Characterization of Stovetop Cooking Oil Fires

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Abstract

A series of cooking fire experiments were conducted by the National Institute of Standards and Technology (NIST) to examine the hazard associated with cooking oil fires. First, a series of twelve experiments were conducted on a free-standing stove situated in the open. The experiments were based on scenarios outlined in the draft UL 300A standard for fire suppression apparatus. Both gas and electric ranges were tested. The amount of oil and types of cooking pans were varied in the experiments. Oil was heated on a cook top burner until autoignition took place. Measurements of oil and pan temperatures, heat release rates, and heat fluxes characterized the hazard of the ensuing fires.

Next, two experiments were conducted using a full-scale residential kitchen arrangement to examine the hazard associated with the free burning oil fires situated within a compartment equipped with commercial furnishings, fiberboard cabinets, and countertops. The dimensions of the test room were 3.6 m x 3.4 m x 2.4 m high. Corn oil was heated on a cook top burner until autoignition took place. Measurements of room temperatures, heat fluxes, and heat release rates showed that even small cooktop fires spread and grew ultra-fast within the kitchen compartment.

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1. INTRODUCTION

According to U.S. fire statistics during the period from 2010 to 2014, cooking equipment was involved in 46 % of reported home fires and more than 450 home fires daily associated with cooking [1]. In 52 % of the cases, the first item ignited was related to cooking oil or other Class IIIB combustible liquids, fats, and grease. Although only 5 % of cooking fires extended beyond the room of origin, more than 60 % of civilian deaths and direct property damage was associated with these fires [1]. This statistic indicates that fast and active fire protection at the initial stage of a cooking fire is necessary to minimize its damage. Relatively little research, however, has been conducted to characterize the behavior of cooking oil fires.

Koseki et al. measured various burning properties of vegetable oils, such as the flash point, flame height, burning rate, and effective heat of combustion [2]. The burning characteristics of vegetable oil was compared with lubricating oils and hydrocarbon fuels. Liu and coworkers have considered water mist suppression of large cooking oil fires with industrial applications [3, 4]. In residential kitchens, Chow et al. investigated suppression of cooking oil fires in an open kitchen [5]. They compared the performance of water mist and dry powders in suppressing cooking oil fires and found that the discharge pressure was a key parameter for suppression of cooking oil fires [6]. Hamins et al. considered suppression of residential kitchen fires using a number of suppressant types including wet and dry chemical systems, water mist and water sprinklers [7].

To optimize fire safety engineering design for residential kitchens - a high risk area - in terms of tenability and effective fire detection/suppression strategies, it is important to understand the detailed character of kitchen fires, including the process of fire development, from ignition to fire spread and growth.

The present study endeavors to characterize residential kitchen cooking fire scenarios. Experiments were conducted using various cooking oil amounts and pan sizes for fires burning on cooktops in the open and in a full-scale kitchen equipped with residential furnishings.

2. EXPERIMENTS

2.1 Cooktop fires

The experimental set-up used the pan sizes and the amount of oil specified by UL300A [8]. Four types of cooking pans were used, which varied in size, shape, and material of construction as shown in Table 1. Pans A, B and C were actual commercial cookware and included a cast iron skillet, a deep pot or “Dutch oven”, and a sauce pan, respectively. Pan D was a custom fabricated 53 cm by 46 cm rectangular pan, 7.6 cm deep, designed to cover a large portion of the cooktop surface, representing an oil spill fire. Both electric and gas cooktops were tested. A single burner was used to heat the test pan, which was filled with the volume of cooking oil shown in Table 1.

Table 1. Summary of pans and amounts of oil used in the experiments

Type	Shape	Dimension (cm)	Depth (cm)	Material	Pan Mass (g)	Oil Volume (ml) **
Pan A	Round	33*	5	Cast iron	4230 ± 10	1650 ± 10
Pan B	Round	25*	18	Stainless Steel	1250 ± 10	4500 ± 10
Pan C	Round	10*	5	Stainless Steel	1420 ± 10	215 ± 5
Pan D	Rectangular	53 x 46	7.6	Steel	3000 ± 800	1600 ± 20

* inner diameter of pan lip

** specified in UL300A

The maximum power delivered to the electric stovetop heating element was about 2400 W and 1500 W for the large and small coils, respectively. For the gas stovetop, the flow rate of natural gas was measured to estimate the power output. The volume flow rate was measured to be 2.58 ± 0.12 lpm, which corresponded to a heat release rate of 1.4 kW assuming complete combustion.

The cooking oils specified by the draft UL 300A test method are peanut and vegetable oil [8]. For this study, corn oil was used instead of vegetable oil, since vegetable oil is typically a mixture of various types of oils. Table 2 lists the thermo-physical and combustion properties of peanut and corn oils, including their density, specific heat, flash point, and autoignition temperature. The autoignition temperature of the corn oil is significantly lower than that of peanut oil, whereas the density is about the same.

Table 2. Thermo-physical and combustion properties of vegetable oils [9,10]

Oil type	Density [kg/m^3]	Specific heat [kJ/kg°C] @35°C	Flash point [°C]	Auto ignition temperature [°C]
Corn	918	1.673	254	392
Peanut	920	2.045	282	445

2.2 Cooktop fire burning in the open

Figure 1 shows the schematic of the test apparatus for the stovetop fire experiments under an exhaust hood in the open. The ignition event and subsequent fire behavior were characterized.. The entire test was recorded using a digital video camera, including the periods of oil heating, ignition, fire growth, and suppression. The camera was positioned about 5 m from the stove. For most experiments except fire tests with Pan C, the cooktop was de-energized shortly after ignition was observed and the fire was suppressed before it became fully developed to prevent thermal damage to the experimental apparatus and equipment.

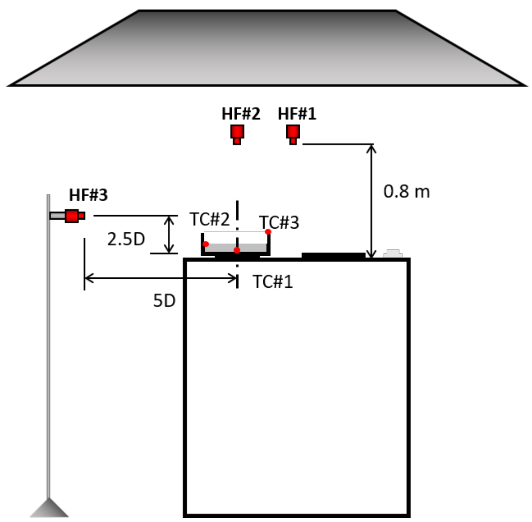


Figure 1. Schematic diagram of the apparatus used for stovetop fire characterization.

The test matrix for cooktop fires burning in the open is shown in Table 3. Twelve full scale fire tests were conducted to investigate ignition and stovetop fire characteristics, such as ignition time, mass loss rate, heat release rate, and heat flux emitted by the fire. Table 3 lists the mass of oil tested and the experimental conditions, including the types of cooktop, oil, and pan used. Corn oil was used in 7 tests and peanut oil was used in 5 tests. Pan C was used in 5 experiments, which was the most, followed by Pans A and B, which were used 3 times each. Pan D was used once. Pans A and B were tested on the large rear heating element and Pan C was tested on the small heating element. Pan D was tested using all four stovetop burners.

Table 3. Summary of conditions for cooktop fires burning in the open.

Test No.	Stove type	Power (kW)	Oil type	Pan [b]	Initial oil mass (g)
1	Electric	1.5 ± 0.3	Corn	Pan C	187 ± 10
2 [a]	Electric	1.5 ± 0.3	Corn	Pan C	187 ± 10
3	Electric	2.0 ± 0.5	Corn	Pan B	4000 ± 10
4	Gas	1.4 ± 0.2	Peanut	Pan C	185 ± 10
5	Gas	1.4 ± 0.2	Corn	Pan A	1476 ± 10
6	Gas	5.6 ± 0.4 [c]	Corn	Pan D	1432 ± 10
7	Gas	1.4 ± 0.2	Peanut	Pan B	4200 ± 10
8	Electric	2.0 ± 0.5	Peanut	Pan A	1454 ± 10
9	Electric	2.0 ± 0.5	Corn	Pan A	1477 ± 10
10	Electric	2.0 ± 0.5	Peanut	Pan B	4004 ± 10
11	Electric	1.5 ± 0.3	Peanut	Pan C	186 ± 10
12 [a]	Electric	1.5 ± 0.3	Corn	Pan C	191 ± 10

a. repeat of Test 1
b. see Table 1 for a description of the pans
c. all four gas burners were used

The heat release rate was determined using oxygen consumption calorimetry which involved the measurement of many quantities as described in Ref. [11]. The response time of the system is such that it can accurately resolve dynamic heat release rate events of 15 seconds or more. The expanded uncertainty was estimated as ± 11 % for fire sizes larger than 400 kW. For smaller fires, the expanded uncertainty was estimated as 15 % based on calibration and repeat measurements with the dominant component of uncertainty related to measurement of the velocity of the flow in the duct [11].

The mass loss of the cooking oil due to evaporation and burning was measured using a load cell positioned under the stove. All the single stovetop tests were performed under a 3 m × 3 m exhaust hood in the NIST furniture calorimeter. Based on repeated calibration measurements, the standard deviation of the load cell was about 10 g.

Three thin (1.6 mm) stainless steel sheathed type K thermocouples were spring-loaded such that they made contact at various positions on the vessel surface to monitor its surface temperature as a function of time during heating (see Figure 1). The thermocouples were positioned at the center of the pan bottom, on the inner side wall at the oil-fill level, and on the pan rim as shown in Figure 1. Their use was focused on characterizing the temperature at ignition. As specified by the manufacturer, the standard uncertainty was about 2 °C for these measurements [12].

Three water-cooled Schmidt-Boelter heat flux gauges were used to measure the local time varying total heat flux emitted by the fire. The gauges had a wide view angle (150 ° view angle) and were coated with a high emissivity paint with a flat spectral response in the infrared. Their time response was approximately 2 s. The gauges were installed as shown in Figure 1. A heat flux gauge (HF#3) oriented toward the pan was horizontally positioned at a distance of five times the diameter of the pan and a vertical distance 2.5 times the diameter from the center of the pan bottom. Two gauges oriented downward (HF#1 and HF#2) were placed 0.8 m above the center of the pan and above the center of the cooktop, respectively. The manufacturer reported a ± 3 % expanded uncertainty in the heat flux gauge responsivity [13]. The calibration for the heat flux gauges was checked using a secondary standard in a well-characterized radiometer facility and the heat flux measurement uncertainty was estimated to be 5 % [14]. A recent round-robin study of heat flux gauge calibration consistency sent the same heat flux gauges to multiple laboratories around the world and found that while many of the calibrations fell within the ± 3 % range, if all the data was considered, then the expanded uncertainty was reported as ± 8 % [14].

2.3 Cooktop fire burning in a full-scale kitchen

Figure 2 shows the enclosure (3.6 m × 3.4 m × 2.4 m high with a doorway of dimensions 0.90 m × 2.04 m) in which the 2 compartment experiments were conducted characterizing the free-burning cooktop fires. These tests were part of a larger experimental series which is described in detail in Ref. [7]. The mock-up kitchen was built using two layers of 12.7 mm thick gypsum board over steel studs. Vinyl sheet flooring covered a (nominal) 19 mm plywood sub-floor. The cabinets were made of medium density fiber-board (MDF) under an outer vinyl layer and fitted with wood doors. The counters were high gloss MDF with a plastic laminate coating. A commercially available range hood was located 0.54 m above the surface of the stovetop. In the experiments described here, there was no forced flow through the hood and it was assumed that natural convection was negligible. In the first experiment (Test KSG15), the front right burner of the gas stove was set to its maximum power output (1.4 kW) and Pans B (see Table 1), containing 4.5 L of 100% corn oil, was heated to auto-ignition. The second experiment (Test KSG20) was similar in which the front right burner of the gas stove heated Pans B with 1.6 L of 100% corn oil.

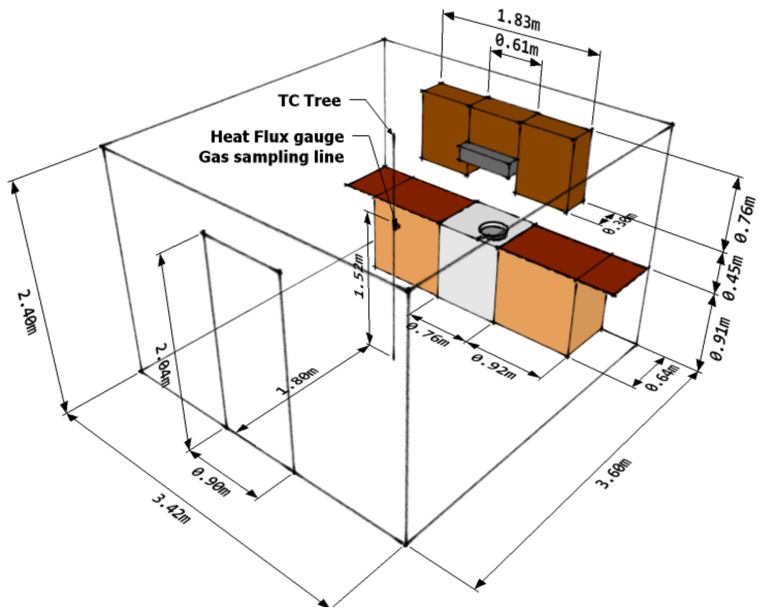
A thermocouple tree stretching from ceiling to floor was used to measure the vertical gas temperature at the center of the enclosure. Type K thermocouples with 0.5 mm bare bead nominal diameter were installed at heights of 27 cm, 57 cm, 88 cm, 118 cm, 148 cm, 179 cm, 209.5 cm and 237.5 cm above the floor. Thermocouples were used to measure the temperature of the oil in the pans and to characterize the vertical temperature profile in the kitchen with regard to tenability at a location 1.5 m above the floor at the center of the room, which necessitated monitoring when the temperature obtained a value of 190 °C [15,16]. Thermocouples located higher in the compartment were expected to obtain higher temperatures.

The inherent thermocouple wire measurement uncertainty was ± 2 °C at 280 °C, increasing to ± 10 °C at 870 °C [12]. This does not include radiative loss effects, which according to an energy balance calculation can lead to a bias of 130 °C too low for a thermocouple reading of 800 °C, assuming that the thermocouples were coated with soot in these fires (which were observed to be smoke-laden) [17,18]. Temperature variance in the zone near the thermocouple is typically much greater than that of the wire uncertainty and the measurement variance in these experiments was typically about ± 15 %.

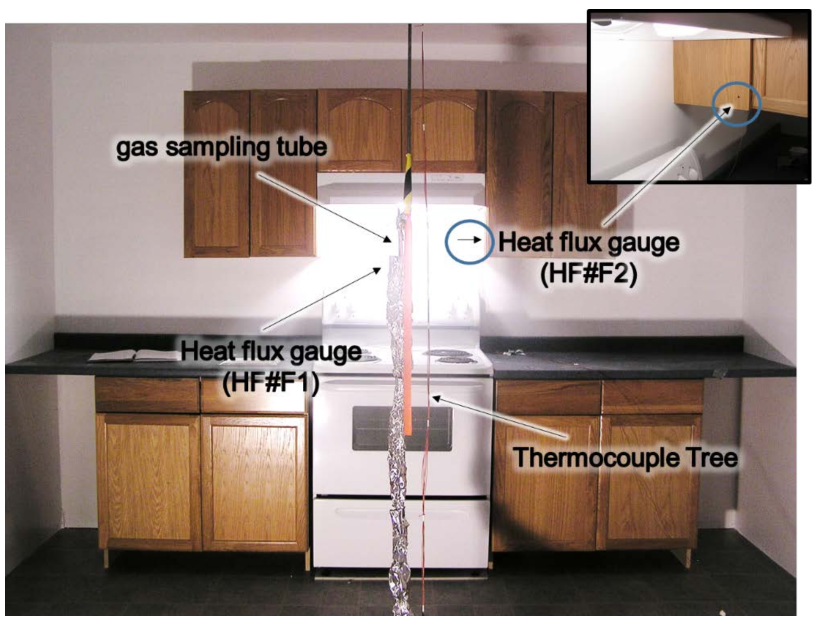
Total heat flux gauges were installed at the center of the enclosure facing the range located 1.52 m above the floor (HF#1) and in the upper cabinet facing the range (HF#2) as shown in Figure 2b. As described in the section above, the expanded uncertainty was estimated as ± 8 % based on Ref. [14].

UL 1626 specifies estimated practical limits for tenability based on temperature [19]. Two limits are specified: a limit at which tenability is instantly compromised and a limit at which tenability is compromised after 2 min of exposure. The estimated instantaneous and 2 min* tenability limits due to temperature are 54 °C and 93 °C, respectively [15]. The SFPE Handbook of Fire Protection Engineering estimates the tenability limit due to heat flux as 2.5 kW/m² for which the time to burn unprotected skin is less than 20 s [16]. These limits are not absolute, since clothing, humidity, skin composition, and other factors can mitigate or exacerbate the impact of the thermal energy for a given heat level and exposure time. These values are helpful benchmarks and are considered here.

* the two min tenability limit requires that the temperature be above 93 °C for a two min period.



(a)



(b)

Figure 2. (a) Schematic drawing of the full-scale mock kitchen and (b) photo of stovetop, cabinets, and instrumentation and close-up of flush-mounted heat flux gauge (HF#F2) on cabinet side-wall.

3. RESULTS

3.1 Characteristics of a cooktop fire burning in the open

Figure 3 presents the average time to ignition as a function of the corn and peanut oil mass for the 11 tests that used the three Pans (A, B, C) on the electric cooktop. The time to ignition varied from 18 min to 80 min, depending on the test conditions. The time to ignition increased as the initial mass of cooking oil increased for the various pan types. On average, the time to ignition of the corn oil was 5 % to 10 % lower than that of the peanut oil, probably due to its lower auto-ignition temperature and specific heat. Other factors such as the pan mass, material type and size also played a role in the heat-up time and time to ignition.

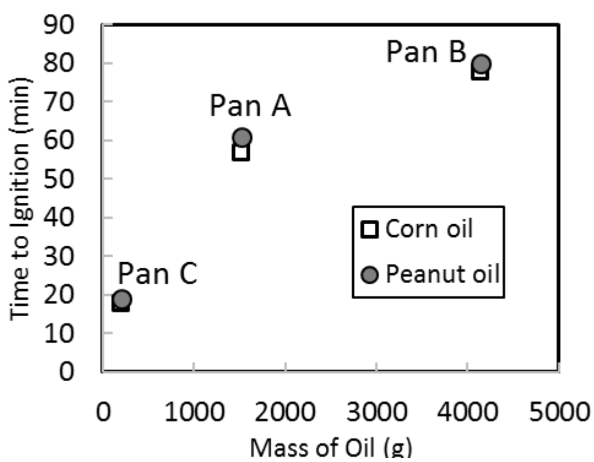


Figure 3. Average time to ignition as function of mass of oil on the electric cooktop for Tests 1-12 (except Test 6).

Figure 4 shows photographs of the evolving corn oil fire in Pan C as a function of time along with the measured heat release rate. As the cooking oil and the pan were heated, copious amounts of oil vapor was generated above the liquid fuel surface, until ignition was observed. When ignited, the initial flame height was very small and the flame was observed to reside within the pan. With time, the liquid oil temperature increased and the fire grew until the flame height was larger than 4 times the pan diameter. Finally, the fuel began to visibly boil. Bubbling oil was observed to overflow the pan and fall onto the stovetop. Flames then spread along the stovetop, serving to heat the outside of the pan, which further heated the oil, thus increasing the heat release rate. The instantaneous flame height was larger than 10 times the diameter of the pan at the time of the peak heat release rate. As the oil was consumed, the fire size diminished and smoke from the fire appeared very dark.

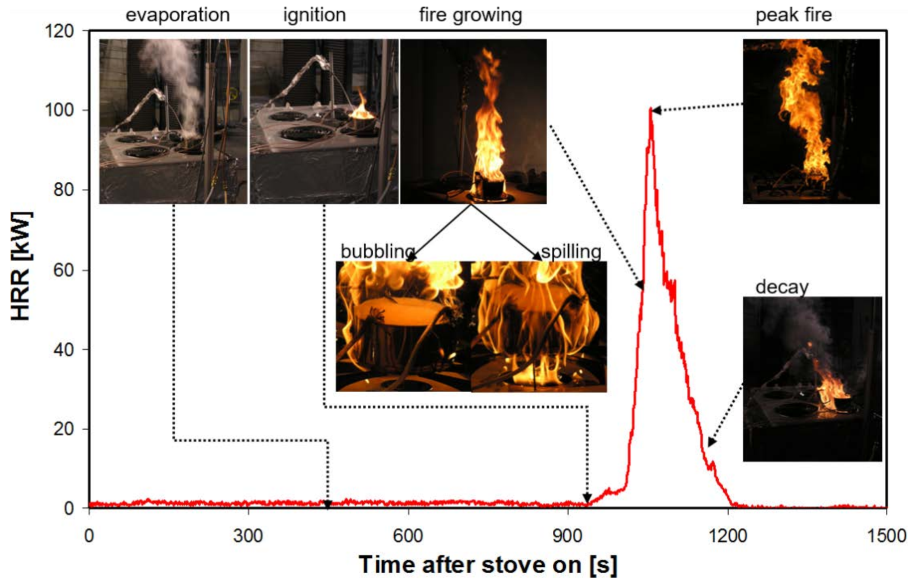


Figure 4. The measured heat release rate as a function of time for corn oil in Pan C. Photographs of key aspects of fire behavior are also shown.

Finally, the fire self-extinguished due to a lack of oil. Fire behavior was observed to fall into three phases:

- A "growing fire" defined as the period after ignition and before the initiation of fuel overflow. During this period, the fire was confined to the original pan and appeared to behave not unlike a typical liquid pool fire except that the fire was heated both from above due to the flames and from below by the stove. Fire growth was enhanced by heat from the stove.
- A "boil-over" phase occurring when bubbling oil spilled over the sides of the pan and fire spread beyond the confines of the original pan. Boil-over was enhanced due to the stove heating the pan from the bottom - and would not otherwise be expected to occur as rapidly, if at all.
- A "decay" phase late in the burn after the maximum heat release rate was observed when the heat release rate decreased as the fuel was consumed. If the cooktop was in a typical kitchen, the decay phase in the heat release rate probably wouldn't be noticeable once secondary objects became involved in the fire and the heat release rate continued to grow.

Figure 5 presents the time history of the temperature at the bottom surface of Pan C during repeat experiments with consumer-grade (100 %) corn oil. During heat-up of the cooking oil, the bottom surface temperature of the pan gradually increased. The results were highly repeatable until the bottom of the pan surface temperature obtained about 300 °C. The time to ignition ranged from about 1072 s to about 1200 s probably due to slight differences in the initial mass of corn oil, the initial oil and pan temperature, and external conditions such as ventilation. In any case, the measured surface temperature of the pan bottom at ignition was almost constant at 350 °C. This value is somewhat lower than the reference auto-ignition temperature of corn oil of 392 °C [9], which may be attributed to the fact that the temperature was not measured at the ignition location, where the local temperature would be expected to exceed the auto-ignition temperature. After ignition, the bottom surface temperature abruptly increased as the oil began to boil-over. The peak value of the temperature on the bottom of Pan C happened at about the same time as the peak heat release rate. The time of fire growth from ignition to peak fire was about 250 s for the 3 tests.

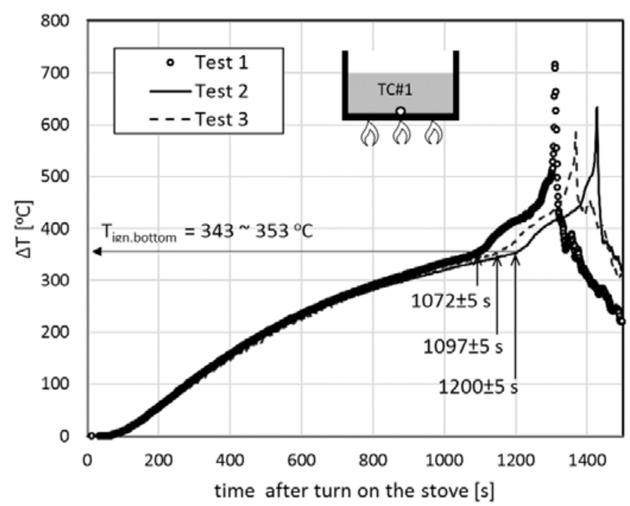
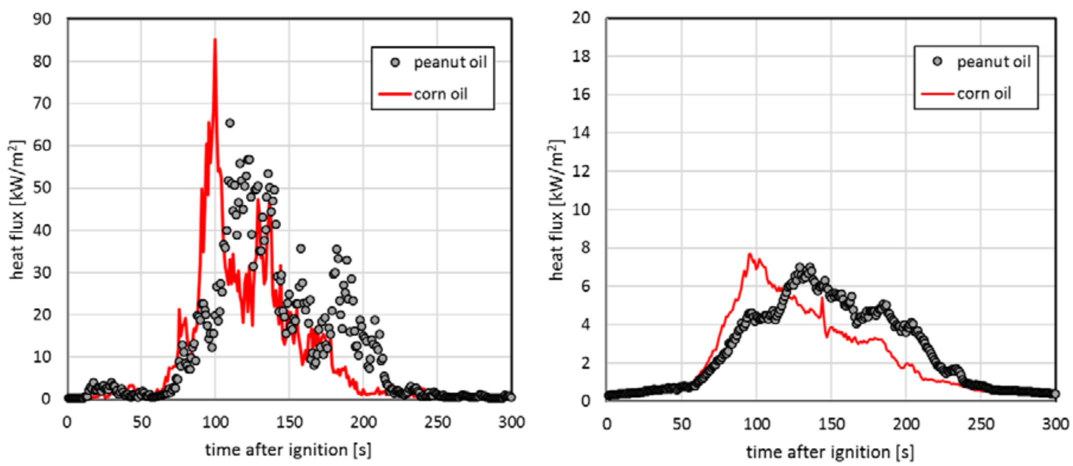


Figure 5. The evolving temperature measured at the bottom of Pan C with corn oil for Tests 1 -3.

Figure 6 shows the measured total heat fluxes at two locations (HF#2 and HF#3; see Figure 1) for corn and peanut oil in Pan C. HF#2 was 0.8 m directly above the pan, which was expected to experience the highest heat flux, whereas HF#3 was positioned to the side of the pan. The overall trend of heat flux was similar, but the corn oil fire burned more quickly than the peanut oil. The peak heat flux was higher than 50 kW/m^2 at HF#2 and less than 10 kW/m^2 at HF#3. Even from this relatively small cooking pan fire, a large heat flux was generated above the fire, which led to fire spread to surrounding combustible materials such as kitchen cabinets, a scenario examined later in this paper. The heat flux to the side was much lower, but was also significant, exceeding the tenability limit for exposure of skin to radiant heat flux which is approximately 2.5 kW/m^2.



(a) HF#2 (b) HF#3

Figure 6. The measured heat flux at locations #2 and #3 (see Figure 1) for peanut and corn oil in Pan C.

Figure 7 compares the measured heat flux at location 2 for corn oil fire in different pans on the electric stove top. For the case of Pan B, the cooktop power was stopped and the fire was suppressed at 280 s after ignition to prevent thermal damage to the instrumentation. The fire growth phase was about 60 s for Pan C fire and 220 s for Pan B fire, respectively; this phase being longer for Pan B due to the larger amount of cooking oil used. Once boil-over occurred, the measured heat flux emitted by Pan B was larger than 120 kW/m^2. This implies that it is important to suppress the cooking oil fire early in its development. Once the boil-over phase occurs, fire suppression is far more challenging as the physical extent and the heat release rate of the fire increases. In this case even if suppression is successful, reignition is a challenge as cooking oil carries large amounts of sensible enthalpy (product of the oil heat capacity and its temperature rise) and it is difficult to cool a significant mass of oil below its autoignition temperature. De-energizing the stove is important to reduce the rate of oil being heated and associated fire growth.

Figure 8 compares the time to reach 20 kW/m^2 after ignition at the heat flux gauge directly above the pan (HF#2 in Figure 1) for corn oil fires in different size pans. A heat flux of 20 kW/m^2 was selected as it is representative of the critical ignition heat flux for many typical materials including the nearby cabinets which were composed of particle board [Steinhaus and Jahn, 2007]. The time for HF#2 to reach 20 kW/m^2

after ignition was nearly proportional to the depth of the cooking oil, whereas the ignition time depended on the mass of oil (as shown in Figure 5).

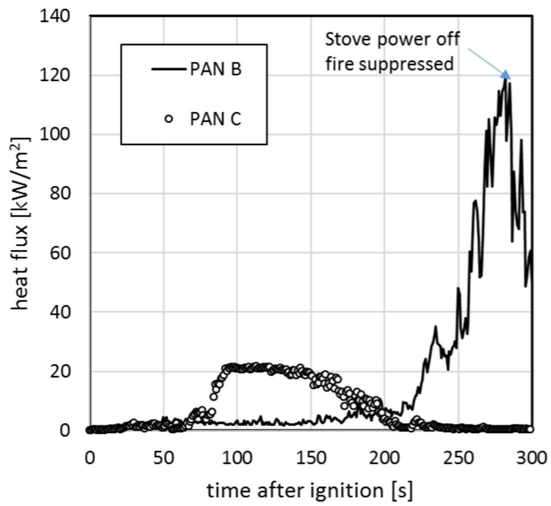


Figure 7. The evolving heat flux measured at the heat flux location 2 after ignition for corn oil.

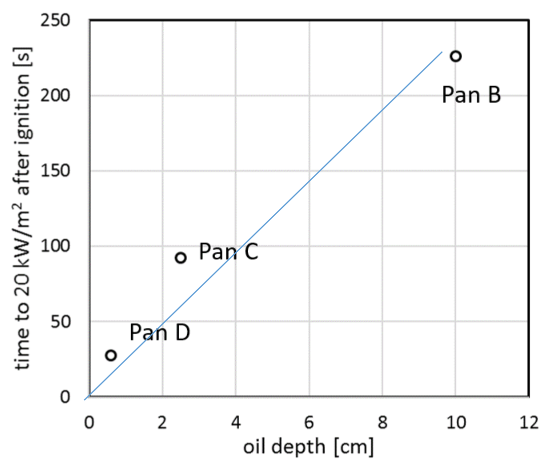


Figure 8. Comparisons of the time required to reach a heat flux of 20 kW/m^2 on heat flux gauge HF#2 (see Figure 1) as a function of oil depth on the electric cooktop.

Figure 9 shows the measured heat release rate as a function of time after ignition of corn and peanut oil in Pan C. For the first 70 s after ignition, the heat release rate gradually increased and boiling was not observed. During this period, the heat release rates of the corn and peanut oil fires were nearly identical. Once boil-over occurred, the heat release rate of the corn oil fire increased slightly faster than the peanut oil fire. The peak heat release rate of the corn and peanut oil fires were very similar - approximately 100 kW.

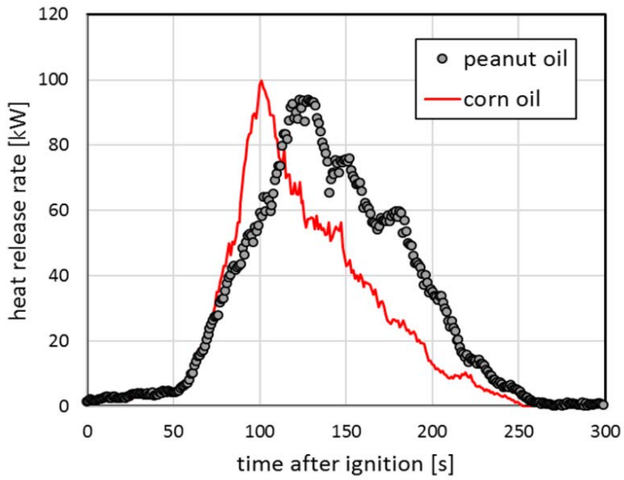


Figure 9. Comparison of the measured heat release rate for peanut and corn oil in Pan C.

3.2 Characteristics of a cooktop fire burning in a full-scale kitchen

For small fires in a big compartment, compartment effects can be considered as negligible. As a fire grows, compartment effects may play a role. For limited ventilation fire conditions, the maximum heat release rate is directly affected by the doorway ventilation factor. The mass flow rate of air through a doorway can be estimated as follows:

$$\dot{m}_{air} = KA\sqrt{H} \qquad (1)$$

where K is an empirical constant, and A and H denote the area and height of the doorway, equal to 1.836 m^2 and 2.04 m, respectively. The value of the empirical constant K is commonly considered 0.5 to obtain the maximum air flow rate [20]. If all the air through the doorway is consumed, then the maximum possible heat release rate within the compartment can be determined as follows:

$$\dot{Q} = \Delta H_{c,O_2} \cdot Y_{O_2,air} \cdot \dot{m}_{air} \qquad (2)$$

where, $\Delta H_{c,O_2}$ and $Y_{O_2,air}$ represent the energy release per unit oxygen consumption (kJ/kg) and the mass fraction of oxygen in ambient air.

Figure 10 compares the measured heat release rate for the full-scale fire test using corn oil in Pan A. The fire grew rapidly after ignition. The calculated fast and ultra-fast fire growth [21] curves are shown in the figure, where α is the fire growth coefficient used to characterize the rate of fire growth in the t^2 fire growth model:

$$\dot{Q} = \alpha\ (t - t_o)^2 \tag{3}$$

and t_o is the incubation period which depends on the fire scenario. There was a relatively long pre-heat time before autoignition of the corn oil occurred. The initial fire growth approximately followed a fast t^2 fire growth curve before the fire spread to the neighboring wood cabinet. After 6 min, the fire propagated into the surrounding cabinet, and fire growth approximately followed an ultra-fast t^2 fire growth curve. Because the main objective of the full-scale tests was to understand the initial fire spread from the cooking oil fire, the fire was manually suppressed just after a heat release rate of 3.5 MW was reached at about 480 s after ignition, to prevent significant thermal damage to the experimental compartment and apparatus. The results of a second experiment shown in Figure 11 yielded similar results as shown in Figure 10 - with the maximum heat release rate measured as nearly 4 MW before the fire was manually extinguished.

The estimated maximum heat release rates in these fires based on the doorway dimensions and Eq. 2 was about 3.9 MW, so the fires were not expected to grow much larger than that seen in Figures 10 and 11.

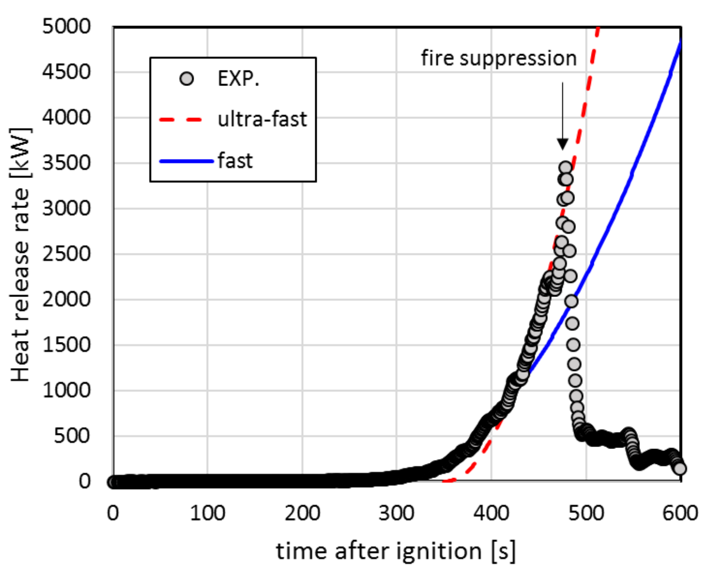


Figure 10. Comparison of the measured heat release rate and the t^2 fire growth model during the full-scale kitchen compartment fire (Test KSG15) burning 4.5 L of corn oil in Pan A. A value of α = 0.187 kW/s^2 indicates "ultra-fast" t^2 fire growth.

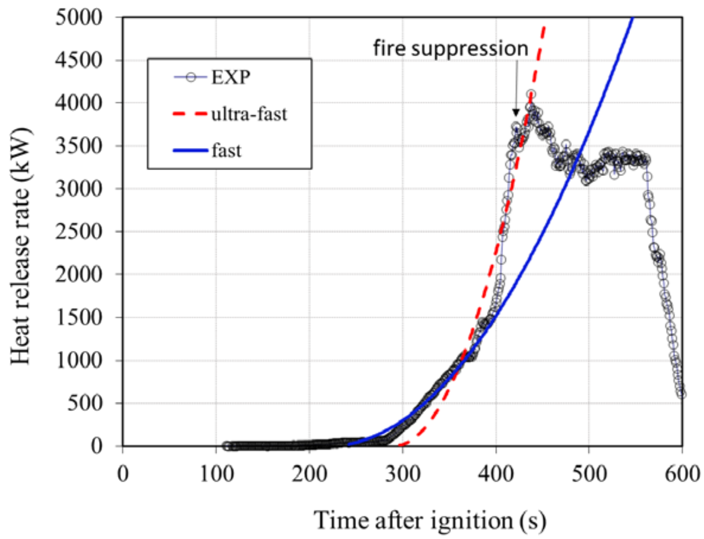


Figure 11. Comparison of the measured heat release rate and the t^2 fire growth model during the full-scale kitchen compartment fire (Test KSG20) burning 1.6 L of corn oil in Pan B. A value of α = 0.187 kW/s^2 indicates "ultra-fast" t^2 fire growth.

Figure 12 shows an example from the fire literature of fire growth trends in a kitchen where heated cooking oil was not part of the fire scenario [20]. The fire was ignited by a 10 cm x 10 cm square methanol pool fire that was not heated by the stovetop. A near-steady heat release rate of approximately 3.4 kW was generated by the methanol pool. The heat from the methanol pool ignited the fiberboard cabinets and their heat release rate was relatively large compared to the methanol pool fire. In this case, fire growth was relatively slow compared to the cooking oil fires. The estimated fire growth factor (α in Equation 3) was 0.0042 kW/s^2, which was smaller by about a factor of 50 when compared to the results shown in Figures 10 and 11 for cooktop fires in the presence of cooking oil heated on a stovetop. When heated cooking oil ignites, it presents a particularly fast-growing fire.

Figure 13 shows the measured temperature as a function of time at different heights above the floor (along the thermocouple tree) at the center of the compartment and heat flux measurements onto the cabinet and towards the compartment center during the full-scale fire test considered in this study (see Figure 2). The time to reach a temperature of 190 °C at a height of 1.5 m, which is a limiting condition for tenability [16], occurred about 6 min after ignition. The maximum compartment temperature reached approximately 800 °C during the under-ventilated phase of the fire. The fire plume was observed to lift above the stove, moving through the gap between the cabinets. The heat flux onto the cabinet reached 20 kW/m^2 and continued to grow 270 s after ignition and the cabinets were observed to ignite shortly after that. At 400 s after ignition, the heat flux in the center of the room peaked at about 160 kW/m^2, the oxygen concentration was measured to be less than 3 %, and the carbon monoxide concentration peaked at 3.2 % by volume [7].

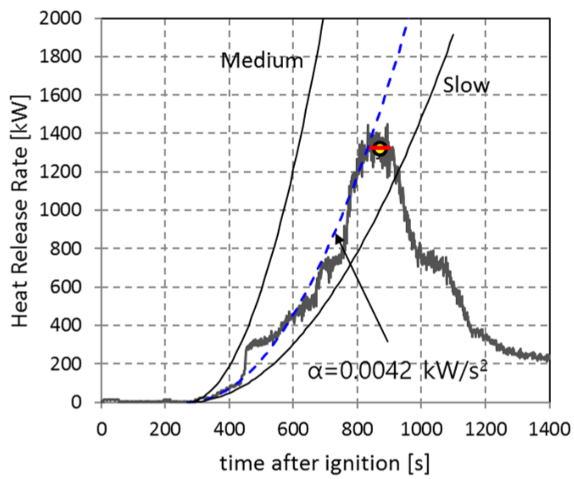
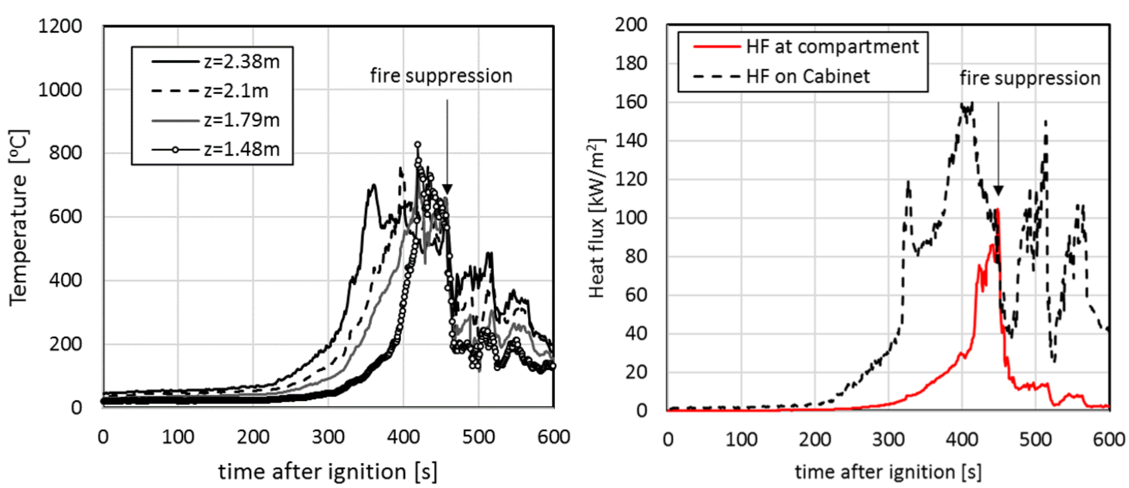


Figure 12. The measured heat release rate of a full-scale kitchen fire using a 3 kW ignition source in the presence of cabinets and the absence of a heated cooking oil fire [22].



(a) temperature

(b) heat flux

Figure 13. The measured gas temperature at different heights above the floor on the thermocouple tree (compartment center) and the measured heat flux onto the cabinet and at the center of the compartment (see Figure 2 for measurement locations).

4. SUMMARY AND CONCLUSIONS

A series of cooking fire experiments were conducted to examine the hazard associated with cooking oil fires. First, a series of twelve experiments were conducted on a free-standing stove situated in the open. The experiments were based on scenarios outlined in the draft UL 300A standard for residential fire suppression. Both gas and electric ranges were tested. The amount of oil and types of cooking pan were varied. Oil was heated on a cook top burner until autoignition took place. Measurements of oil and pan temperatures, heat release rates, and heat fluxes characterized the hazard of the ensuing fires.

Next, two experiments were conducted using a full-scale residential kitchen arrangement to examine the hazard associated when free burning cooking oil fires were situated within a compartment equipped with residential furnishings, including a non-operating range hood with ventilation fan, and fiberboard cabinets and countertops. Corn oil was heated on a cooktop burner until autoignition occurred. Room temperature, heat fluxes, and heat release rates were measured. The results showed that stovetop cooking oil fires could rapidly spread and grow within a furnished kitchen compartment. From a geometrically small (< 0.1 m^2) cooking pan fire, a large heat flux was generated by the plume directly above the fire, which led to fire spread to surrounding combustible materials in a range hood and nearby kitchen cabinets. Subsequent fire growth and spread was ultra-fast, leading to a fire heat release rate on the order of several MW and heat fluxes at the compartment center on the order of 100 kW/m^2, representing untenable conditions - all within a few minutes.

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