obscuration, and temperatures. Smoke was measured above the range, on the ceiling, and on one wall primarily with laser-based smoke meters and photoelectric smoke detectors. Temperatures were measured at the pan and also at each smoke measurement device location. Two high definition video cameras and a digital still camera were used as well.

Table 1 provides the matrix of tests and their conditions. Canola oil and peanut oil were chosen for the NIST study because the Jensen Hughes results showed that they presented a challenge to the use of photoelectric smoke detection technology with late, high-temperature smoke production and similar or slightly earlier ignition times as other oils [2]. To allow comparison, the same amount of oil was chosen as well: 300 mL ±3 mL for a 6.4 mm (¼ in) depth in the pan. Bacon (224 g ± 2 g) was also selected as a meat for unattended cooking because it tends to produce smoke and ignite relatively early compared to cooking oils. Hamburgers (112 g ± 1 g per patty) were selected as a surrogate for food undergoing an attended cooking process because smoke is often produced even while attended that can activate smoke alarms in adjacent rooms. Fifteen unattended and six attended cooking experiments were conducted. Oils and bacon were cooked on high heat while the hamburgers were cooked with typical procedures which involved flipping them at specified times and decreasing the heat from high to medium.

Table 1. Test matrix with experimental conditions are listed for each.

Unattended Cooking			**Attended Cooking**		
Test No.	**Food**	**Range Hood**	**Test No.**	**Food**	**Range Hood**
1	Canola Oil	Off	16	1 Hamburger	Off
2	Canola Oil	Off	17	2 Hamburgers	Off
3	Peanut Oil	Off	18	2 Hamburgers	Off
4	Bacon	Off	19	3 Hamburgers	Off
5	Canola Oil	On	20	1 Hamburger	Off
6	Peanut Oil	On	21	1 Hamburger	Off
7	Canola Oil	On			
8	Peanut Oil	On			
9	Peanut Oil	Off			
10	Peanut Oil	On			
11	Peanut Oil	Off			
12	Canola Oil	Off			
13	Canola Oil	On			
14	Bacon	Off			
15	Bacon	Off			

Results and Discussion

Fig. 2 is a plot of the food temperatures and duration of heating time at ignition for all of the experiments. Solid symbols represent the data for experiments with the range hood off. Symbols with the same color and shape are for experiments using the same foodstuff. There is no clear pattern of difference in ignition time or temperature related to the hood status. The plot does show similarly wide ranges of time and temperature for all of the foods tested. Peanut oil generally (but not always) had higher ignition temperatures than canola oil. This is consistent with what was found in the Jensen Hughes study [2].

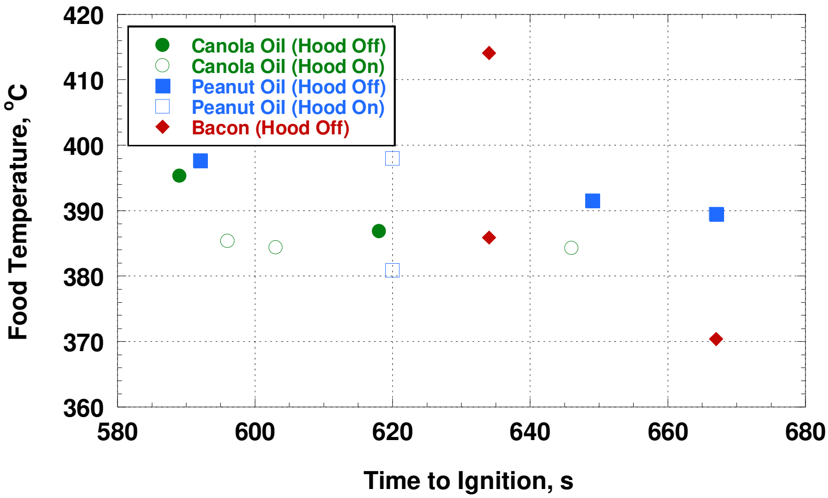

Fig. 2. Food temperature versus ignition time for all experiments.

The reason for conducting experiments that represent attended, yet smoky, cooking as well as those that represent unattended cooking and lead to ignition is to determine if there is a sufficient difference between the smoke levels long enough before ignition to provide an alarm or warning threshold. It is important that the threshold is above maximum normal cooking obscuration levels so nuisance warnings are not experienced. The threshold should also be at minimum obscuration levels achieved during unattended cooking to allow the most time available for warning and manual shutdown or automated shutdown before ignition occurs.

Fig. 3 is a plot of the minimum obscuration levels for the smoke meter located on the ceiling for all of the experiments versus time before ignition. The time before ignition axis starts with 2 min before ignition on the left and ignition at 0 s on the right. The line drawn across the bottom of the plot is the maximum obscuration at the ceiling at any time during any of the hamburger experiments, 15.2 %/m. The plot shows that for the ceiling smoke meter position, which captures smoke as it starts to build a layer, all of the minimum obscurations for the different foods at 1 min before ignition and later are higher than the maximum obscuration produced by any of the hamburger experiments. This reveals that a time window on the order of 1 min is available at the ceiling location, during which a warning threshold could indicate approaching ignition without also being triggered by nuisance smoke levels.

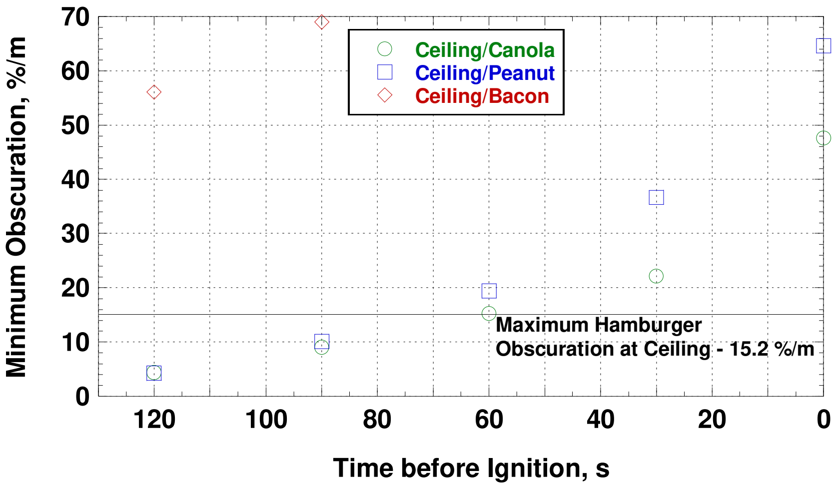

Fig. 3. Minimum obscuration for the ceiling smoke meter location plotted versus time before ignition. The maximum obscuration at the ceiling location is shown for all of the hamburger experiments. Some bacon data points are higher than the range displayed.

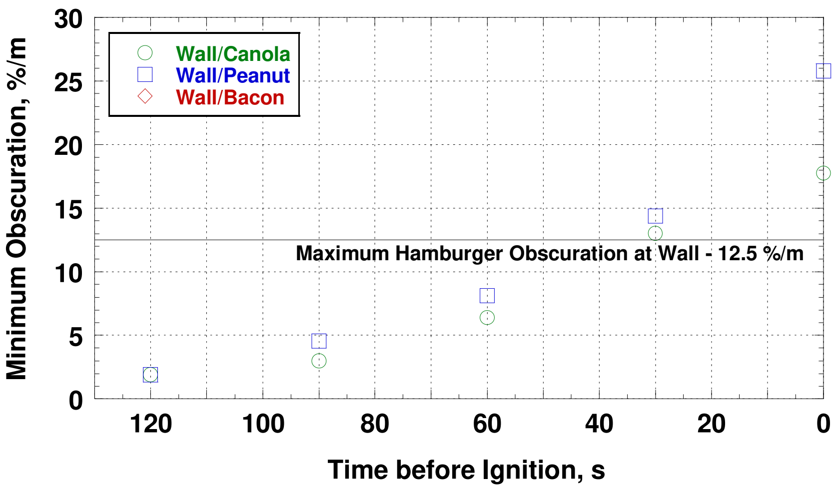

Fig. 4. Minimum obscuration for the wall smoke meter location plotted versus time before ignition. The maximum obscuration at the wall location is shown for all of the hamburger experiments. The bacon data points are higher than the range displayed.

Fehler! Verweisquelle konnte nicht gefunden werden. is similar to the previous figure but is for the wall location. The line drawn across the bottom of the plot is the maximum obscuration at the wall location at any time during any of the hamburger experiments, 12.5 %/m. The plot shows that for the wall smoke meter position, which sees smoke after it has been further diluted (compared to at the ceiling) and descended as a thickening smoke layer, the minimum obscurations for the different foods are only greater than the maximum hamburger obscurations about 30 s to 35 s before ignition. This shows that a time window only on the order of 30 s is available at the wall location when a warning threshold could indicate approaching ignition without also being triggered by nuisance smoke levels. This is still sufficient time for a burner to be de-energized even accounting for the continued heating and increasing temperature (overshoot) of the pan and food after power is cut. This overshoot period was found to be about 5 s [2].

Conclusions and Future Work

The following findings were observed:

- Similar qualitative results were found to the earlier NIST effort [7].
- Ignition temperature results were comparable to Jensen Hughes' results [2].
- Smoke production above the range usually reached unacceptably high obscuration levels greater than 52 %/m (20 %/ft) at least 2 min before ignition.
- A 2 min window was found between normal cooking smoke levels (for hamburgers) and approaching-ignition smoke levels from unattended cooking for smoke measured above and near the range burner.
- A 1 min window was found between normal cooking smoke levels (for hamburgers) and approaching-ignition smoke levels from unattended cooking for smoke measured at the ceiling.
- A 30 s window was found between normal cooking smoke levels (for hamburgers) and approaching-ignition smoke levels from unattended cooking for smoke measured on the wall.
- The standard threshold smoke detectors not designed for kitchen use alarmed minutes before ignition.
- Standard smoke detectors used for this study do not have the dynamic range to provide smoke measurement data beyond their programmed alarm threshold.

There are useful time windows (which vary by measurement location) for differentiation of smoke obscuration levels generated by normal and unattended cooking situations that could be utilized to either (1) alert an occupant to return and de-energize the range or (2) interface with an automatic de-energizing device connected to the range. This limited set of data was conducted in a single kitchen configuration. Results in kitchens of different dimensions than the configuration used in this test series could be impacted by the larger or smaller kitchen volumes. Larger kitchen volumes could decrease/delay the obscuration concentrations resulting in less time between alarm and ignition.

Follow-on work is needed by industry and organizations working on increasing cooking fire safety to establish standards for kitchen-deployed unattended cooking alarms that are not necessarily built into a range. Photoelectric (or ionization) devices might need to be detuned to alarm or activate de-energizing devices at much higher smoke levels to allow the detectors to be positioned in areas of higher smoke concentrations. Additional more severe or smoky normal cooking activities (e.g., stir frying) would need to be performed to ensure that the higher alarm thresholds are sufficiently high to not cause nuisance alarms. It will be important to clearly differentiate unattended cooking alarm devices designed for kitchen use from standard smoke detectors to prevent inappropriate installations. While range-centric devices are gradually being developed along with standards, using smoke detection technology could more quickly and easily bring about significant decreases in residential cooking fires.

Acknowledgements

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