The Effect of Concentration and Particle Size Distribution from Cooking Nuisance Sources on Smoke Alarms

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Abstract

A new nuisance test was introduced to the ANSI/UL 217 Standard for Safety Smoke Alarms with a broiling hamburgers cooking scenario. This study examines alarms that are certified to the new standard and older alarms against a broiling hamburger scenario and against several other nuisance cooking scenarios. During these tests, the aerosols produced from the cooking were measured using an electrical low pressure cascade impactor to quantify the aerosol concentrations and diameters at the time of alarm. Overall, the broiling hamburger test produced the largest mean particle sizes and resulted in the second highest mass concentration of all the cooking scenarios.

Keywords: Smokes, cooking aerosols, size distribution, nuisance alarms

Introduction

Smoke alarms that pass the new flaming, smoldering, and nuisance tests introduced in ANSI/UL 217-2015 Standard for Smoke Alarms 8th Edition [1] have started to reach the consumer market over the past few years. After the effective date of June 2024, all smoke alarms in the US will need to meet the current edition with these new tests. The new nuisance test exposes smoke alarms to aerosols produced by broiling hamburgers with the expectation that the alarms do not sound before reaching a target obscuration level. However, it is unclear if this single nuisance test achieves a goal of broadly reducing nuisance alarms. Alarms certified to the 7th Edition were previously tested in a study with several nuisance sources including broiling and frying hamburgers, stir-frying vegetables, and toasting bread [2]. These nuisance sources produce particles with mass mean diameters ranging from 0.41 μm (broiling hamburgers) to 0.77 μm (dark toasting bread) [3]. A companion paper [4] will report on experiments of new (8th Edition or later certified) and legacy (7th Edition certified) smoke alarms exposed to various kitchen nuisance sources to determine if alarms certified to the new standard broadly reduce the number of nuisance alarms compared to the previous generation of alarms. The current study will present additional data gathered on aerosol concentration and size distributions measured at the time nuisance alarms occur for both legacy and new detectors. The study is designed to provide insight on particle characteristics of a broad range of nuisance sources that cause nuisance activations in alarms certified to the 7th Edition and new alarms certified to 8th Edition or later and could provide guidance on improvements to newer alarms if needed

Experimental Method

Experiments were conducted in a small (305 cm x 312 cm) mock kitchen, the layout of which is shown in Figure 1. To create nuisance sources, a variety of foods were cooked, including broiling hamburgers, frying hamburgers, frying bacon, and toasting bread. All experiments were conducted under normal cooking conditions with no intentional burning or ignition of the food. The broiling hamburger experiments included broiling two frozen hamburgers on a broiler pan in the oven with the door cracked approximately 8 cm for 20 min following the current standards testing procedure. Toasting bread was completed in a toaster for 180 s for toast and 240 s for dark toast. The remaining experiments were completed in round 20 cm stainless-steel skillets on a 15 cm diameter electric coil cooktop. The bacon was cooked on the 0.86 kW

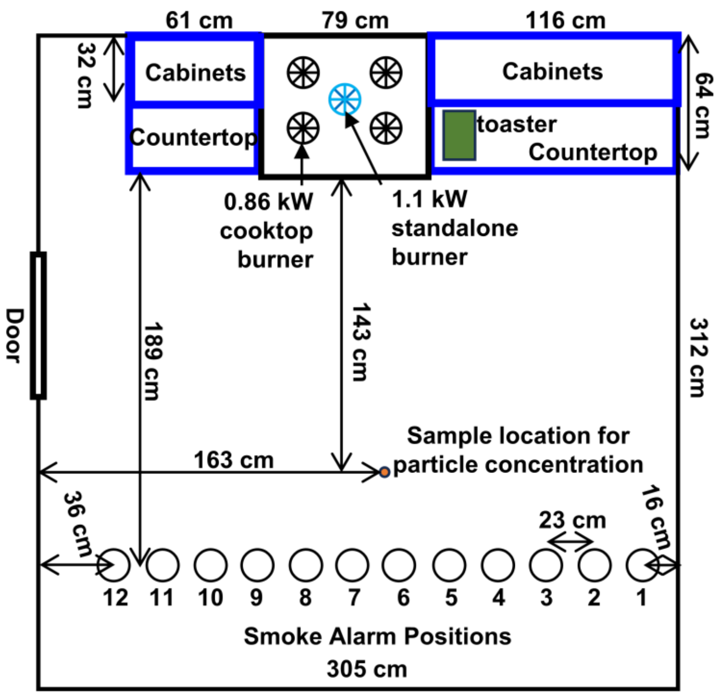

Figure 1. Layout of mock kitchen showing the location of the cooktop, toaster, detectors, and concentration sampling location.

cooktop burner for an average of 450 s (flipped after 300 s) and the fried burger was cooked on 30 mL of vegetable oil on the 1.1 kW stand-alone burner. The oil was heated for 100 s before the burger was added, then the burger was cooked for 180 s on high heat, then 150 s on half heat, then flipped and cooked for an additional 180 s on half heat, for a total of 610 s cooking time.

Each experiment was conducted with 12 smoke alarms installed on the ceiling (244 cm), including a mix of new alarms and legacy alarms exposed to the cooking aerosols. In total, four alarms certified to the new edition and six alarms certified to the 7th Edition were investigated. The 7th Edition alarms included two ionization alarms, two photoelectric alarms, and four dual ionization and photoelectric alarms. The alarms will not be identified by make and manufacturer but only by their primary sensor technology and to which edition the alarms were certified. Two of the new alarms are assumed to have ionization sensors in them due to radioactive material markings. The other two new sensors did not have radioactive material markings and presumably employ light-scattering sensors. The positions of alarms were changed after two repeat tests of each cooking scenario for three different poitions, for a total of 6 tests per cooking scenarios. In all, the results of 30 tests are presented in this paper.

Additionally, particle size and concentrations were measured near the smoke alarms; the location of the sampling port is displayed in Figure 1. The particle size distribution and concentration of the aerosol sample were measured using an electrical low-pressure impactor (ELPI). The ELPI charged the particles prior to passing them through 14 impactor stages [5]. The charge at each of the 14 stages was measured to obtain the concentration and the aerodynamic diameter of particles across a total range of 6 nm to 10 μm [5] at a rate of 1 Hz. The density of the particles was assumed to be 1 g/cm^3 for all food types. The uncertainty ranges from 20 % for the small diameter particles to 12 % for the large diameter particles [6].

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Results

The mass mean diameter and the mass concentration of the aerosol sample at the time of alarm were calculated for each cooking scenario. Figure 2 shows the alarm position, the mass mean diameter, and the mass concentration at the time of alarm activation for the cooking scenarios with meat. The total number of alarm activations was greatest during the fried bacon scenarios (Figure 2a). Both the mass concertation and the mass mean diameters at the time of alarm were greater for the bacon (Figure 2a) than for the other meats (Figure 2b&c). On average, the mass concentration at alarm for frying bacon ranged from 5.72 mg/m^3 for the new alarms to 8.44 mg/m^3 for the dual alarms and the average mass mean diameter ranged from 0.39 μm for the new alarms to 0.47 μm for the dual. The broiled burgers had average mass concentrations at

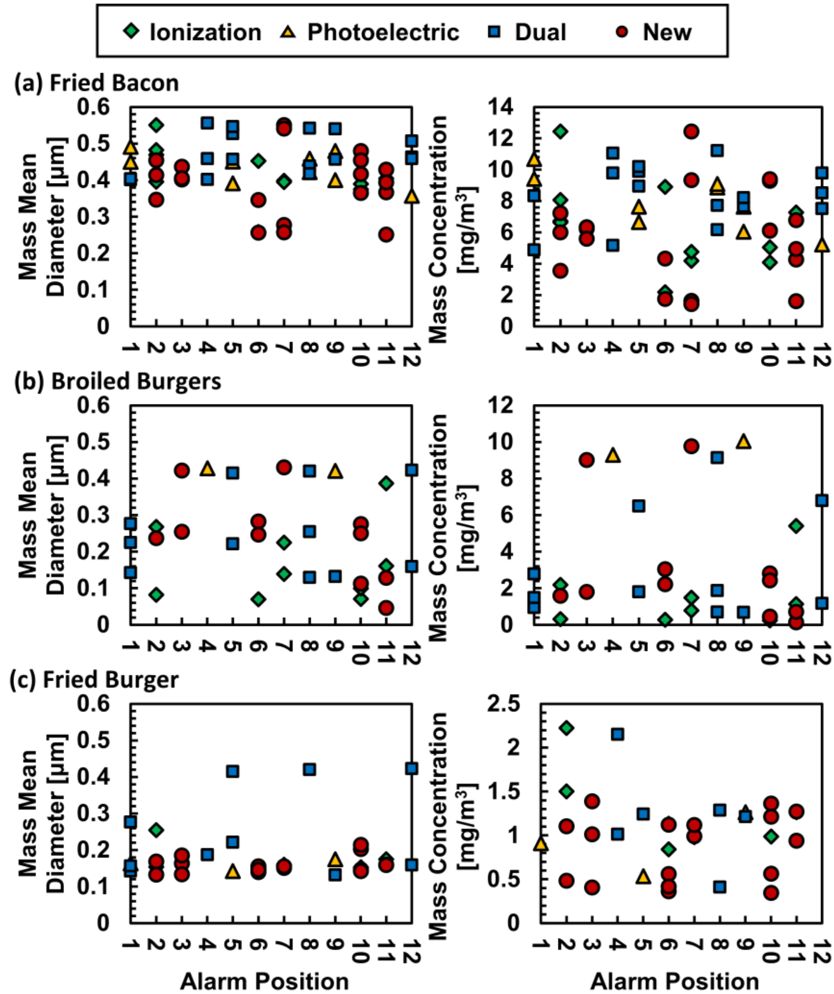

Figure 2. The mass mean diameter and the mass concertation at the time of alarm for (a) fried bacon, (b) broiled burgers, and (c) a fried burger.

alarm activation that ranged from 1.36 mg/m^3 for the ionization detectors to 9.68 mg/m^3 for the photoelectric detectors and had average mass mean diameters that ranged from 0.17 μm for the ionization alarms to 0.42 μm for the photoelectric alarms. The fried burger had average mass concentrations at alarm activation that ranged from 0.86 mg/m^3 for the new alarms to 1.28 mg/m^3 for the ionization alarms and had average mass mean diameters that ranged from 0.16 μm for both the photoelectric and the new alarms to 0.19 μm for the dual detectors.

The mass concertation and the mass mean diameter for both toasting scenarios are shown in Figure 3. Understandably, more alarms

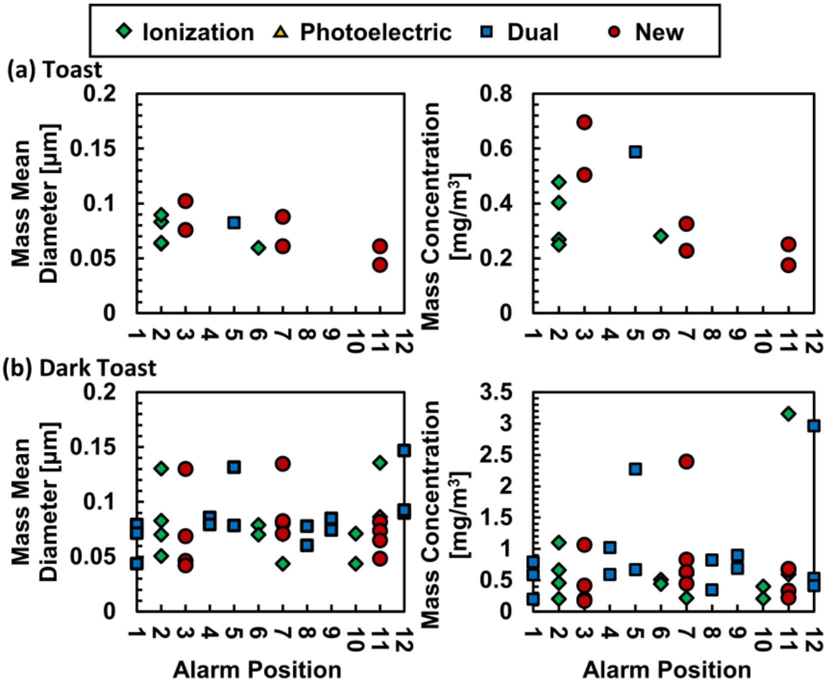

Figure 3. The mass mean diameter and the mass concertation at the time of alarm for (a) toast and (b) dark toast.

occurred during the dark toast tests (Figure 3b) than the regular toast tests (Figure 3a). None of the photoelectric alarms were activated during any of the toasting tests. For the remaining alarms during the normal toasting scenario, the average mass concentration at alarm ranged from 0.34 mg/m^3 for the ionization alarms to 0.59 mg/m^3 for the dual alarms, and the average mass mean diameters ranged from 0.07 µm for the ionization and the new alarms to 0.08 µm for the dual alarms. As can be seen in Figure 3b, the dark toast had higher mass concentrations and mass mean diameters at alarm. The average mass concentration at the time of alarm activation for the dark toast ranged from 0.68 mg/m^3 for the new alarms to 0.92 mg/m^3 for the dual alarms, and the average mass mean diameter was 0.08 µm for the ionization and new alarms and 0.09 µm for the dual alarms.

The mass concentrations and number concentrations over time for representative tests of each cooking scenario are shown Figure 4. In general, the mass concentration increased while the heat source was on then decreased in the last two minutes of data collection after the heat source was turned off. The exception was the fried burger (Figure 4a), which had the peak mass concertation around the time the patty was flipped; then the mass concentration decayed for the remainder of the test. While the meats tended to have larger mass concentrations at the

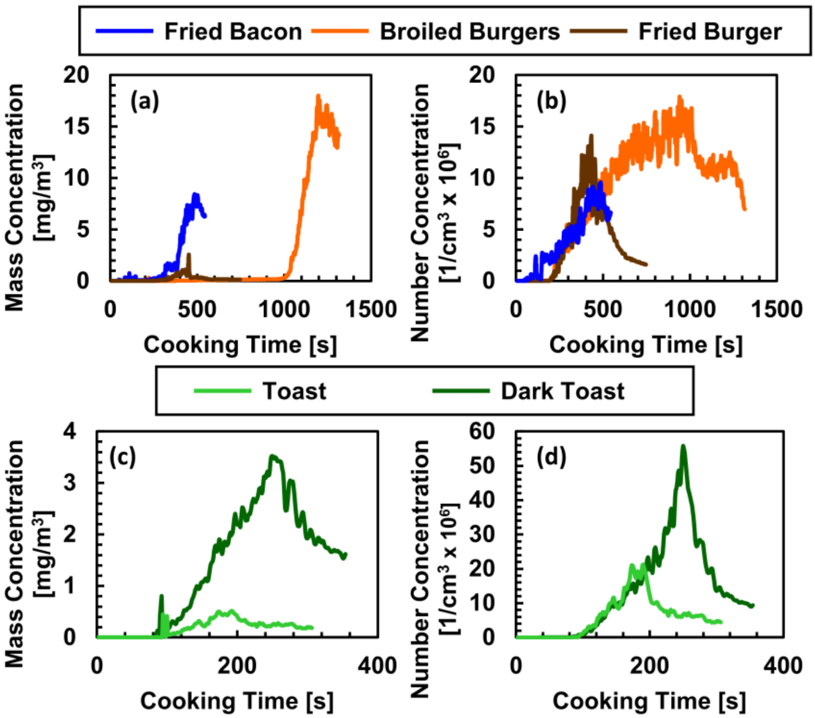

Figure 4. (a) Mass concentrations and (b) number concentrations of the three meats over time and (c) mass concentrations and (d) number concentrations of the toasts over time from single representative tests of each cooking senario.

time of alarm (Figure 2) compared to that of the toasts (Figure 3), the number concentrations of the toasts (Figure 4d) are greater than that of the meats (Figure 4b), a result of the small particle size produced by the toast. Also note that the number concentration of the broiled burgers (Figure 4b) decrease slightly around 1000 s which is the same time that the mass concentration drastically increases (Figure 4a), indicating that fewer but significantly larger particles are being produced.

The distribution of particle sizes clearly varies for each food source and cooking scenario. Figure 5 shows an example case of the cumulative mass fraction in each size bin for each cooking scenario at halfway through cooking and at the time the time the heat source was turned off. Halfway through cooking (Figure 5a) was prior to most alarm activations and the mass of the particles mostly came from those of small diameters (<0.1 μm). The toast, the dark toast, and the fried burger had similar distributions at the end of the test (Figure 5b) compared to at the halfway point through the test (Figure 5a). In contrast, the broiled burgers and bacon distributions have shifted to larger particles by the end of the test compared to the halfway point. At the end of cooking scenarios (Figure

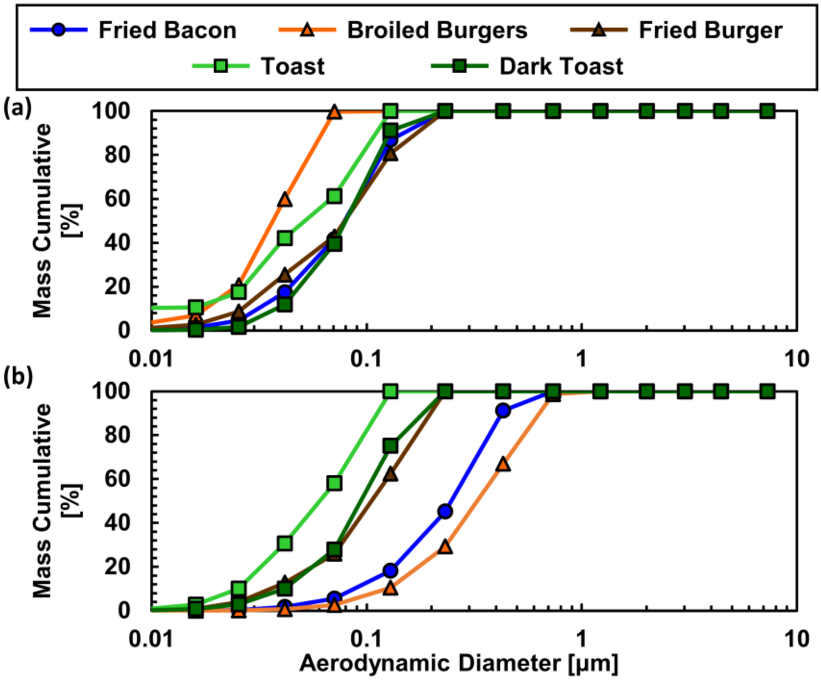

Figure 5. Representative cumulative mass distributions at (a) halfway through cooking and (b) the time the heat sources were turned off for each cooking senario.

5b), the toast has the smallest particles, all of which have aerodynamic diameters less than 0.1 µm; whereas, less than 20 % of the mass of particles from the fried bacon and broiled burgers is composed of particles smaller than 0.1 µm. The dark toast and fried burger have very similar particle sizes at the time of the heating shut off. The broiled burgers have the smallest particles at halfway through the test but have the largest particles at the end of cooking. The burgers do emit some small particles similar in size to the background particles early during the test demonstrated by the increase in the number concentration in (Figure 4b), but the greatest mass of aerosols are emitted after the cooking time is 80% complete as seen in Figure 4a.

Conclusions

A range of cooking scenarios caused various types of smoke detectors to alarm at different mass concentrations with different mass mean diameters. The broiled burger test that is included in the new standard produces particles of the largest size and ends with some of the highest mass concentrations of all five cooking scenarios. While the broiled burgers resulted in some of the largest particles and highest mass concentrations, this source initially produces smaller particles at concentrations sufficient to activate ionization alarms and then later, larger particles at concentrations that activate photoelectric alarms. No single cooking nuisance source fully captures the characteristics of all potential nuisance sources, but the broiled burger source covers a range of particle sizes and concentrations that challenge legacy alarms.

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