Developing Test Methods for Cooktop Pre-Ignition Detection

Joshua B. Dinaburg, P.E., Dr. Daniel T. Gottuk, Ph.D.

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INTRODUCTION

COOKTOP RANGE PRE-IGNITION DETECTION

- Cooking Fire Problem
- Emerging Technologies and Detection Methods
- Standardized Test Development
- Fire Test Data
- Conclusion & Questions
COOKING FIRE PROBLEM

RANGE TOP FIRES

- 91,000 US home fires annually (2006-2010, [1])
  - 300 deaths
  - 3,700 injuries
- Many more near misses, small fires, and minor injuries go unreported
- Range fire events previously evaluated [2]:
  - Ignited food materials in pans
  - Unattended cooking
  - Spilled food materials on stove
  - Ignition of clothing touched to element or flame
  - Electric and gas ranges

PRE-IGNITION DETECTION

- Potential measurable pre-ignition indicators:
  - Elevated temperature
    - Heating element
    - Pan surface
    - Food materials
    - Surrounding air
  - Smoke production
  - Gas production
- Evaluated in previous report [1]

EXISTING PRODUCTS / DEVICES

- Heating Element Temperature Sensor
- Pan Temperature Sensor
- Plume Air Temperature
- Smoke Detection

- Most available products are for retro-fit to existing cooktops
EXISTING/PROPOSED STANDARDS

JAPAN
- JIS 2103 [1] and JIS 2093 [2]
- Require temperature controllers for gas cooktops
- Limit oil temperature to maximum of 300°C (572°F)

EUROPE
- European Stove Guard Standard EN50615:2015
- Ratified on January 5, 2015
- Allows testing of any smoke detector, fire detector, motion detector, CO detector, or extinguisher with separate categorical distinctions
- Limits oil temperatures to 330°C and devices must not respond prior to 200°C
- Multiple pots/panns and oil volumes tested

US
- UL 858 Standard for Household Electric Ranges
- Proposal in review stage, submitted by AHAM
- Only for electric coil ranges, no retrofit devices, no smoke devices
- 30 minute no ignition criterion proposed

COOKTOP FIRE TESTING

- Realistic cooking fire scenarios
- Representative of the most hazardous or difficult to detect conditions (bounding)
- Repeatable and Reproducible
- Allow for evaluation of a range of prevention options
  - Sensing technologies (temperature, smoke, gas)
  - Control methods (shutdown, power reduction)
  - Retrofit devices, permanent install, limited range/pan applicability
- Device Performance Criteria
  - Ignition prevention, temperature limitations, time restrictions
  - Acceptable activation ranges
    - Minimum to prevent excessive nuisances
    - Maximum to prevent ignition with margin of safety
TEST SETUP

Laser Smoke Measurement

O₂, CO, and CO₂ gas sampling

Temperature

Pan Surface Temps

Oil Temps
IDENTIFY MOST CHALLENGING SCENARIOS

FACTORS EVALUATED

- Oil Type
  - Multiple fresh oils
  - Aged/Used oils
- Oil Depth
- Range Top
  - Electric coil
  - Glass ceramic
- Pan materials
  - Aluminum
  - Stainless steel
  - Cast iron
- Pan Size
IDENTIFY MOST CHALLENGING SCENARIOS

METRICS

Test Metrics

- Pan Temperature
- Oil Temperature
- Smoke Obscuration

Time Before Ignition (sec)

Temperatures °C

Obscuration (%/m)
IDENTIFY MOST CHALLENGING SCENARIOS

METRICS

Test Metrics

- Pan Temperature Reaches 300 °C
- Oil Temperature
- Smoke Obscuration
- Time window until ignition
IDENTIFY MOST CHALLENGING SCENARIOS

METRICS

Test Metrics

- Oil Temperature Reaches 325 °C
- Pan Temperature
- Oil Temperature
- Smoke Obscuration

Time window until ignition

Time Before Ignition (sec)

Temperatures °C

Obscuration (%/m)
IDENTIFY MOST CHALLENGING SCENARIOS

METRICS

Test Metrics

- Oil Temperature Reaches 325 °C
- ΔT Between pan and oil temp
- Pan Temperature
- Oil Temperature
- Smoke Obscuration
- Time window until ignition
IDENTIFY MOST CHALLENGING SCENARIOS

METRICS

Test Metrics

ΔT Between pan and oil temp

Oil Temperature Reaches 325 °C

Pan Temperature

Oil Temperature

Integrated area below smoke curve

Time window until ignition

Smoke Obscuration

Obscuration (%/m)

-700 -600 -500 -400 -300 -200 -100 0

Time Before Ignition (sec)

Temperatures °C

-700 -600 -500 -400 -300 -200 -100 0

Time Before Ignition (sec)

Temperatures °C
IDENTIFY MOST CHALLENGING SCENARIOS

METRICS

Test Metrics

- Pan Temperature
- Oil Temperature
- Smoke Obscuration

Smoke Obscuration Reaches 5%/m
Time window until ignition

- Time Before Ignition (sec)
- Temperatures °C
- Obscuration (%/m)
METRICS FOR PRE-IGNITION DETECTION

- Effluent temperatures and gas concentrations showed little response prior to ignition
  - CO buildup was highly variable
    - (0-50 ppm) measured prior to ignition
    - Not consistent test to test and not measureable in all tests
  - Temperature, O\textsubscript{2}, CO, and CO\textsubscript{2} respond drastically after ignition occurred
  - Neglected from further analysis in this report
IMPACT OF VARIABLES ON DETECTION

- The oil type did not impact ignition temperatures
  - Heat-up rates affected
  - Does affect smoke temperature – lower FFA values (canola, fresh) smoke at higher temperatures and present greater challenge to prevention

- The pan material impacts heating rates/ignition times
  - Mass, heat capacity, conductivity, absorptivity
  - Contact surface area and uniformity

- The range type affects heating rate/ignition time
  - More power heats faster, shorter time windows for pan/smoke operation
  - Smooth top range with temperature sensor can delay with some pans, even with greater power output

- The pan size affects heating rate/ignition time
  - Thicker pan heats slower and delays ignition
  - Larger pan heats much slower and delays ignition, creates less uniformity in temperature across surface

- The oil depth affects heating rate/ignition time
  - Deeper oil heats slower/ignites later
  - Consistent oil temperatures at varying depths (1/8, 1/4, 3/8 inch depths)
CORRELATION OF INPUT VARIABLES

TOTAL HEATING TIME TO IGNITION CORRELATED TO VARIABLES

- Burner power
- Pan size and shape
- Pan mass and thermal properties
- Oil depth and total volume
“CHALLENGING" SCENARIOS CORRELATED WITH THE TOTAL HEATING TIME TO IGNITION

- Available time window between pan temperature or smoke measurement and ignition

- Pan temperature and oil temperature at ignition decreased with increasing heating time

Correlation = 1.00
Slope = 0.76 sec/sec
SELELCING CHALLENGING SCENARIOS

DETECTION CHALLENGE  →  TOTAL HEATING TIME TO IGNITION

- Specific variables are not important
  - Pan type, range type, oil volume, etc.
  - The oil type/age/usage does impact challenge for smoke detection

- Faster ignition
  - Shorter available time for devices to act
  - Less margin for safety
  - Same affect for smoke or temperature based devices

- Slower ignition
  - Lower pan and oil temperatures measured at ignition
  - Increased challenge to fixed temperature measuring devices
  - Reduced safety margin between response and ignition

Fastest test to ignition may not be most challenging to detect prior to ignition occurring, dependent on detection technology.
PERFORMANCE CRITERIA

ASSESS PERFORMANCE BY OIL TEMPERATURE, INDEPENDENT OF DETECTION METHOD

- Maximum Temperature Allowance
  - Oil temperature cannot exceed threshold with the device enabled
  - 350°C should prevent any ignitions as shown by testing, additional margin for safety could be considered

<table>
<thead>
<tr>
<th>Location</th>
<th>Temperature at Ignition</th>
<th>Minimum Remaining Time To Ignition</th>
<th>Pan Temperature Range</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Min [°C (°F)]</td>
<td>Max [°C (°F)]</td>
</tr>
<tr>
<td></td>
<td></td>
<td>[sec]</td>
<td>Min [°C (°F)]</td>
</tr>
<tr>
<td>Pan</td>
<td>385 (725)</td>
<td>130</td>
<td>263 (505)</td>
</tr>
<tr>
<td>Oil</td>
<td>374 (705)</td>
<td>85</td>
<td>316 (601)</td>
</tr>
<tr>
<td></td>
<td>300 °C (572 °F)</td>
<td>60</td>
<td>342 (648)</td>
</tr>
<tr>
<td></td>
<td>325 °C (617 °F)</td>
<td>29</td>
<td>365 (689)</td>
</tr>
<tr>
<td></td>
<td>350 °C (662 °F)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Representative Existing Temperature Criteria for Prevention Devices

- Japanese Standard JIS 2103, 2093 – Oil temp limit of 300°C (572°F)
- European Standard EN50615:2015 – Oil temp limit of 330°C (626°F)
- UL 858 Proposal – No ignition occurs within 30 minutes of heating
TESTS SEPARATED BY HEATING TIME TO IGNITION

○ FASTEST (Less than 8 minutes of heating)
  • 8 in aluminum pans on 2600 W coil with ¼ in of canola and peanut oil
  • Stainless steel on coil and smooth top range
  • Cast iron pan on smooth top range

○ SLOW (15-20 minutes of heating)
  • Aluminum pan on smooth top range
  • Aluminum pan on coil with ½ in of oil

○ SLOWEST (20 min to 1 hour of heating)
  • 14 inch aluminum pan on 8 inch coil burner
  • Very inconsistent tests, 1 did not reach ignition after 1 hour
RECOMMENDED TESTING

TESTS SEPARATED BY HEATING TIME TO IGNITION

**Total Heating Times - Pan Temperatures**

<table>
<thead>
<tr>
<th>Ignition Time</th>
<th>Pan Temperatures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longer Than 20 minutes</td>
<td>2078 sec (1199-3488)</td>
</tr>
<tr>
<td>15-20 minutes</td>
<td>1045 sec (974-1137)</td>
</tr>
<tr>
<td>Less Than 8 minutes</td>
<td>421 sec (371-475)</td>
</tr>
<tr>
<td>Avg. Ignition Time</td>
<td>1426 sec (579-2812)</td>
</tr>
<tr>
<td>Avg. Time Smoke (5%/m) to Ign.</td>
<td>520 sec (410-659)</td>
</tr>
<tr>
<td>300°C to Ign.</td>
<td>114 sec (88-133)</td>
</tr>
<tr>
<td></td>
<td>148 sec (120-180)</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Average Pan Temp (°C)</th>
<th>Ign &gt; 20 min</th>
<th>15 min &lt; Ign &lt; 20 min</th>
<th>Ign &lt; 8 min</th>
</tr>
</thead>
</table>

**Graph**

- X-axis: Time Before Ignition (sec)
- Y-axis: Pan Temperature (°C)
- Legend: Ign > 20 min, 15 min < Ign < 20 min, Ign < 8 min

**Legend**

- Red: Ign > 20 min
- Blue: 15 min < Ign < 20 min
- Green: Ign < 8 min
MINIMUM TEMPERATURE ALLOWANCE

- Prevent devices that are too sensitive and may nuisance alarm or prevent normal cooking
  - Pan bottom temperatures of 246–289°C (475–550°F)
  - Food temperatures from 232–260°C (450–500°F)
- EN50615:2015 uses a minimum criteria of 200°C

- Normal cooking should stay below smoke point of oil
  - 130°C for used fast food oil
  - Minimum 240°C for used lard
  - Maximum 310°C for canola oil
  - Some high temp cooking may smoke in used or high FFA oil

NUISANCE REJECTION

OIL TYPE/USAGE AND SMOKE PRODUCTION

[Diagram showing the relationship between food temperature, time before ignition, and smoke production, with different lines representing various oil types and usage stages.]
Temperatures do not change between fresh and heavily used oil.

Type/age/previous usage affects potential for nuisance smoke production:
- Similar effects as shown for oil with high (lard) and low (canola) FFA
- Less drastic impact than used oils

Food cooked in oil and/or presence of particulate in oil may further increase nuisance smoke production.
Most challenging test depends on detection technology
  • Detection challenge well correlated with time to ignition
  • Both fast and slow tests are potentially challenging

Most test variables do not require detailed specification
  – Pan type, range type, and oil amount: affect heating rates only
  – Any combination acceptable if fast or slow ignition
  – Flexibility to gas ranges, induction range, glass top and coils

Detection with smoke or other effluent requires further development
  • Test space size and ventilation should be tested and validated
  • Most challenging scenario should be evaluated (i.e. large kitchen, operating exhaust fan)
QUESTIONS?

Contact
Joshua B. Dinaburg
+1 410-737-8677
jdinaburg@jensenhughes.com

For More Information Visit
www.jensenhughes.com

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