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Small Scale Test and Criterion for Flammability of Aircraft Cabin Materials

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Background

- Small changes in the composition of certified aircraft cabin materials are often needed due to unavailability of the original components or environmental regulations

- Recertification of the entire constructions are costly

- Aircraft manufactures and supplies petitioned the FAA to explore the alternative means of compliance in 2015

- Material Similarity Task Group was created to develop a method and criterion for comparing samples using ASTM D7309.

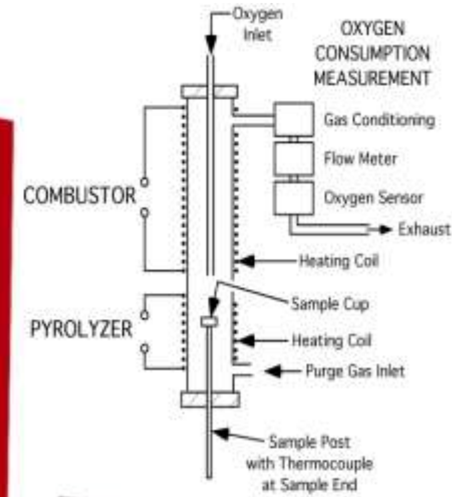
Pass/Fail FAA Flammability Tests
(≥ 2-Parameters)

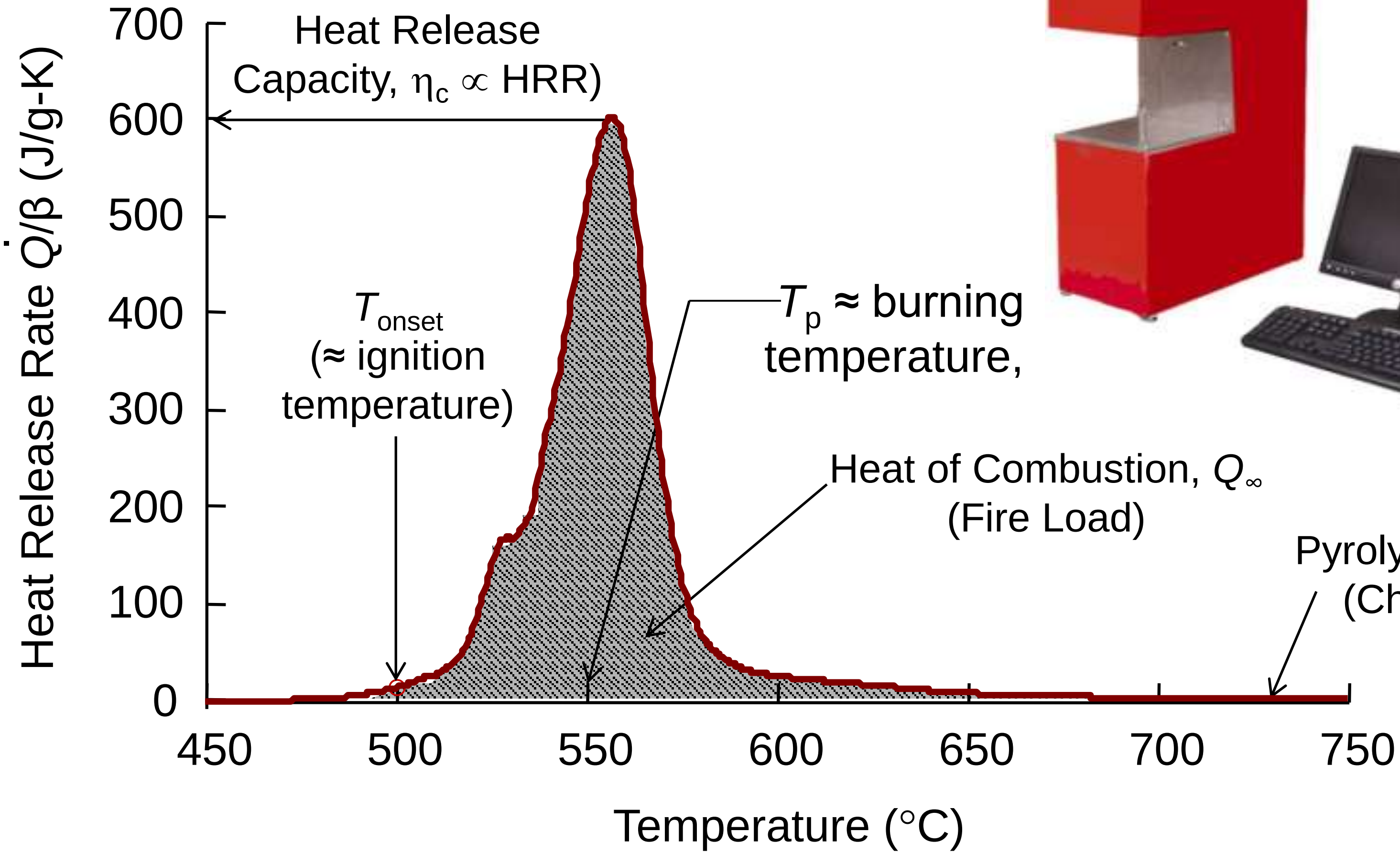
OSU Rate of Heat Release Apparatus (Large Area Materials)
• Peak HRR
• 2-min HR

Radiant Panel (Thermo-acoustic Insulation)
• Flame propagation distance
• After flame time

Vertical Bunsen Burner (All other materials)
• Flame time
• Flame drip time
• Burn length

MCC Individual Fire Properties



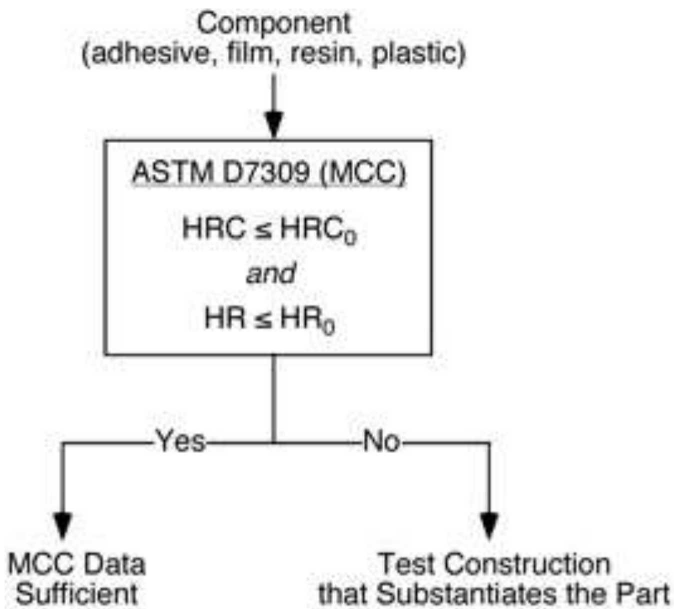


Decomposition
Kinetic Parameters E /A

β = Heating Rate (K/s)

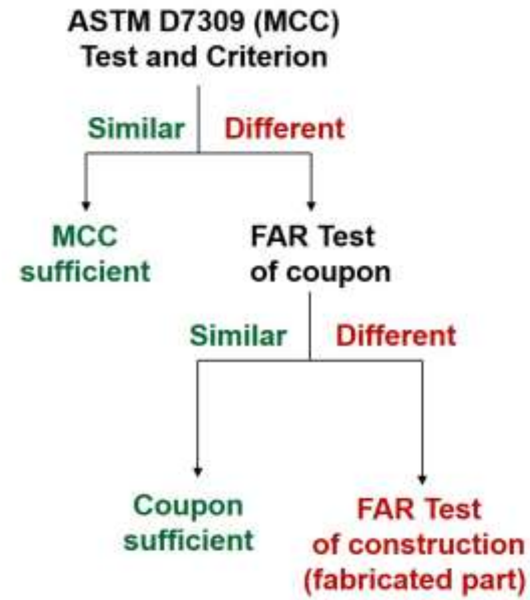
Iterations of the similarity approach

JUNE 2016



- MCC guidance document was presented on FAA website on June 2016
- Decision flow chart includes 2 MCC parameters **HRC and HR**
- The basis for comparing HRC and HR is the reproducibility limit from ASTM D 7309 standard

JUNE 2018



- Updated MCC guidance document was presented in 2018
- **HRC and IGC** were used as the MCC parameters to generate new parameter **FGC**
- FGC was compared between samples using $t_{0.05}$ 95% confidence level

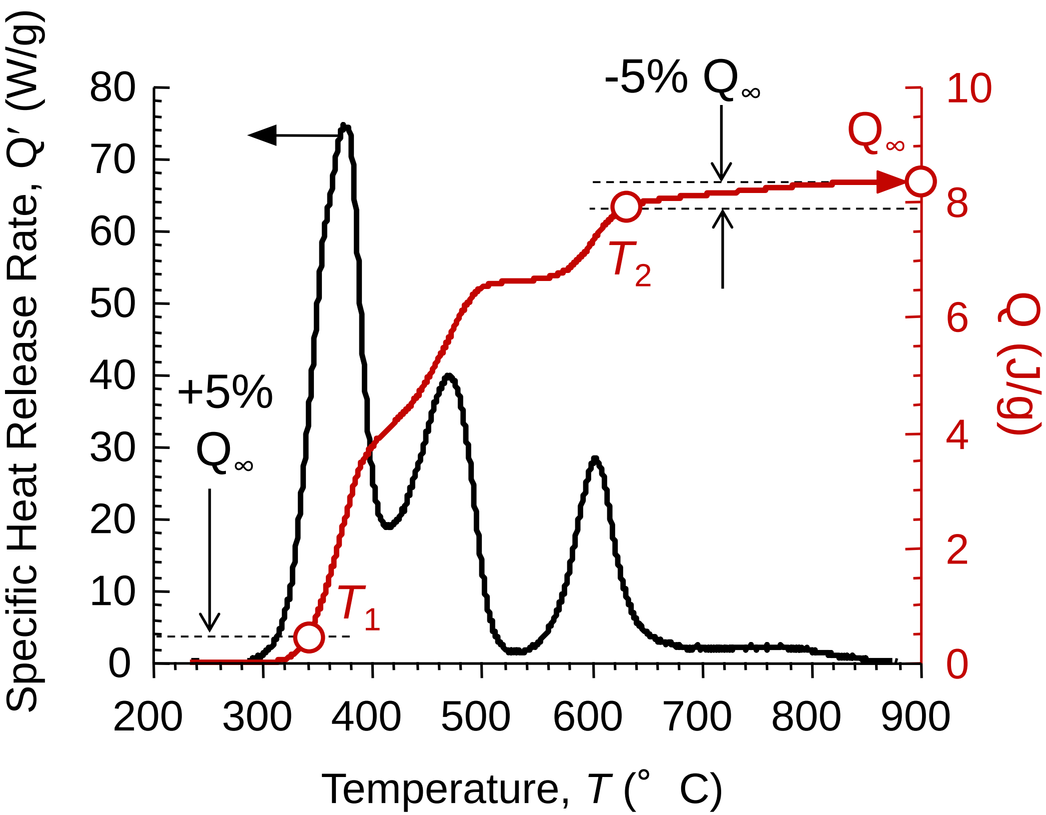
MCC Combined Properties
(*Flammability Parameters*)

$$\text{Ignition Capacity (IGC)} = \frac{\text{Heat Released}}{\text{Heat to Ignite}} = \frac{Q_\infty}{c_p(T_{ign}-T_0)} \propto \frac{Q_\infty}{\Delta T_{ign}}$$

$$\text{Heat Release Capacity (HRC)} = \frac{\text{Heat Released}}{\text{Heat to Pyrolyze}} = \frac{Q_\infty}{L_g(T_{ign}-T_\infty)} \propto \frac{Q_\infty}{\Delta T_p}$$

Fire Growth Capacity (FGC) = HRC + IGC

MCC procedure for FGC

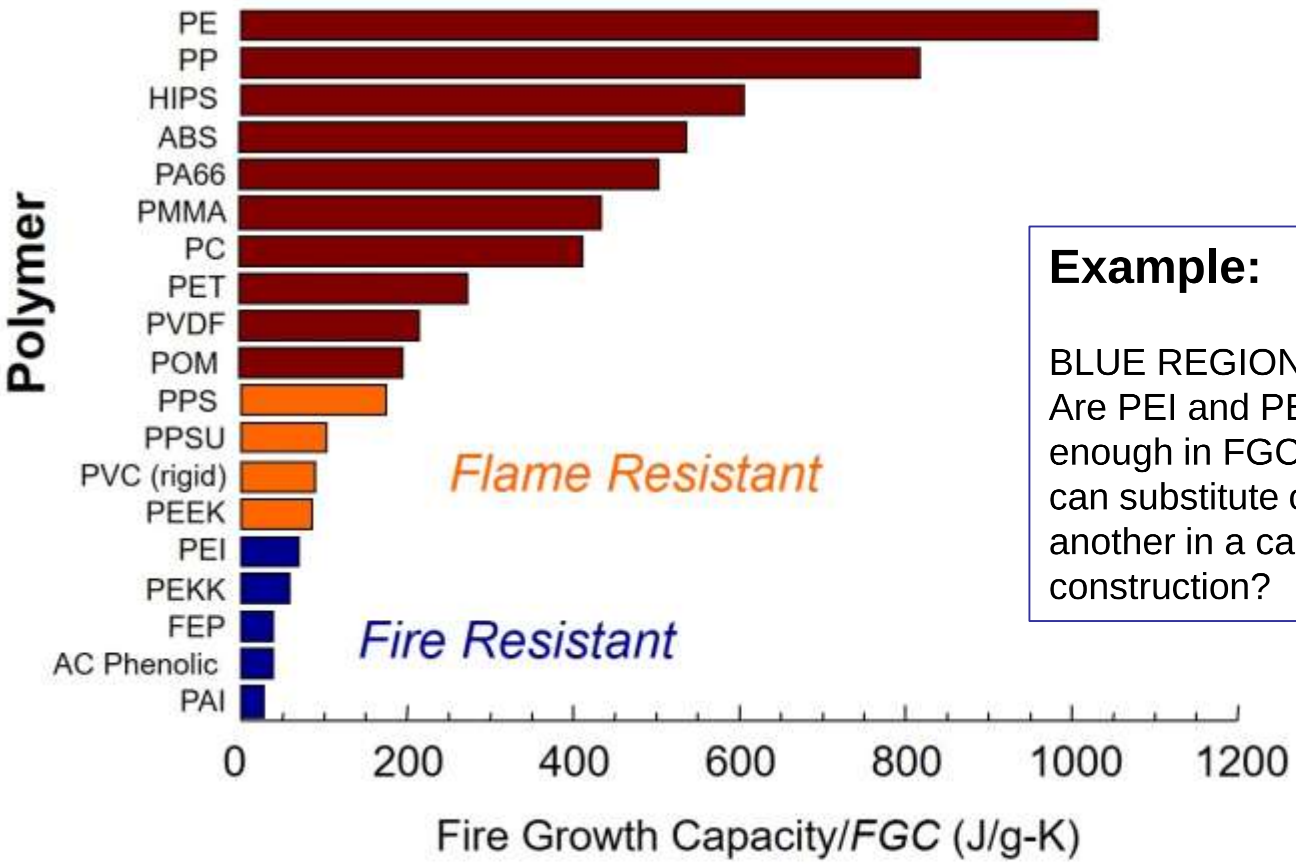


T_0 = Standard Temperature = 25° C
T_1 ≈ Ignition temperature
T_2 = Burnout temperature

$$FGC = \left(\frac{Q_\infty}{T_2 - T_1}\right)\left(\frac{T_2 - T_0}{T_1 - T_0}\right)$$

1. Measure specific heat release rate Q′ versus temperature *T* as per ASTM D7309 (5 replicates)
2. Integrate Q′/β versus *T* to obtain Q versus *T*, i.e., Q(*T*)
3. Obtain total heat release $Q(T_\infty) = Q_\infty = h_c$(J/g)
4. Obtain T_1 at 5% deflection from Q(T) baseline, i.e., at $0.05Q_\infty$
5. Obtain T_2 at Q_∞-($0.05Q_\infty$), i.e., $0.95Q_\infty$.
6. Calculate Fire Growth capacity (FGC)

FGC of database polymers



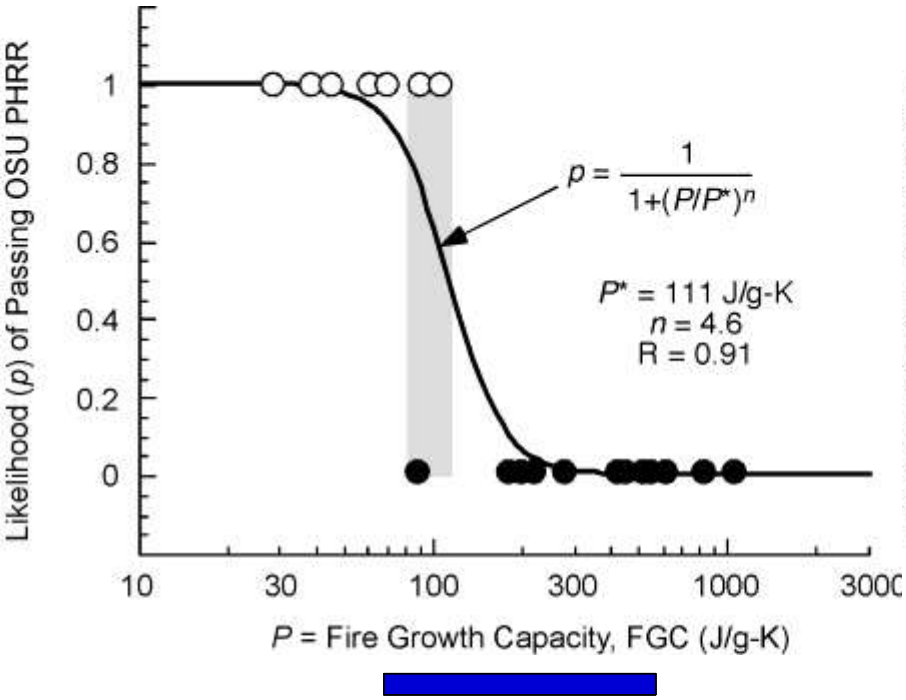
Example:

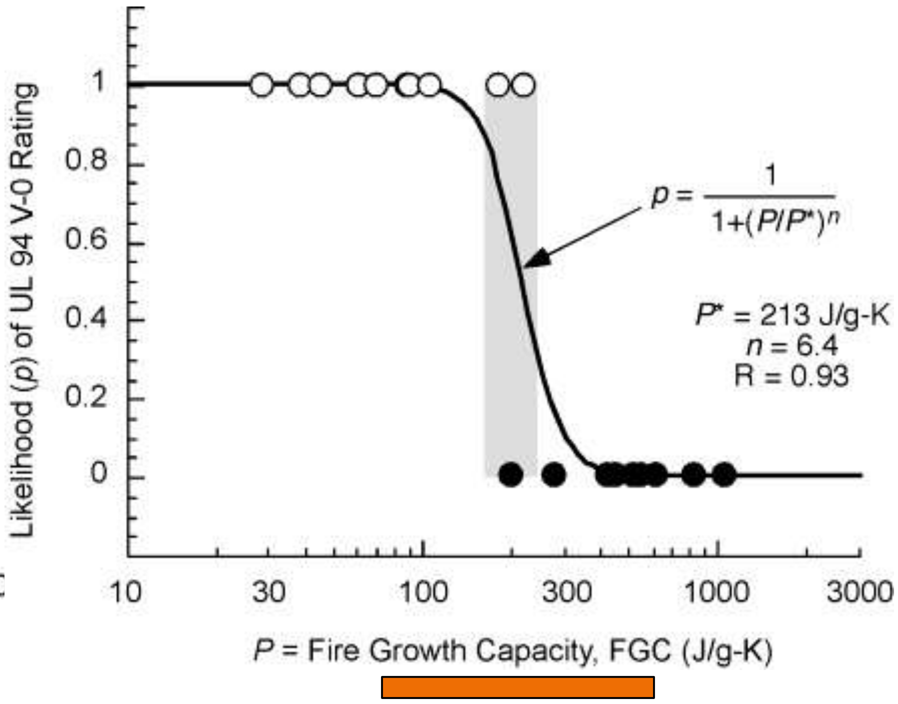
BLUE REGION:
Are PEI and PEKK close enough in FGC that you can substitute one for another in a cabin material construction?

The motivation was to identify MCC parameter that captures the process of early growth and use it to compare the flammability of materials. Flame resistance is relative to test method.

NOTE: Categories are qualitative flammability resistance ranges.

FGC and bench scale tests





- Probabilistic analysis of pass/fail results (data from previous slide)
- Grey area is the uncertainty, most due to the presence of thermal stability term in FGS equation

Current criterion for similarity

- Substitute material A and certified material B are the materials for comparison
- Microscale Fire properties are determined for the materials A and B, $\mathbf{P_a}$ and $\mathbf{P_b}$. Secondary calculation is needed to determine average values for $\mathbf{P_{ab}}$ (*P* = *FGC*).
- Bench-scale fire performance $\mathbf{X_b}$ (peak heat release rate OSU, 2-minutes total OSU, burn length, after time VBB) for certified material B along with variance for fire test B is required. Fire performance for substitute material A is optional and can be used in the intermediate inequity.

$$\frac{|P_a - P_b|}{P_{ab}} \leq \frac{|X_a - X_b|}{X_{ab}} \approx \frac{2\sigma_{Xb}}{X_b}$$

Assumes $\mathbf{X_a}$ is within 2 sigma of $\mathbf{X_b}$

Case studies using standard material coupons

OSU case study

Phenolic Resins
Pure Resins in MCC vs. 2-ply Glass Fabric/Resin Laminates in OSU

MCC

Sample	FGC
A	44±1
B (ref)	41±1

$$\frac{|P_a - P_b|}{P_{ab}} \leq \frac{|X_a - X_b|}{X_{ab}} \approx \frac{2\sigma_{Xb}}{X_b}$$

A/B basis B basis

OSU and comparison results

Sample	X=pHRR, kW/m^2	σ_X	X=THT@2min, kW-min/m^2	σ_x
A (2-ply)	28	(11)	20	(7)
B (2-ply)	39	10	31	6
A/B basis	True		True	
B basis	True		True	

VBB case study

2 types of Nylon samples provided by DIEHL
12 Seconds VBB

MCC

Sample	FGC
A	464±3
B	499±8

$$\frac{|P_a - P_b|}{P_{ab}} \leq \frac{|X_a - X_b|}{X_{ab}} \approx \frac{2\sigma_{Xb}}{X_b}$$

A/B basis   B basis

VBB

Sample	Burn length, mm	σ_X	Flame time, s	σ_X
A 1.5mm	21	(0.9)	2	(1.3)
B 1.5mm	18	2.1	0.1	0.4
A 3mm	5	(0.5)	0.6	(0.7)
B 3mm	3	0.5	1	0.5

	Burn length, mm		Flame Time, s	
Sample set	**A/B basis**	**B basis**	**A/B basis**	**B basis**
1.5 mm	True	True	True	True
3 mm	True	True	True	True

Summary

- FAA-Industry Fire Test Working Group is developing a process for comparing material formulations
- New approach involves using Fire Growth Capacity (FGC) parameter to determine similarity
- Proposed approach needs to be validated through the case study

Backup slides

Improved MCC accuracy

- Heat release rate calculation that accounts for O_2 and CO_2 in combustion gases.
- Proper baseline correction for MCC

More Accurate Heat Release Rate, Q′(*t*)*

$$Q'(t) = \frac{E\rho_{O_2}}{m_0} F\left\{X^0_{O_2} - X_{O_2}\right\}$$

Original Standard ASTM D7309 (2013)

Revised Standard ASTM D7309 (2019)

F = Flow Rate

X_{O_2} = mole (volume) fraction O_2

$$Q'(t) = \frac{E\rho_{O_2}}{m_0} \left\{F_0 X^0_{O_2} - F X_{O_2}\left[1 - \phi\left(X^0_{O_2} - X_{O_2}\right)\right]\right\}$$

$$\phi = \begin{cases} 1/3, \text{ if } H_2O \text{ removed from combustion stream.} \\ 0, \text{ if } H_2O \text{ and } CO_2 \text{ removed.} \end{cases}$$

*H. Guo, R.E. Lyon and N. Safronava, Accuracy of the Heat Release Rate Measured in Microscale Combustion Calorimetry, *Journal of Testing and Evaluation*, 46(3), 1090-1098 (2018).

MCC baseline correction

$$\text{Baseline} = Q_0'(T) = \frac{C_1}{T} - C_2 \quad \begin{cases} C_1 = \dfrac{Q_1' - Q_2'}{(T_2 - T_1)/T_1T_2} \\ C_2 = \dfrac{Q_1' - Q_2'}{(T_2 - T_1)/T_2} - Q_1' \end{cases}$$