

A SCIENTIFIC APPROACH TO CHARACTERIZE SMOKE FROM FLAMING AND SMOLDERING FIRES

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Underwriters Laboratories Inc has developed smoke characterization analytical test protocols to characterize smoke during flaming and smoldering modes of combustion. This report describes the method of analysis, preliminary results covering current standardized fire test materials.

Develop smoke characterization analytical test protocol using flaming and smoldering modes of combustion

In this task test analytical test methodologies were developed to characterize smoke particles for the current materials used in UL 217 standard, as well as additional selected materials commonly found in residential occupancies.

Standard Materials Used in UL 217 -

UL 217 standard specifies three materials as combustion smoke sources to evaluate the performance of smoke detectors. The materials are: (i) shredded newspaper; (ii) wood brand; and (iii) heptane/toluene mixture.

Common Residential Materials -

A wide range of products and associated materials may be found in homes. A list of some typical products found in a home is presented in Table 1.

Table 1 – Products Found in Residences

Residential Space	Typical Products
Bedroom and Living Room	Appliance wiring Bed clothing Candles Carpeting Drapes Mattress Paper products Plastic enclosures for electrical

	products Upholstered furniture Wall paper Wood furniture
Kitchen	Appliance enclosures Appliance wiring Cabinets Cooking materials Counter tops Food containers Foods Wall paper
Storage Areas	Paints Fuels Packaging materials

In this task, approximately 30 materials were initially screened to develop data on materials' combustibility, and smoke particle size distribution. Based upon the results, a subset of approximately 12 materials was selected that provided a broad range of behavior and performance.

Material Screening Tests -

Materials were initially screened using the Cone Calorimeter¹. The Cone Calorimeter is a versatile apparatus used to determine the combustibility properties of materials and products. The apparatus consists of a conical shaped electrical heater capable of heating a test sample with radiant heat flux of up to 100 kW/m², a load cell, a laser smoke obscuration system, and gas analysis equipment. An electric spark igniter is used to ignite the thermal decomposition gases. The heat release rate is measured using the oxygen depletion method.

The Cone Calorimeter provides combustibility properties for ventilated fires similar to fires in their early stages of development. Thus it is well suited for the smoke detector research project.

In addition to standard instrumentation, the Cone Calorimeter was instrumented to capture smoke from burning samples to measure particle size distribution, and gas-phase effluent composition.

The equipment used to measure particle size distribution was a wide range particle size spectrometer, Model WPS 1000XP from MSP Corporation. The instrument uses a combination of electrical mobility (DMA) and light scattering techniques to provide particle size distributions from 30 nm to 10,000 nm. The

¹ ASTM E1354 – Standard Test Method for Heat and Visible Smoke Release rates for Materials and Products Using an Oxygen Consumption Calorimeter, American Society for Materials and Testing, 100 Barr Harbor Drive, West Conshohocken, PA 19428-1959.

instrument requires a flow of 1L/min that is divided between the DMA and light scattering modules to develop the particle size distribution. The sample was extracted from the exhaust of the Cone Calorimeter and metered into the particle size spectrometer.

The gas-phase effluent components will be measured using a Fourier Transform Infrared spectrometer (FT-IR) equipped with a gas-sampling cell. Smoke samples were extracted from the Cone Calorimeter exhaust duct. The instrument has a measurement range from 600 to 4,000 (cm^{-1}) wavenumber, a path length of 10m, and resolution of 0.5 cm^{-1} . The UL FT-IR equipment has gas calibration library to calculate the concentration of the key gas components detected.

The screening tests were conducted at heat flux levels that provide both smoldering and flaming modes of ignition. The results obtained include ignition time, weight loss, heat and smoke release rates, gaseous combustion product, and smoke particle size distributions.

The following data was considered for selecting common residential materials for detailed characterization and testing in the UL Smoke Detector Room Test:

- Melting and charring behavior
- Smoldering and ignition time
- Weight loss rates
- Heat release rates
- Heat of combustion
- Smoke release rates
- Smoke particle size distribution
- Extinction cross-section area

The selected materials represented a broad range of performance based upon the above properties.

Material Characterization Tests -

Material and combustibility profiles of the selected materials were developed to document the traceability of the materials investigated. The material and combustibility profiles include material chemistry, thermal response to heating, and the potential heat value. The test methods characterize the materials include the following:

- Differential Scanning Calorimeter (DSC);
- FT-IR for materials chemistry (plastics only);
- Thermo-gravimetric Analyzer (TGA) with smoke cell and gaseous FT-IR attachments; and
- Oxygen bomb calorimeter.

Replicate tests were conducted as appropriate for the material.

Cone Calorimeter Characterization Tests -

Cone calorimeter tests were conducted in piloted and non-piloted modes to develop data representing open flame ignition and smoldering scenarios respectively.

Common Materials Found in Residential Setting – The test specimens were 100 x 100 mm dimension with sufficient thickness to provide data on its combustibility and smoke particle size. For liquids, a petri dish was used with 50 ml of test liquid.

Test Procedure -

Smoldering tests were performed with radiant heat flux of approximately 15 kW/m² without the electric spark igniter. Flaming tests were performed with radiant heat flux of 35 kW/m², and the electric spark was used to ignite the thermal decomposition gases. Additional heat fluxes were used if necessary to achieve the goal of smoldering and flaming smoke generation. A portion of the exhaust flow was extracted to analyze for soot particle size distribution using the wide range particle size spectrometer.

The results of the test include ignition time, heat and smoke release rates, particle size distribution, weight loss, and gas component analysis. The weight loss data was used to calculate effective heat of combustion, and smoke extinction cross-section area.

A minimum of two tests were performed for each material.

Product Calorimeter Characterization Tests

Tests on finished products and intermediate scale mockups were performed using a product calorimeter. Smoldering mode tests were conducted using a cigarette ignition source, as this is a prevalent in many residential fires². Flaming mode tests were conducted using standard protocol ignition sources (i.e., TB 603 dual burner for mattresses).

- Mattress
- Upholstered furniture
- Synthetic Carpet
- Wool Carpet
- Appliance Housing (e.g., coffee maker)

² Mattress and Bedding Fires in Residential Structures, Vol. 2(17), U.S. Fire Administration, Department of Homeland Security, February 2002.

- Corn oil on electric/gas heater
- Cotton Fabrics
- Textile blends (Polyester and cotton)

In addition, tests were performed on the UL 217 fuel packages using the ignition sources as described in the standard.

Several products/materials that have shown to generate unwanted smoke alarms were selected based upon input of the FPRF Technical Panel. These products were tested using natural scenarios for generating the smoke. Examples of these are (i) bread in a toaster; (ii) cooking grill with accumulated grease.

In these tests, ignition time, heat and smoke release rates, smoke particle size characteristics, and gaseous components were measured. In addition, the tests were digitally recorded.

Develop smoke profiles and particle size distributions in Smoke Detector Test Room

Tests were conducted to determine the smoke obscuration profiles and particle size distributions of selected materials in flaming and smoldering modes in UL's Smoke Detector Test Room. The test room is used to investigate smoke detector performance for obtaining UL certification.

These tests also determine the influence of smoke aging (agglomeration, coagulation) as it travels from the combustion source to the smoke detector locations.

Ceiling Velocity – The velocity of the ceiling flow near the MIC was measured using instrumentation appropriate for the expected low flow rates. FDS simulation of the scenario, with small fires (e.g., 5 kW), show that the velocity approximately 0.1 m (4 inches) below the ceiling is in the range of 0.2 to 0.4 m/s.

Weight Loss – The sample weight loss was recorded during the test using a load cell.

Smoke Particle Size Distribution – The smoke particle size distribution was measured using the WPS 1000XP instrument described in Task 1. Smoke samples were collected from two potential locations using a gas-sampling probe. One location will be 1 meter above the sample, and the other location will be near the MIC detector. The results from the two locations will provide an understanding of smoke aging as it travels from the source to the ceiling.

Gas effluent concentration - Using a gas FT-IR gas effluent components was measured via extraction from the Cone Calorimeter exhaust. The instrument has

a measurement range from 600 to 4,000 (cm^{-1}) wavenumber and path length of 10m. UL also has gas calibration library to provide concentration of the key gas components detected.

Video and Photography – Digital video and still cameras were used to document the fire tests.

Data Acquisition – All data was acquired using automated data acquisition systems and stored in electronic format.

A schematic of the test room with the instrumentation is shown in Figure 1.

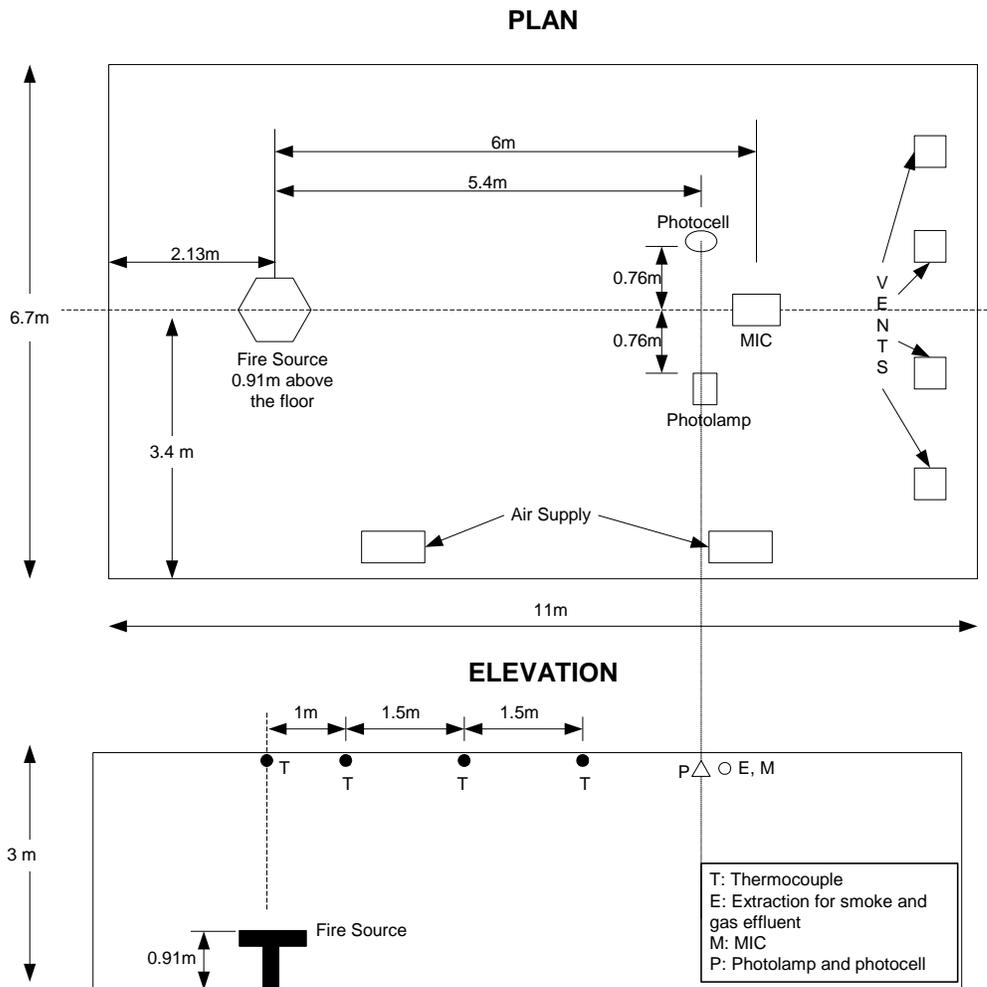


Figure 1 – Smoke Detector Test Room

Test Procedure -

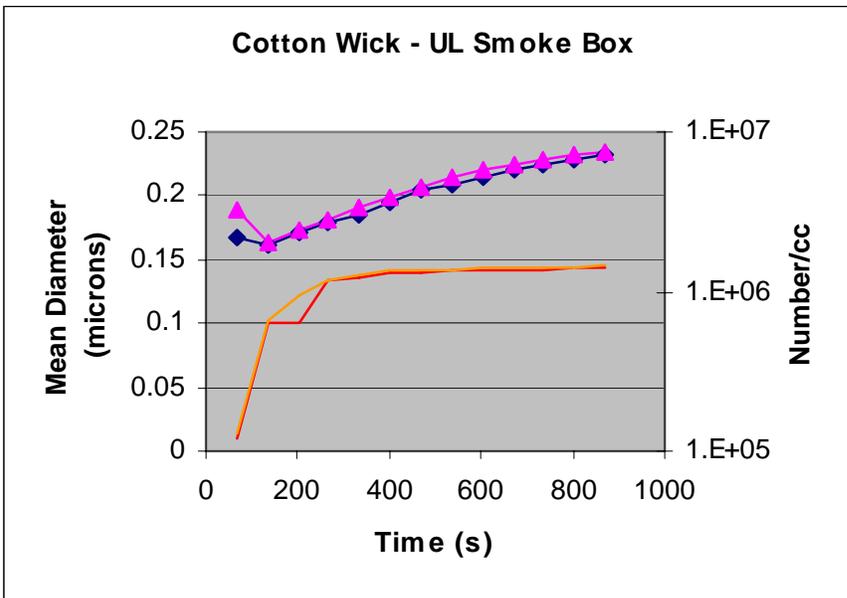
A minimum of two tests was conducted for each test material and combustion mode.

Correlate analytical data and performance in the smoke detector room and identify recommendations

The data is currently being analyzed and correlated from the investigations to identify potential recommendations to the existing test standard (UL 217).

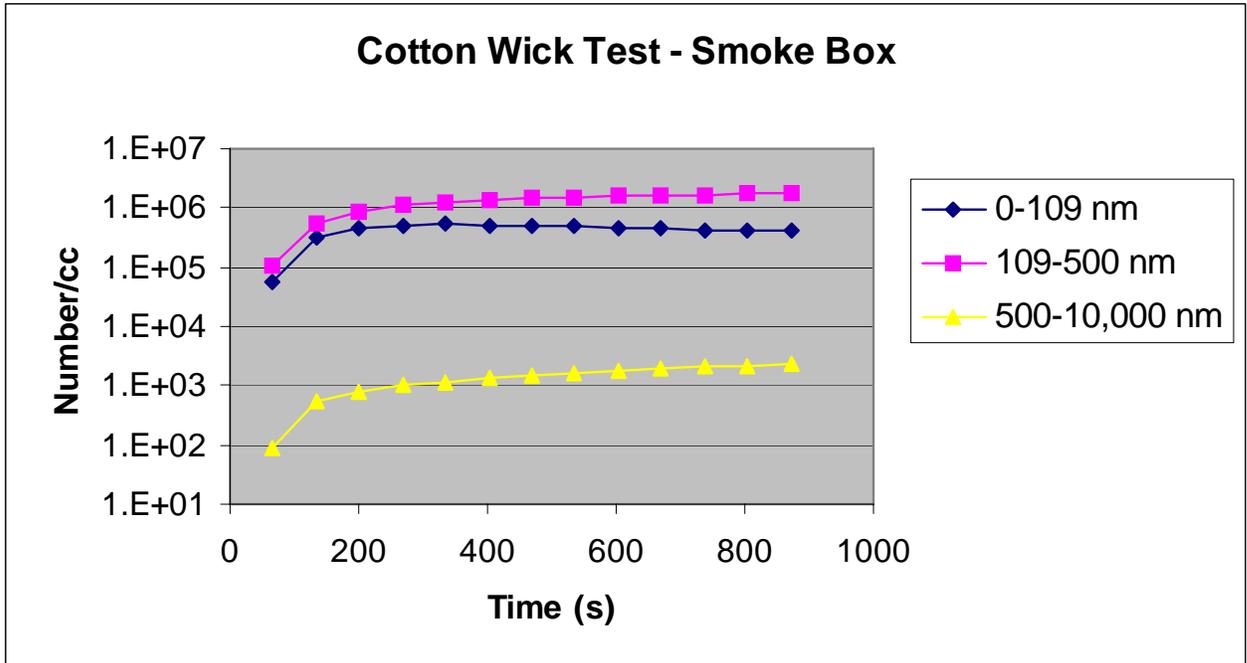
Preliminary Results

Smoke Box Information –



Time (s)	Mean Diameter (microns)
67	0.168
134	0.162
201	0.171
268	0.18
335	0.185
402	0.194
469	0.204
536	0.209
603	0.214
670	0.22
737	0.225
804	0.229
871	0.233

Change in Particle Size -



Develop Final Report

A final technical report will be developed. The report will include an executive summary, detailed description of the test samples, test equipment and the instrumentation used. The report will also include test procedures used and the results obtained. All analysis techniques used for comparative or correlative purposes will be discussed. The report will highlight the findings and provide any recommendations for improving smoke detector performance evaluation. It will also provide data that may be used by the industry for new smoke sensing technology, materials and additives and a variety of end-product applications.