International Aircraft Materials Fire Test Forum
Virtual Meeting, June 8-11, 2020

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.*

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

- *FGC of 30 polymers and flammability correlations*.
- Repeatability of *FGC*.

14 CFR 25 (FAA) Fire Tests

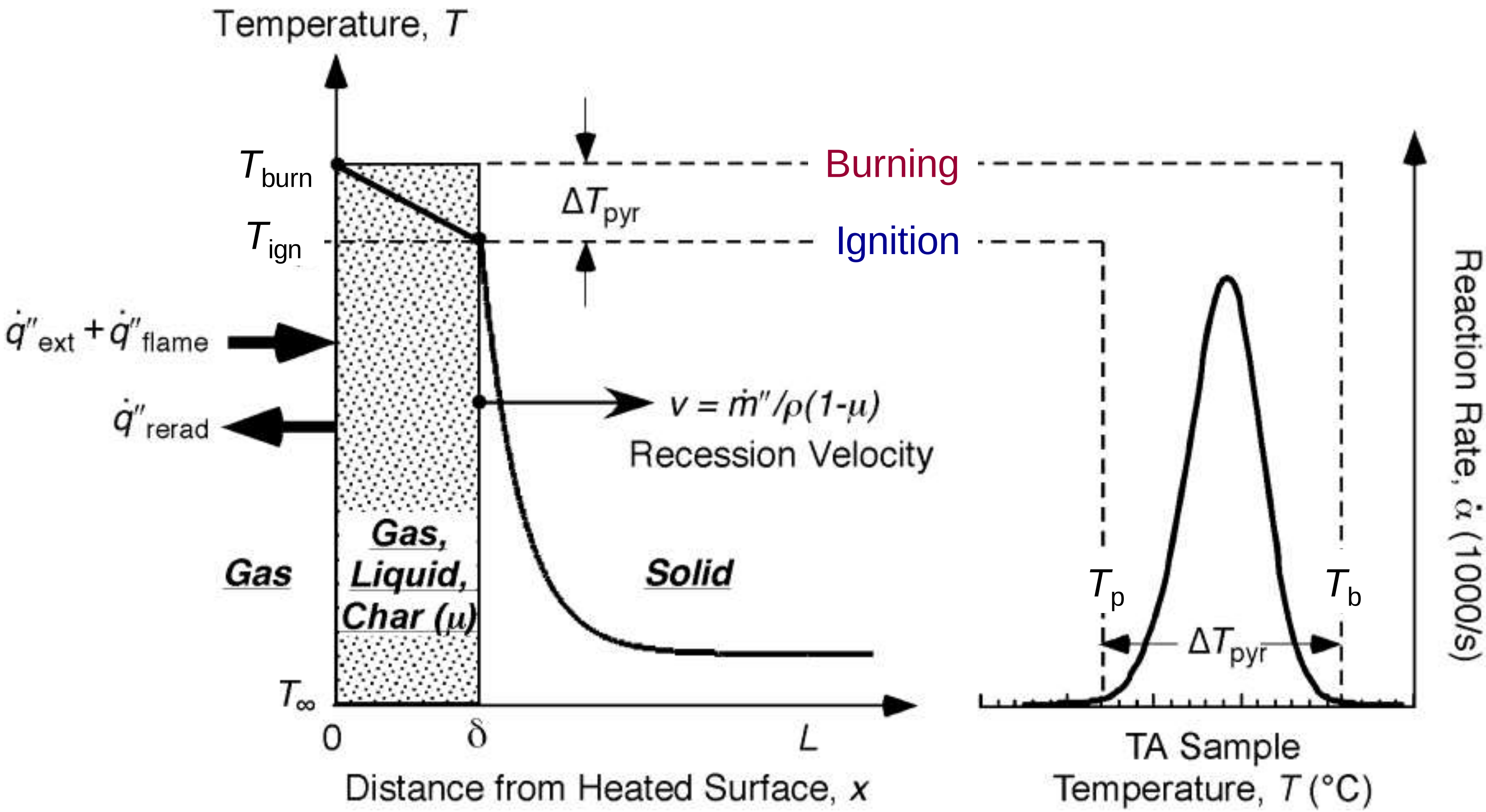
FAA Rate of Heat
Release Apparatus
(Aircraft materials)

Radiant Panel
- Flooring
- Insulation
- Aircraft materials

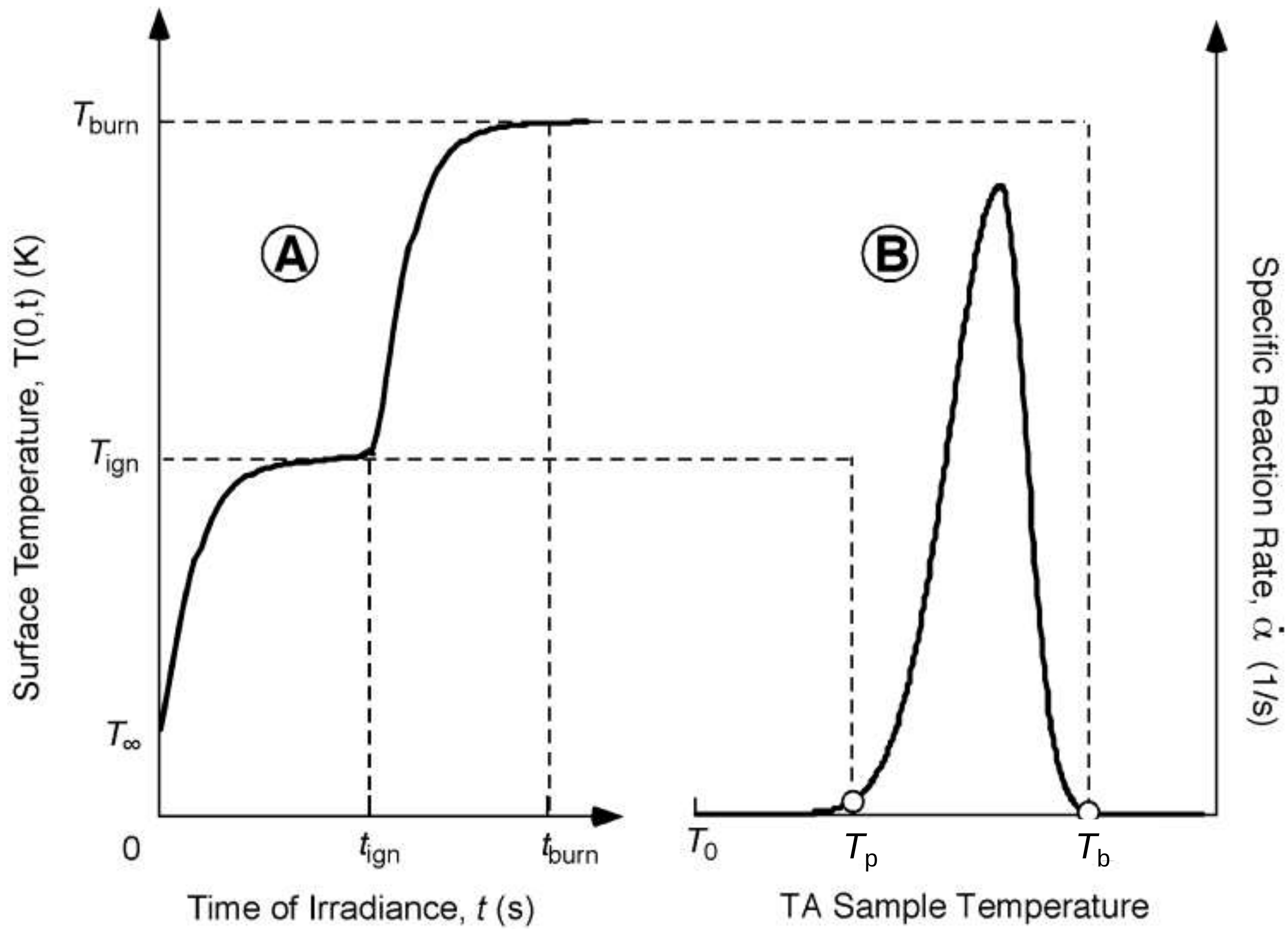
Vertical Bunsen Burner
- UL
- FAA
- ASTM

Burning Model of Solids

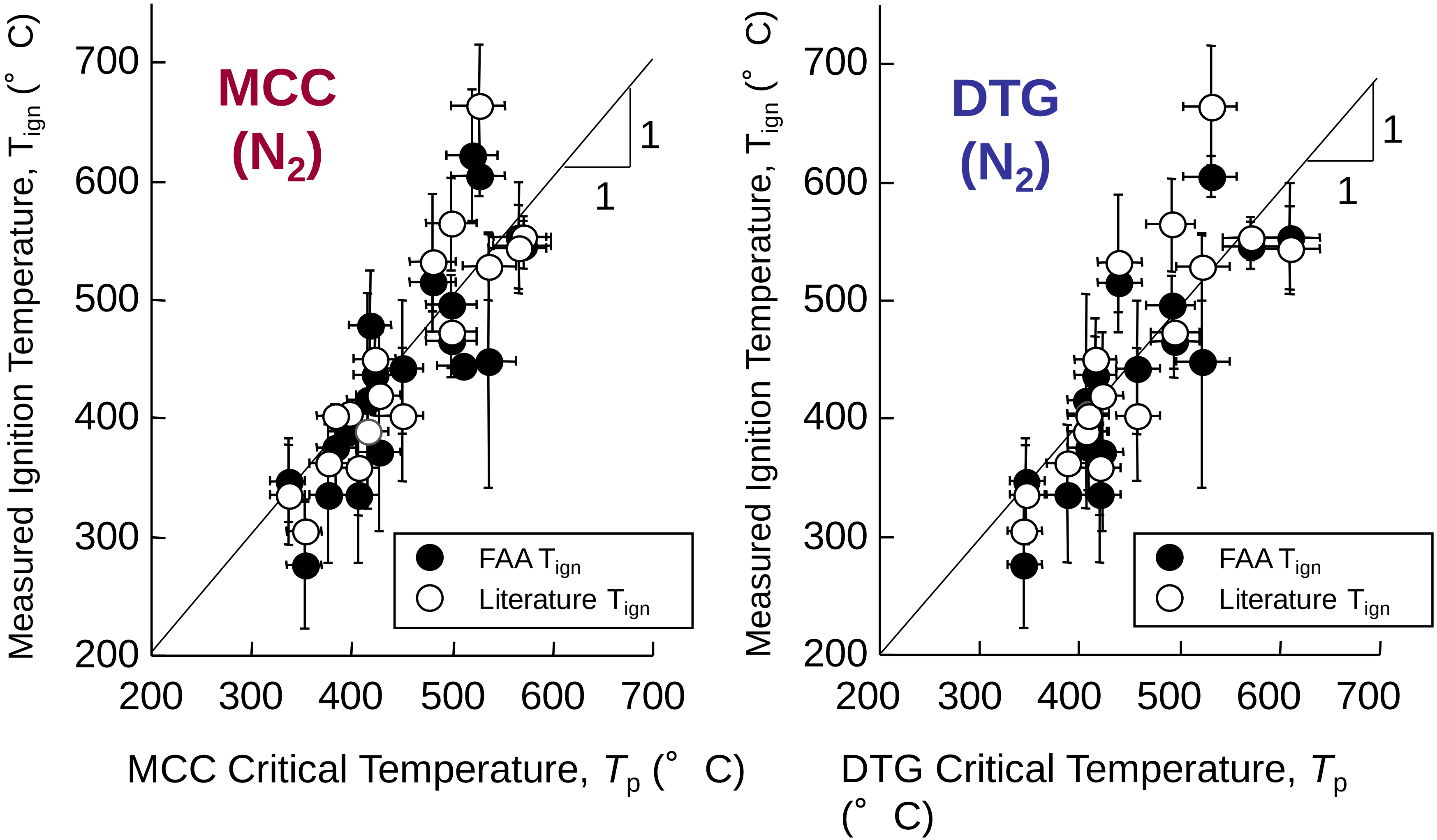
- *T_{burn} and T_{ign} bound pyrolysis zone in fire*
- *T_b and T_p bound pyrolysis interval in MCC*



Fire Temperatures in Cone Calorimeter and MCC
(Hypothetical)

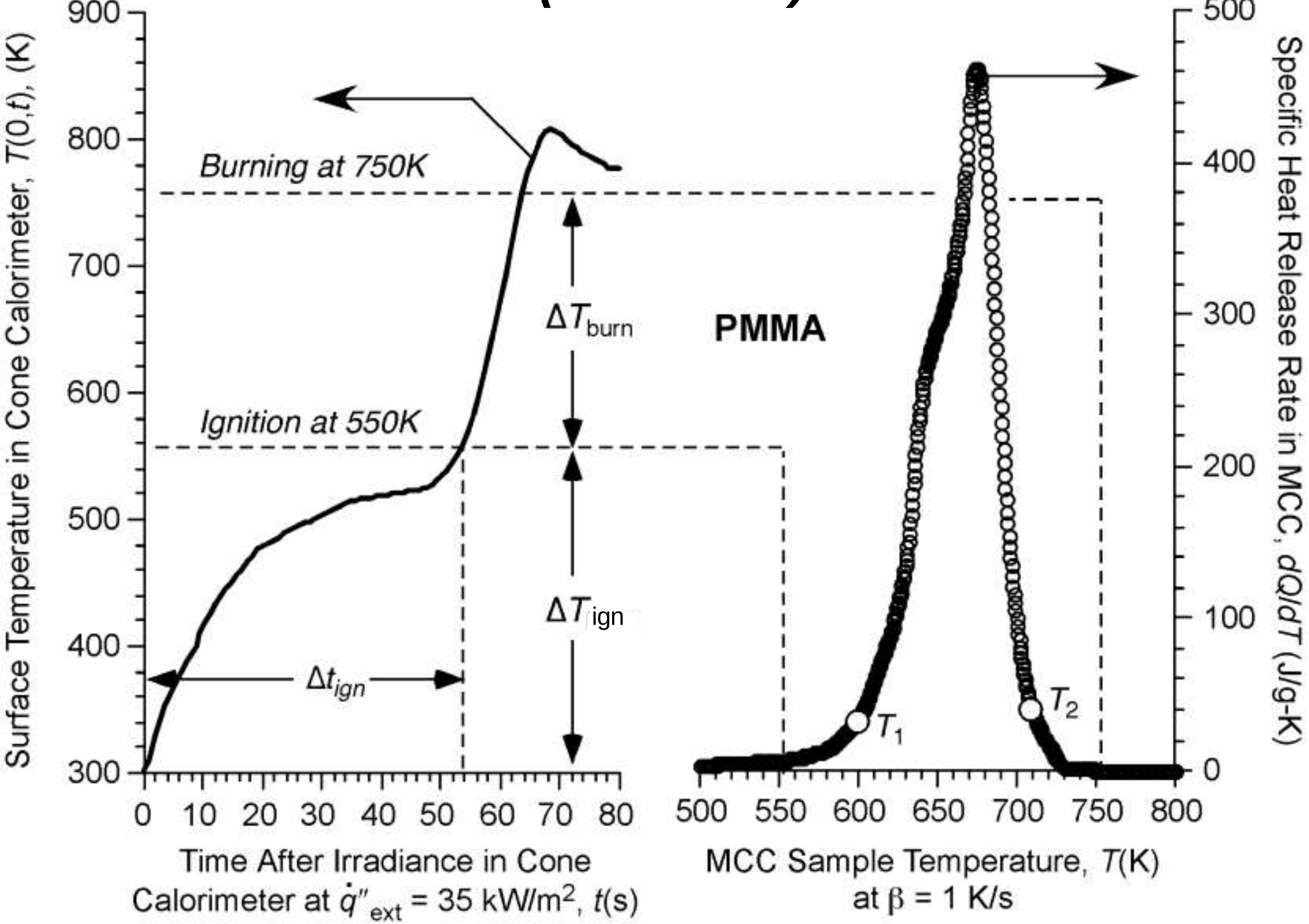


Ignition Temperatures: MCC ≈ Cone

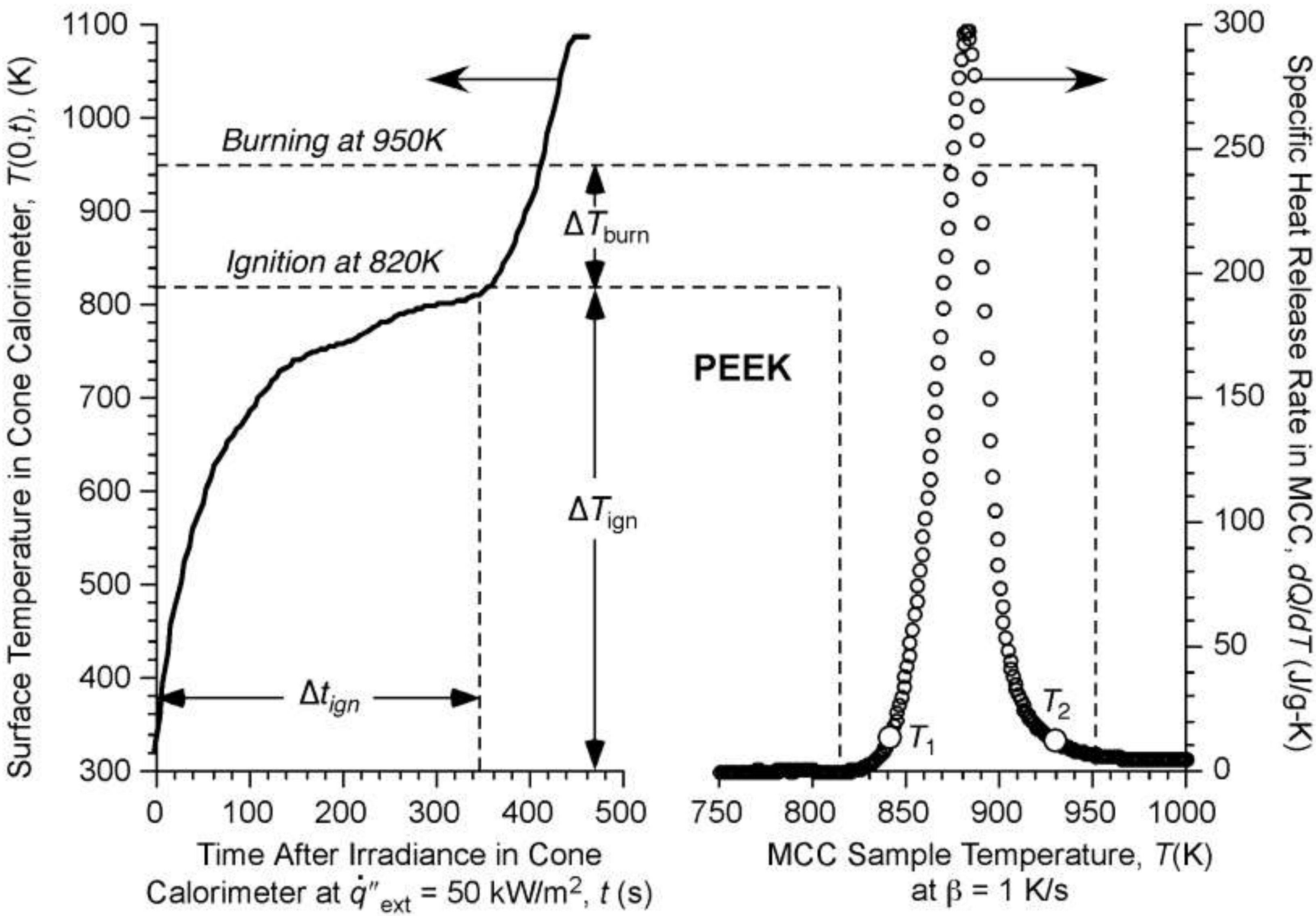


R.E. Lyon, N. Safronava, S. Crowley, Thermal Analysis of Polymer Ignition, *Fire and Materials*, 42, 668-679 (2018)

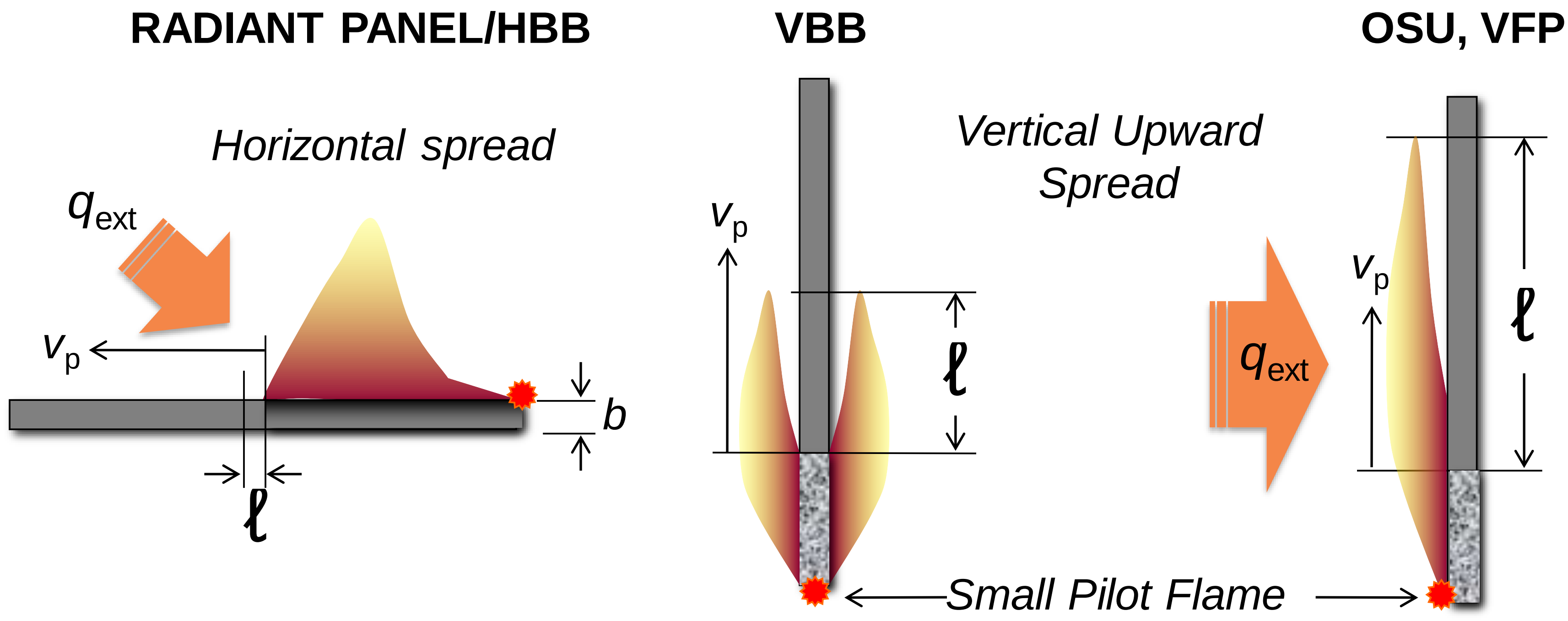
Fire Temperatures in Cone Calorimeter and MCC
(Measured)



Fire Temperatures in Cone Calorimeter and MCC
(Measured)



Fire Growth at Bench-Scale is 2-D



$$\textbf{Flame Spread Velocity, } v_y = \frac{\text{Heated Length}}{\text{Time to Ignition}} = \frac{\ell}{t_{ign}} \propto \frac{\dot{q}''}{\Delta T_{ign}}$$

$$\textbf{Burning Velocity, } v_x \propto \frac{\dot{q}''}{\Delta T_{burn}}$$

Fire Growth Capacity (FGC)

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

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

(**Burning Rate**)(**Flame Spread Rate**)

Symbol	TA Property	Fire Parameter
Q_∞	Heat of Complete Combustion	Effective Heat of Combustion
T_p	Incipient Pyrolysis Temperature	Ignition Temperature
T_b	Final Pyrolysis Temperature	Burning Temperature
T_0	Ambient Temperature	
c_p	Heat Capacity of Solid	
H_g	Heat of Gasification of Solid	

Accurate FGC by Correcting for Baseline Drift in the MCC

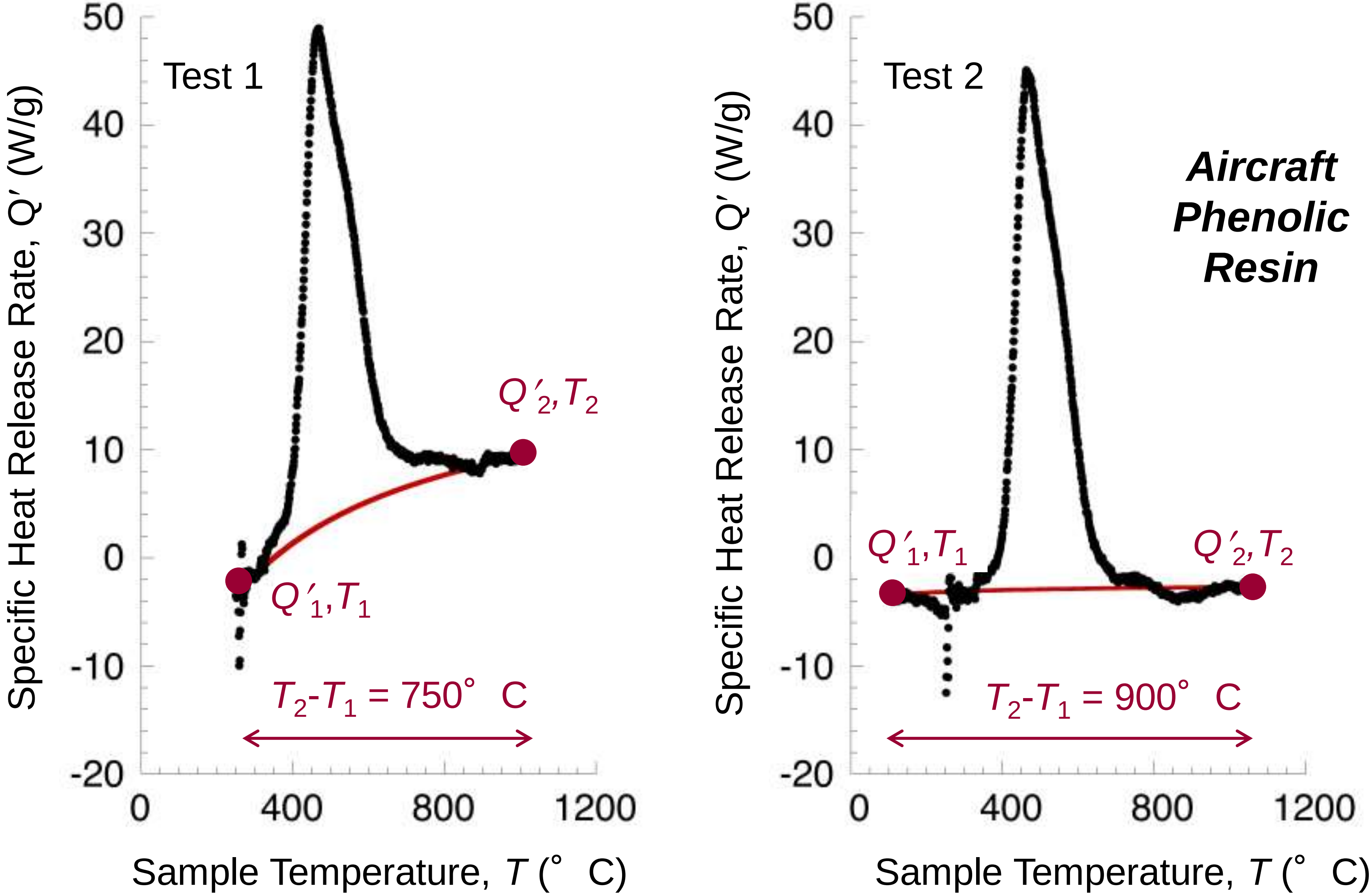
Thermal expansion of the purge gas in the pyrolyzer during the test has the effect of:

- Increasing the terminal flow rate (Methods A and B).
- Diluting O_2 at the sensor (Method A).

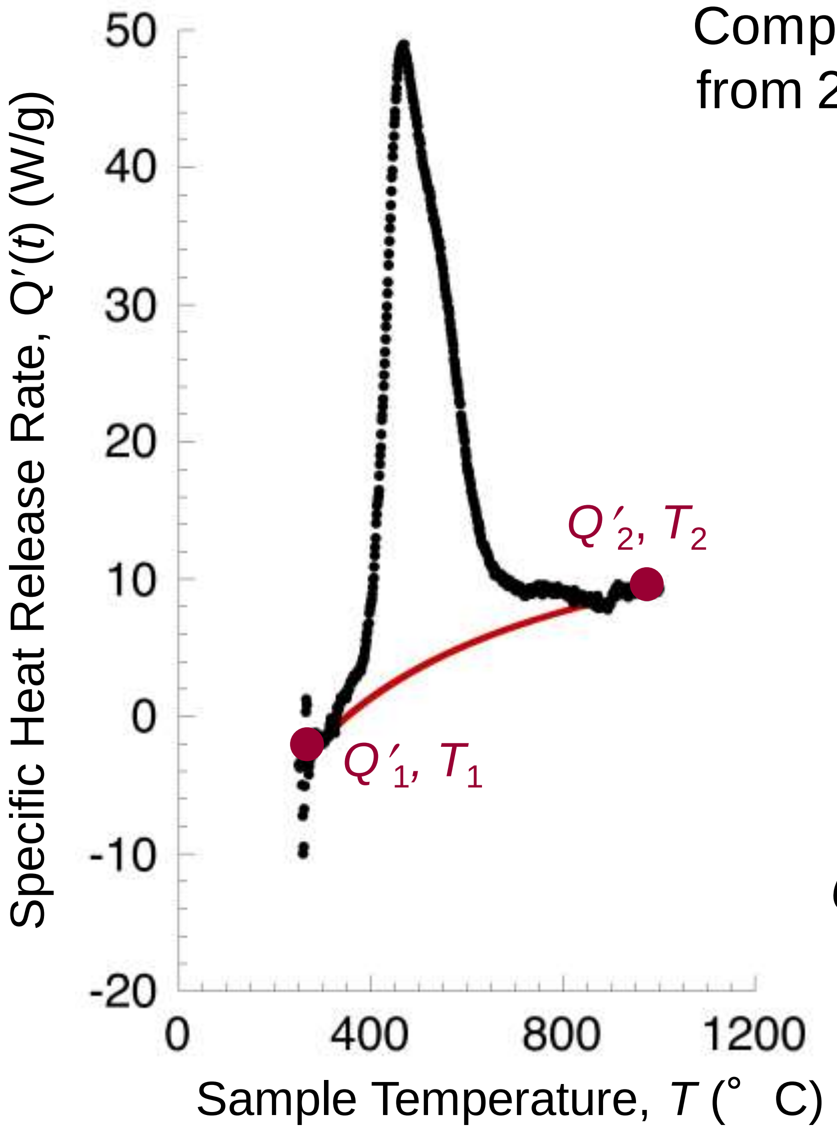
This change in the *zero-point* value of the specific heat release rate, Q'_0 is described by the ideal gas law, with T the sample/pyrolyzer temperature at $Q'(t)$

MCC Baseline = $Q'_0 = \frac{C_1}{T} - C_2$

At High Sensitivity Baseline Drift is Mainly Due To O_2 Sensor Fluctuations



Correcting MCC Data for Baseline Drift



Compute Baseline Coefficients, C_1, C_2 from 2 data points, (Q_1',T_1) and Q_2',T_2)

$$C_1 = \frac{Q_1' - Q_2'}{(T_2 - T_1) / T_1 T_2}$$

$$C_2 = \frac{Q_1' - Q_2'}{(T_2 - T_1) / T_2} - Q_1'$$

The specific heat release rate at sample temperature T is:

$$Q'(T) = Q'(t) - Q_0' = Q'(t) - \frac{C_1}{T} + C_2$$

Baseline Correction to D7309-19 is Balloted Item in ASTM D20.30 Subcommittee on Thermal Properties of Plastics

12. Calculation or Interpretation of Results

12.1 Calculate the specific heat release rate, $Q(t)$ (W/g) at time t during the heating program as per (15):

$$[illegible] \quad (1)$$

If H_2O and CO_2 are both removed from the combustion stream prior to measuring F and X_{O_2}, see Annex A2.

12.2 For Method A only:

12.2.1 The zero-point value (baseline) of $Q(t)$ changes during the normal operation of the instrument due to systematic thermal expansion of N_2 into the combustor during nonlinear heating, and random O_2 sensor fluctuations. Systematic curvature of the $Q(t)$ baseline shall be corrected by selecting a value Q_1 at sample temperature T_1 immediately preceding combustion, and a value Q_2 at sample temperature T_2 immediately following combustion. The baseline will pass through the

points (Q_1,T_1) and (Q_2,T_2) in the $Q(t)$ history. Two baseline coefficients are calculated from these points at T(K),

$$C_1 = (Q_1-Q_2)(T_2-T_1)/T_1T_2$$

$$C_2 = (Q_1-Q_2)(T_1)/(T_2-T_1) - Q_1$$

The coefficients C_1 and C_2 are then used to calculate the baseline-corrected specific heat release rate $Q(T)$ at sample temperature T from the specific heat release rate at time t,

$$Q(T) = Q(t) + C_1/T + C_2$$

Figure 3 illustrates the baseline correction process and result for a 6mg sample of phenolic resin.

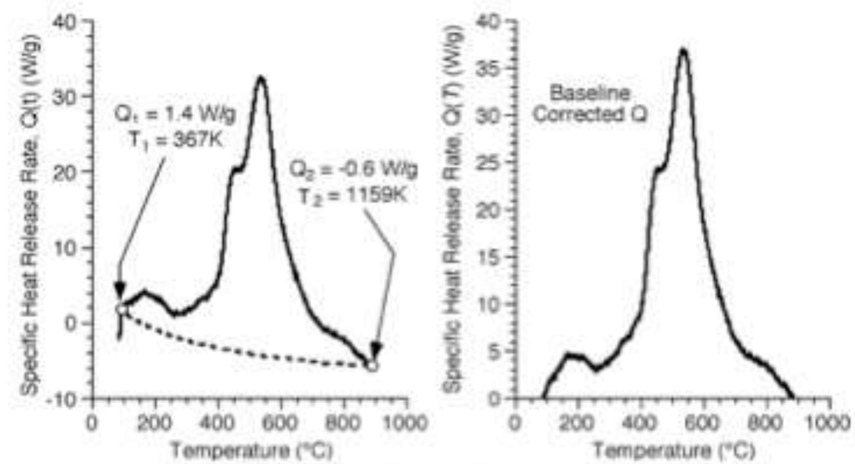
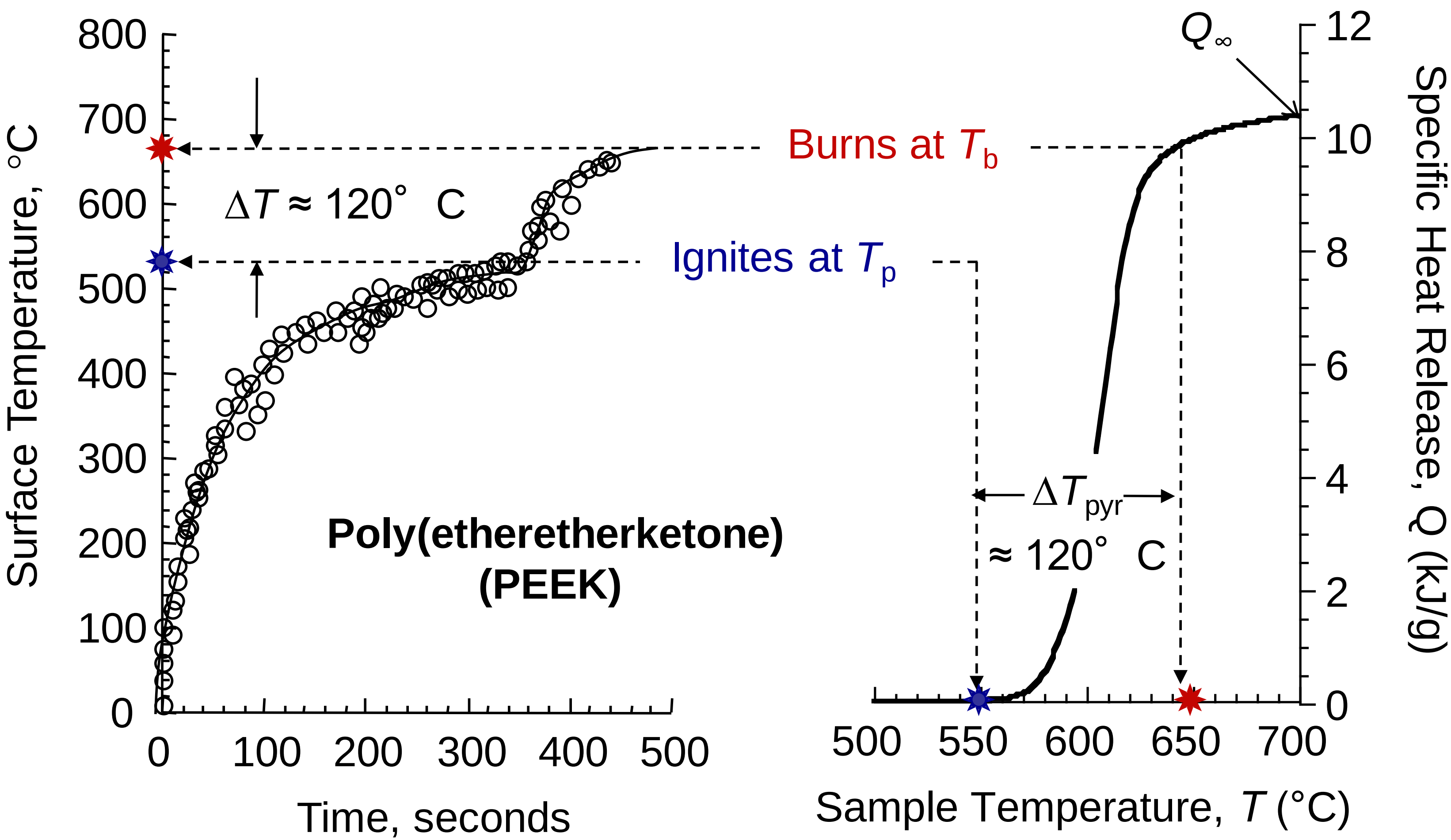


Fig 3 Baseline correction process and result for a 6mg sample of phenolic resin

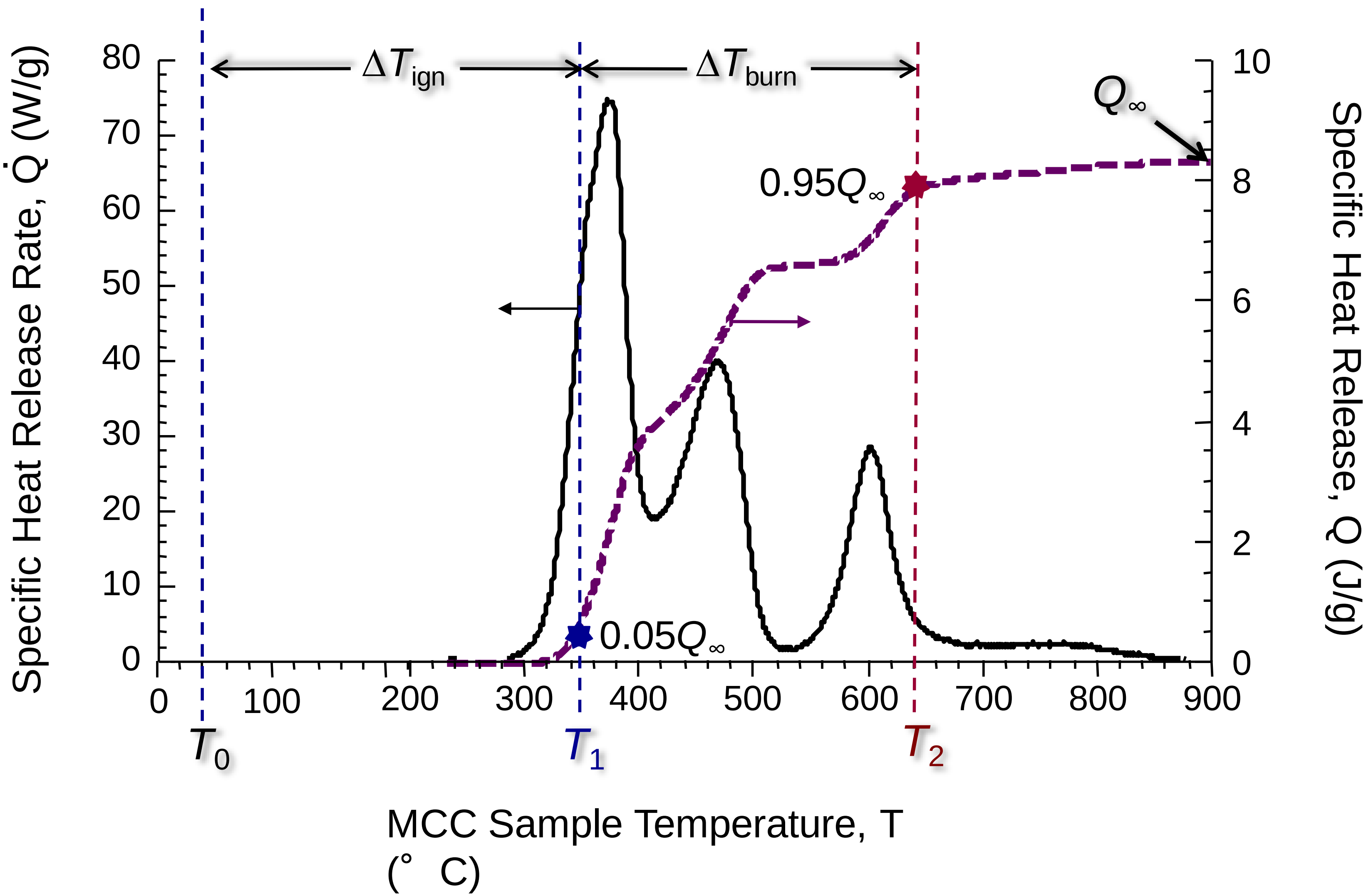
Ignition and Burning Temperatures

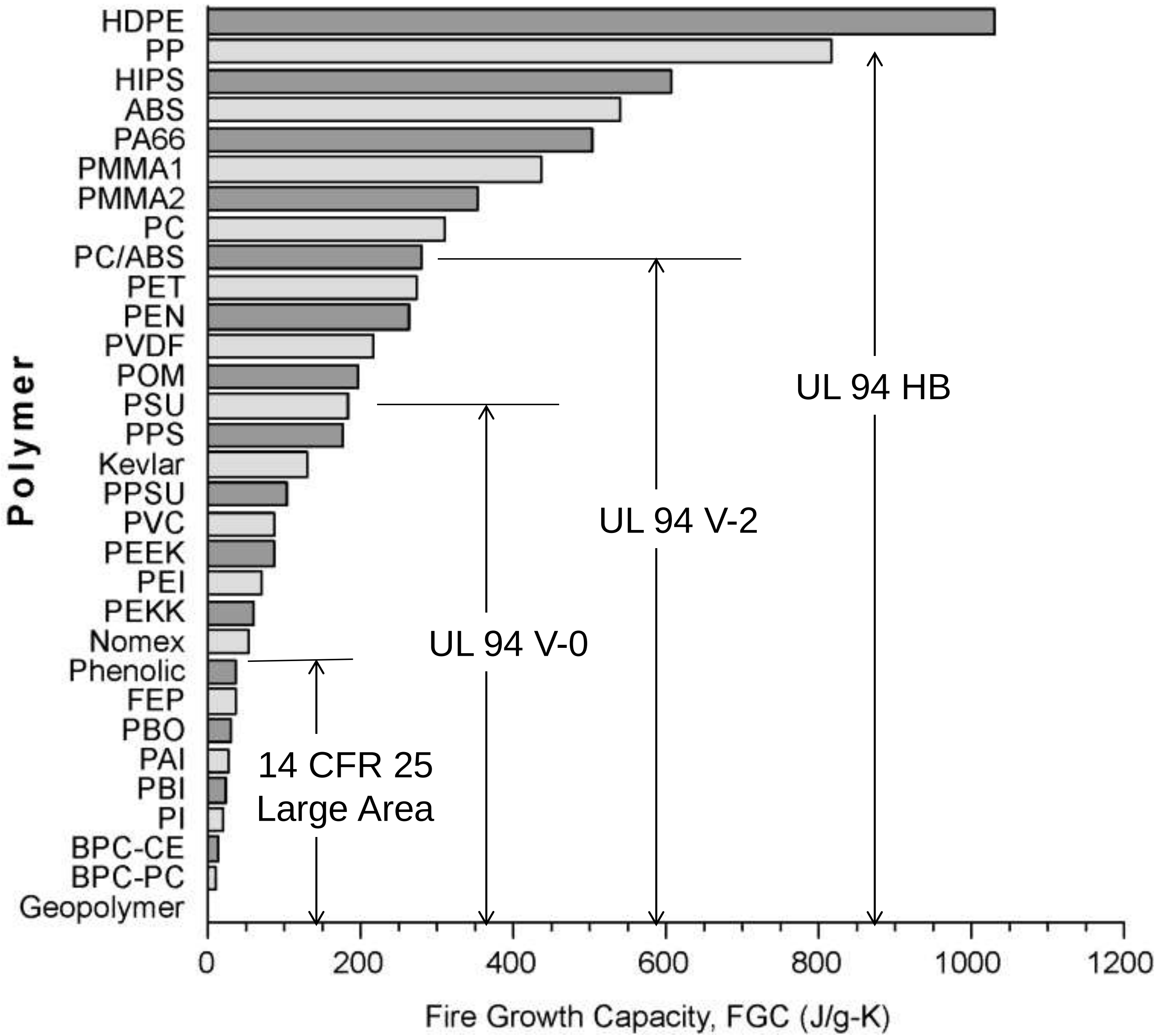
(*From MCC Integral*)



Q_∞, T_p and T_b are TA properties in Fire Growth Capacity/FGC.

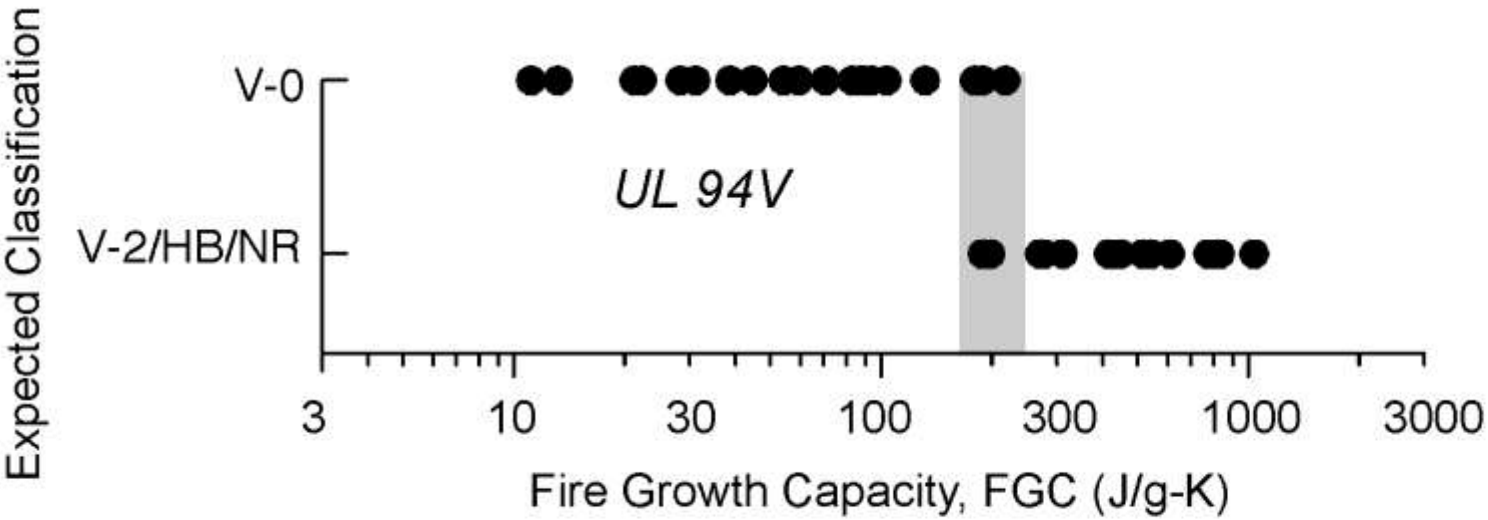
MCC Integral Method for FGC

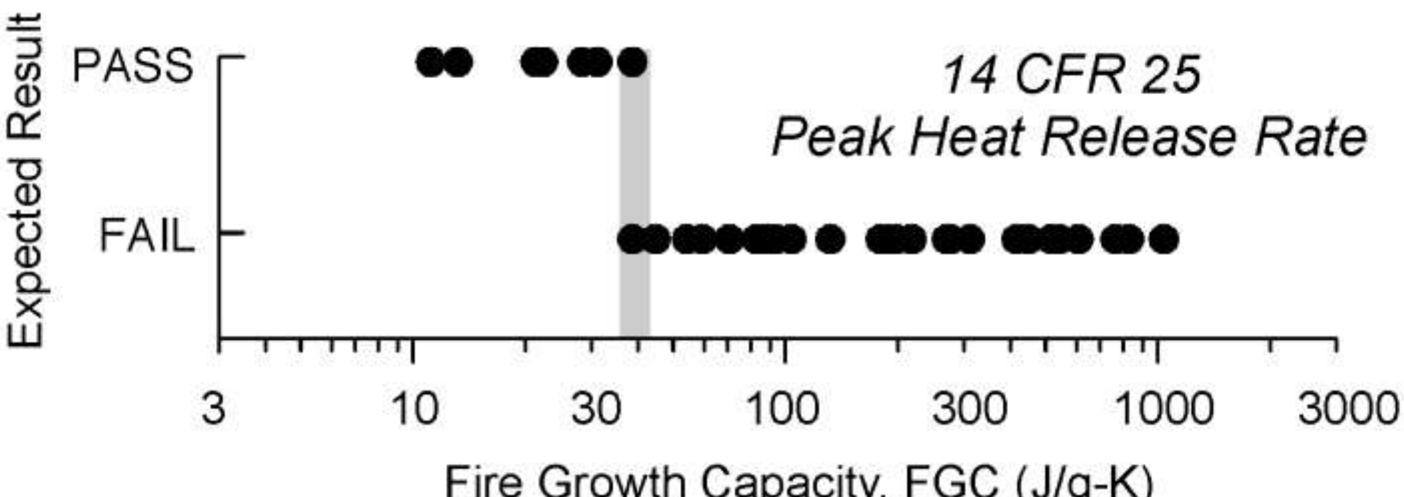




HDPE
PP
HIPS
ABS
PA66
PMMA1
PMMA2
PC
PC/ABS
PET
PEN
PVDF
POM
PSU
PPS
Kevlar
PPSU
PVC
PEEK
PEI
PEKK
Nomex
Phenolic
FEP
PBO
PAI
PBI
PI
BPC-CE
BPC-PC
Geopolymer
Polymer
UL 94 HB
UL 94 V-2
UL 94 V-0
14 CFR 25
Large Area
0
200
400
600
800
1000
1200
Fire Growth Capacity, FGC (J/g-K)

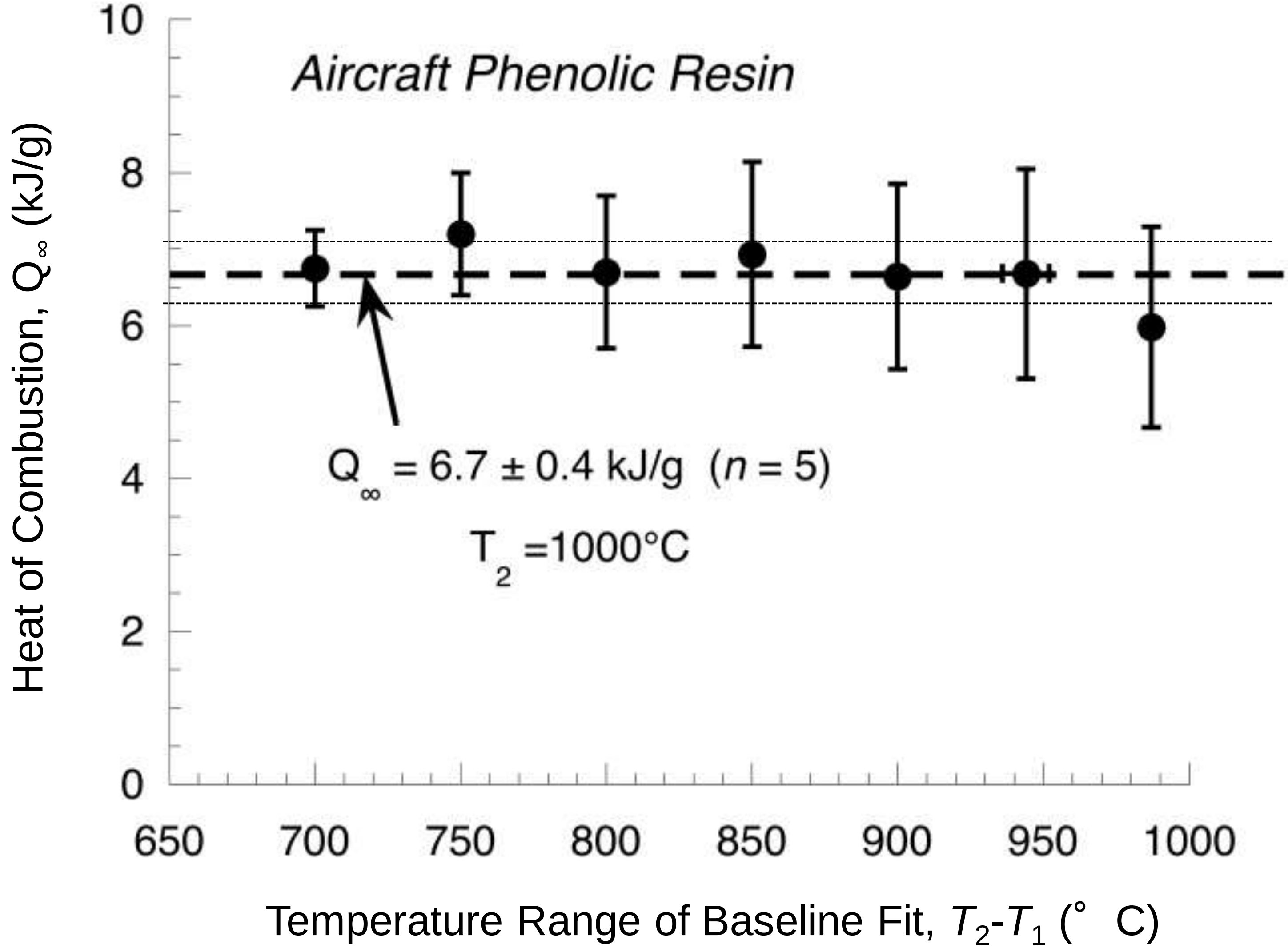
FGC Discriminates Levels of Fire Performance



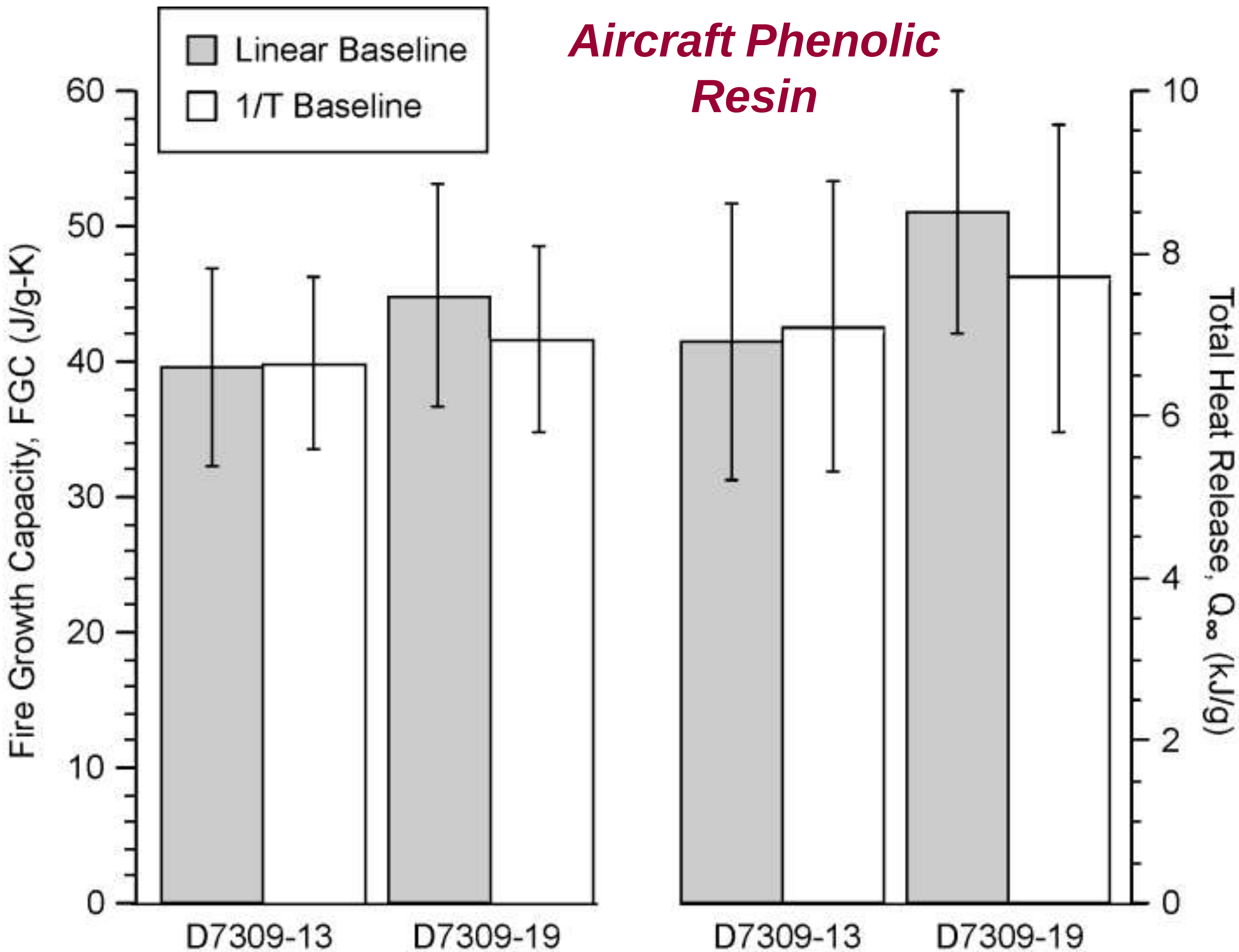


FGC is Independent of Choice of Baseline

$\Delta T = T_2 - T_1$



FGC is Independent of D7309 Version (2013/2019) And Baseline Method (Linear/T^{-1})



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_∞ 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).