MICROSCALE METHOD TO DETERMINE EQUIVALENT FLAMMABILITY (SIMILARITY) OF COMBUSTIBLE COMPONENTS

Richard E. Lyon, Natallia Safronava, Richard N. Walters, Haiqing Guo*
Aviation Research Division
Federal Aviation Administration
W.J. Hughes Technical Center
Atlantic City International Airport, New Jersey 08405
*C-Far, Marmora, NJ
Overview of Talk

- Microscale (10^{-6} kg) fire growth capacity (FGC) combines flame spread & burning rate to better compare materials.

- Increased accuracy, repeatability and reproducibility of FGC by accounting for baseline drift in MCC (ASTM Ballot Item).

- Method of calculating FGC from MCC data.

  \[
  FGC = \left( \frac{Q_{\infty}}{T_{\text{burn}} - T_{\text{ign}}} \right) \left( \frac{T_{\text{burn}} - T_0}{T_{\text{ign}} - T_0} \right)
  \]

- FGC of 30 polymers and flammability correlations.

- Repeatability of FGC.
14 CFR 25 (FAA) Fire Tests

FAA Rate of Heat Release Apparatus (Aircraft materials)

Radiant Panel
- Flooring
- Insulation
- Aircraft materials

Vertical Bunsen Burner
- UL
- FAA
- ASTM
Burning Model of Solids

- $T_{\text{burn}}$ and $T_{\text{ign}}$ bound pyrolysis zone in fire
- $T_b$ and $T_p$ bound pyrolysis interval in MCC

![Diagram of burning model of solids]

- $T_{\text{burn}}$: Burning temperature
- $T_{\text{ign}}$: Ignition temperature
- $T_b$: Boundary temperature in MCC
- $T_p$: Pyrolysis temperature

- $q''_{\text{ext}} + q''_{\text{flame}}$: External heat flux
- $q''_{\text{rad}}$: Radiant heat flux

- $v = \dot{m''}/\rho(1-\mu)$: Recession velocity

- $T_\infty$: Ambient temperature

- $T(x)$: Temperature profile

- $\Delta T_{\text{pyr}}$: Temperate interval

- $\alpha$: Reaction rate
Fire Temperatures in Cone Calorimeter and MCC
*(Hypothetical)*

![Diagram showing surface temperature and specific reaction rate with time.](Image)
Ignition Temperatures: MCC ≈ Cone

Fire Temperatures in Cone Calorimeter and MCC (Measured)
Fire Temperatures in Cone Calorimeter and MCC (Measured)
Fire Growth at Bench-Scale is 2-D

**RADIANT PANEL/HBB**

*Horizontal spread*

$q_{ext}$

$v_p$ → $\ell$

$b$

**VBB**

*Vertical Upward Spread*

$v_p$

$l$

Small Pilot Flame

**OSU, VFP**

$q_{ext}$

$v_p$

$l$

 Flame Spread Velocity, $v_y$

\[
\frac{\text{Heated Length}}{\text{Time to Ignition}} = \frac{l}{t_{ign}} \propto \frac{\dot{q}''}{\Delta T_{ign}}
\]

Burning Velocity, $v_x$

\[
v_x \propto \frac{\dot{q}''}{\Delta T_{burn}}
\]
Fire Growth Capacity (FGC)

\[ \text{FGC} = Q_\infty \left( \frac{1}{T_b - T_p} + \frac{1}{T_p - T_0} \right) \]

\[ = \left( \frac{Q_\infty}{\Delta T_{\text{burn}}} \right) \left( \frac{H_g / c_p}{\Delta T_{\text{ign}}} \right) \]

<table>
<thead>
<tr>
<th>Symbol</th>
<th>TA Property</th>
<th>Fire Parameter</th>
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<tbody>
<tr>
<td>(Q_\infty)</td>
<td>Heat of Complete Combustion</td>
<td>Effective Heat of Combustion</td>
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<tr>
<td>(T_p)</td>
<td>Incipient Pyrolysis Temperature</td>
<td>Ignition Temperature</td>
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<td>(T_b)</td>
<td>Final Pyrolysis Temperature</td>
<td>Burning Temperature</td>
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<td>(T_0)</td>
<td>Ambient Temperature</td>
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<td>(c_p)</td>
<td>Heat Capacity of Solid</td>
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<td>(H_g)</td>
<td>Heat of Gasification of Solid</td>
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Accurate FGC by Correcting for Baseline Drift in the MCC

Thermal expansion of the purge gas in the pyrolyzer during the test has the effect of:

- Increasing the terminal flow rate (Methods A and B).
- Diluting O\textsubscript{2} at the sensor (Method A).

This change in the \textit{zero-point} value of the specific heat release rate, \( Q'_0 \), is described by the ideal gas law, with \( T \) the sample/pyrolyzer temperature at \( Q'(t) \)

\[
\text{MCC Baseline} = Q'_0 = \frac{C_1}{T} - C_2
\]
At High Sensitivity Baseline Drift is Mainly Due To O₂ Sensor Fluctuations

Specific Heat Release Rate, $Q'$ (W/g)

Sample Temperature, $T$ (°C)

Test 1

$Q'_1, T_1$

$T_2 - T_1 = 750°$ C

Test 2

$Q'_2, T_2$

$T_2 - T_1 = 900°$ C

Aircraft Phenolic Resin
Correcting MCC Data for Baseline Drift

The specific heat release rate at sample temperature $T$ is:

$$Q'(T) = Q'(t) - Q'_0 = Q'(t) - \frac{C_1}{T} + C_2$$

Compute Baseline Coefficients, $C_1$, $C_2$ from 2 data points, $(Q'_1, T_1)$ and $(Q'_2, T_2)$

$$C_1 = \frac{Q'_1 - Q'_2}{(T_2 - T_1) / T_1 T_2}$$

$$C_2 = \frac{Q'_1 - Q'_2}{(T_2 - T_1) / T_2} - Q'_1$$
Baseline Correction to D7309-19 is Balloted Item in ASTM D20.30 Subcommittee on Thermal Properties of Plastics
Ignition and Burning Temperatures

(From MCC Integral)

$\Delta T \approx 120^\circ$ C

Ignites at $T_p$

Burns at $T_b$

$Q_\infty, T_p$ and $T_b$ are TA properties in Fire Growth Capacity/FGC.
MCC Integral Method for FGC

Specific Heat Release Rate, $Q$ (W/g)

MCC Sample Temperature, $T$ (°C)

$\Delta T_{\text{ign}}$ $\Delta T_{\text{burn}}$ $0.95Q_{\infty}$ $0.05Q_{\infty}$ $Q_{\infty}$
FGC Discriminates Levels of Fire Performance

**UL 94V**

Expected Classification

- V-0
- V-2/HB/NR

Fire Growth Capacity, FGC (J/g-K)

**14 CFR 25**

Expected Result

- PASS
- FAIL

Peak Heat Release Rate

Fire Growth Capacity, FGC (J/g-K)
FGC is Independent of Choice of Baseline

\[ \Delta T = T_2 - T_1 \]

Aircraft Phenolic Resin

Heat of Combustion, \( Q_\infty \) (kJ/g)

\[ Q_\infty = 6.7 \pm 0.4 \text{ kJ/g} \ (n = 5) \]

\( T_2 = 1000^\circ C \)

Temperature Range of Baseline Fit, \( T_2 - T_1 \) (°C)
FGC is Independent of D7309 Version (2013/2019) And Baseline Method (Linear/$T^{-1}$)

**Aircraft Phenolic Resin**
Conclusions

Ignition temperature ($T_{ign}$) and burning temperature ($T_{burn}$) of components identified in MCC.

MCC data corrected for baseline drift to obtain accurate $T_{ign}$, $T_{burn}$ and total heat $Q_\infty$ of combustion for similarity determination.

Fire growth capacity (FGC) combines flame spread and burning rate in a single parameter and is useful for comparing flammability of polymers at micro ($10^{-6}$ kg) scale.

Microscale (FGC) criteria for equivalent bench (kg) scale flammability of certified and substitute components has been demonstrated (Safronava).