HEAT RELEASE RATE Updates

2017 June Materials Meeting
Cologne, Germany

Materials Working Group

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AGENDA (HR2)

- Thermopile Modification
- Calibration
- DOE Round II
- Next

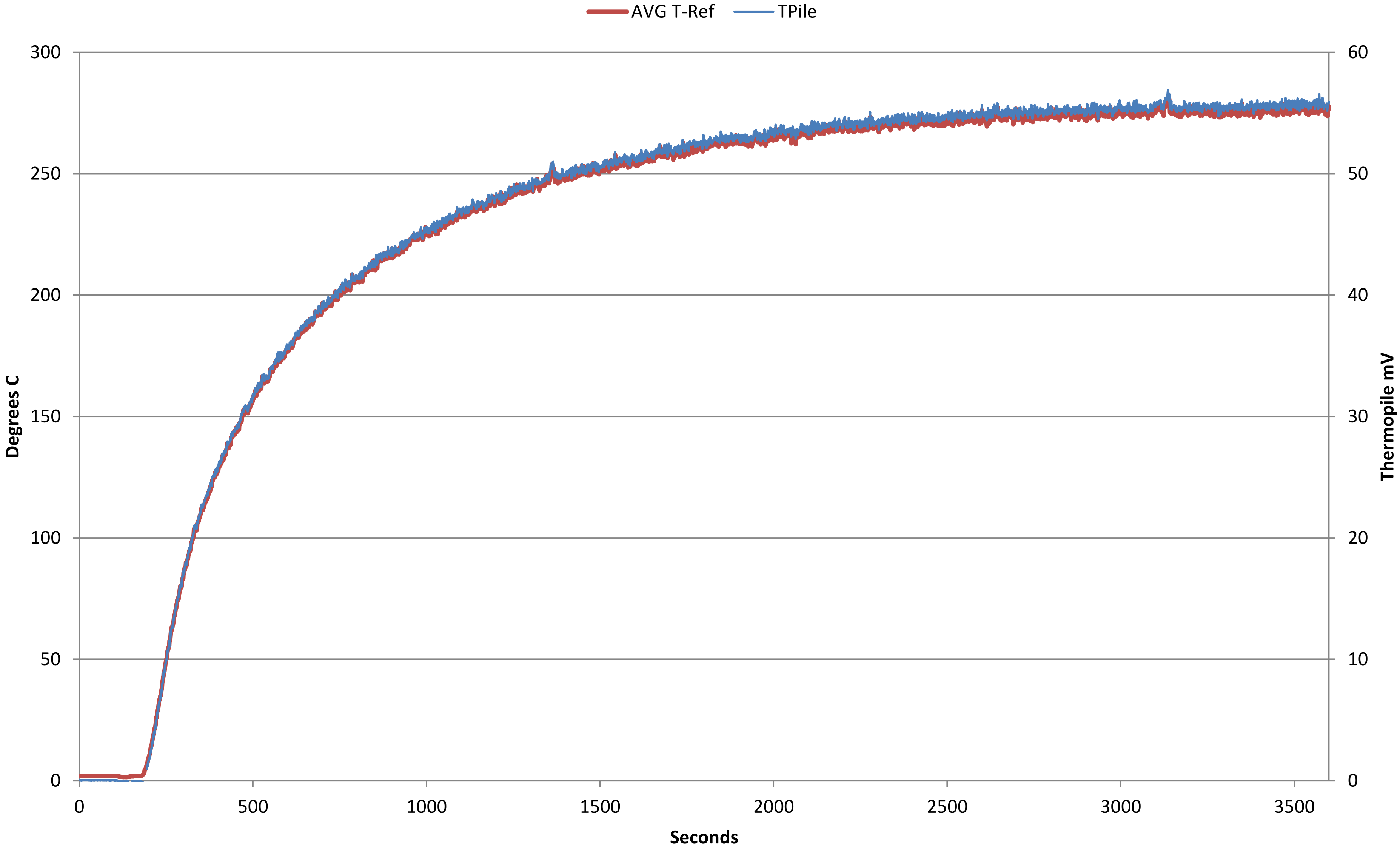
2017 IMFTWG: HR2 Task Group

Thermopile Modification

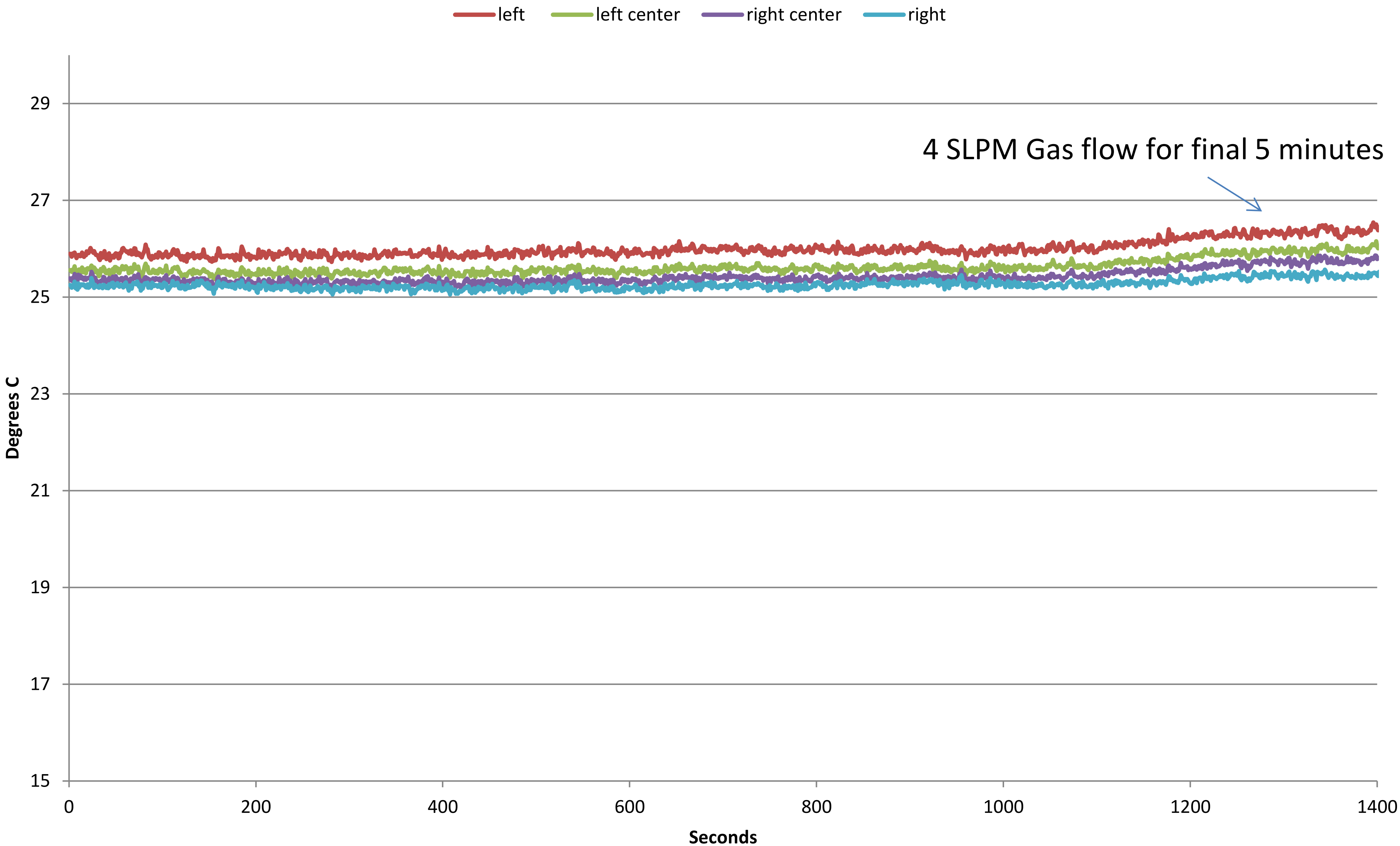
- 5 hot thermocouples input to DAQ (TC_{hot}).
- 1 Reference thermocouple (lower plenum) input to DAQ (TC_{Ref}).
- All thermocouples displayed as independent temperature readings (using electronic cold junction software).
  - ❖ This would eliminate 5 lower plenum penetrations reducing leakage potential (3 Thermocouples, 1 thermocouple wire, 1 signal output wire)
- Thermopile Temperature output calculated as:

$$(TC_{LR} + TC_{LF} + TC_{Center} + TC_{RF} + TC_{RR}) / 5 - TC_{Ref}$$

Modified vs Conventional Thermopile Data (Warm Up)



Lower Plenum TC's Temperatures



Thermopile Change Recommendation

- Good Thermopile mV / Temperature Correlation
- Stable temperatures in the lower plenum area
- TC inputs to DAQ as Temperature (not mV) eliminating potential Seebeck Coefficient issues if not wired correctly (by reading TC mV's)
- Ability to monitor all temperatures independantanty
- Reduction in potential for air leakage (reduced # of penetrations)
- It is recommended to crossover to the Thermopile Temperature Signal going forward

Thermopile Change Recommendation

Manufacturer Software mod’s:

- Install new calibration routine which will include Calibration / Validation of results
- Calculate the average of the 5 hot TC’s then subtract reference temperature and display as thermopile temperature rise (Air entering/leaving).
- The Thermopile stability requirement will now need to reference temperature in place of mV during warm up.
- The Thermal Stability Voltage (TSV) will change to Thermal Stability Temperature (TST).

Thermopile Change Recommendation

- The updated range for the TST (20 second average temperature)

  From: 85 +/- 3 mV

  To: 400 +/- 20 °C

- The new calibration factor range:

  From: 0.085 +/- 0.010 kW/mV

  To: 17 +/- 2 W/°C

Thermopile Change Recommendation

Change to the calculation of calibration factor K_h as follows:

From: $K_h = \frac{(210.8-22)kCal}{mol} * \frac{mol\ (CH4)}{22.41L} * \frac{Watt*min}{0.01433\ kCal} * \frac{kW}{1000W} * \frac{\Delta F}{\Delta mV}\ kW/mV$

To: $K_h = \frac{(210.8-22)kCal}{mol} * \frac{mol\ (CH4)}{22.41L} * \frac{Watt*min}{0.01433\ kCal} * \frac{1000W}{1000W} * \frac{\Delta F}{\Delta °C}\ W/°C$

Change to the calculation of Heat Release Rate:

From: Heat Release Rate = $(T'pile_{mV} - BL_{mV}) * \frac{K_h}{0.02323}$ kW/m^2

To: Heat Release Rate = $(T'pile_{°C} - BL_{°C}) * \frac{K_h \div 1000}{0.02323}$ kW/m^2

Fun With Numbers: Calculating Theoretical Heat Release Rate

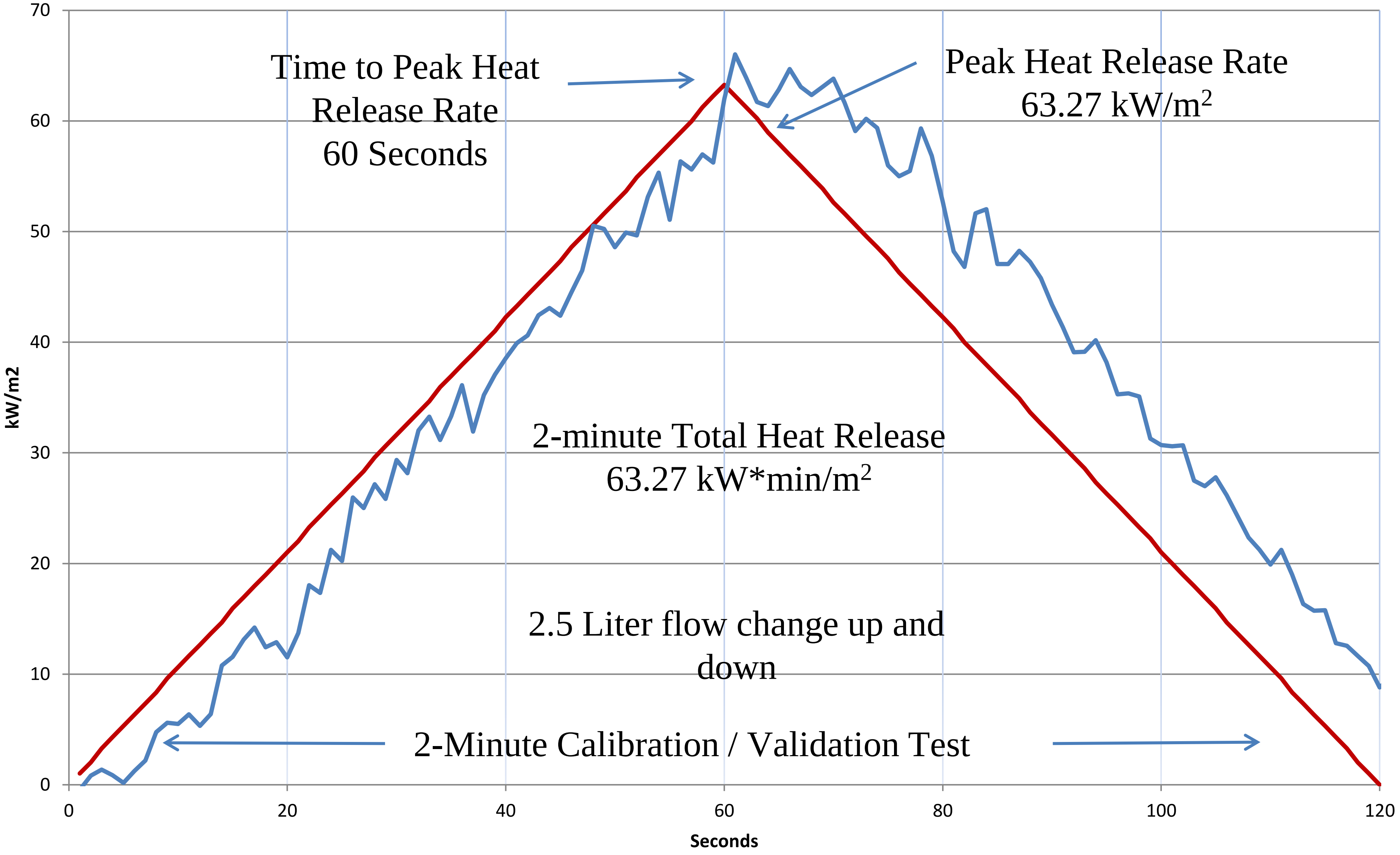
- $$\mathrm{CF} = \frac{(210.8 - 22)}{(22.41 * 0.01433 * 1000)} * \frac{\Delta \mathrm{L}}{\Delta \mathrm{mV}} = \frac{\mathrm{kW}}{\mathrm{mV}}$$

- $$\frac{\mathrm{CF}\ (\frac{\mathrm{kW}}{\mathrm{mV}})}{\frac{\Delta \mathrm{L}}{\Delta \mathrm{mV}}} = 0.589714 = \frac{\mathrm{kW}}{\mathrm{L}}$$

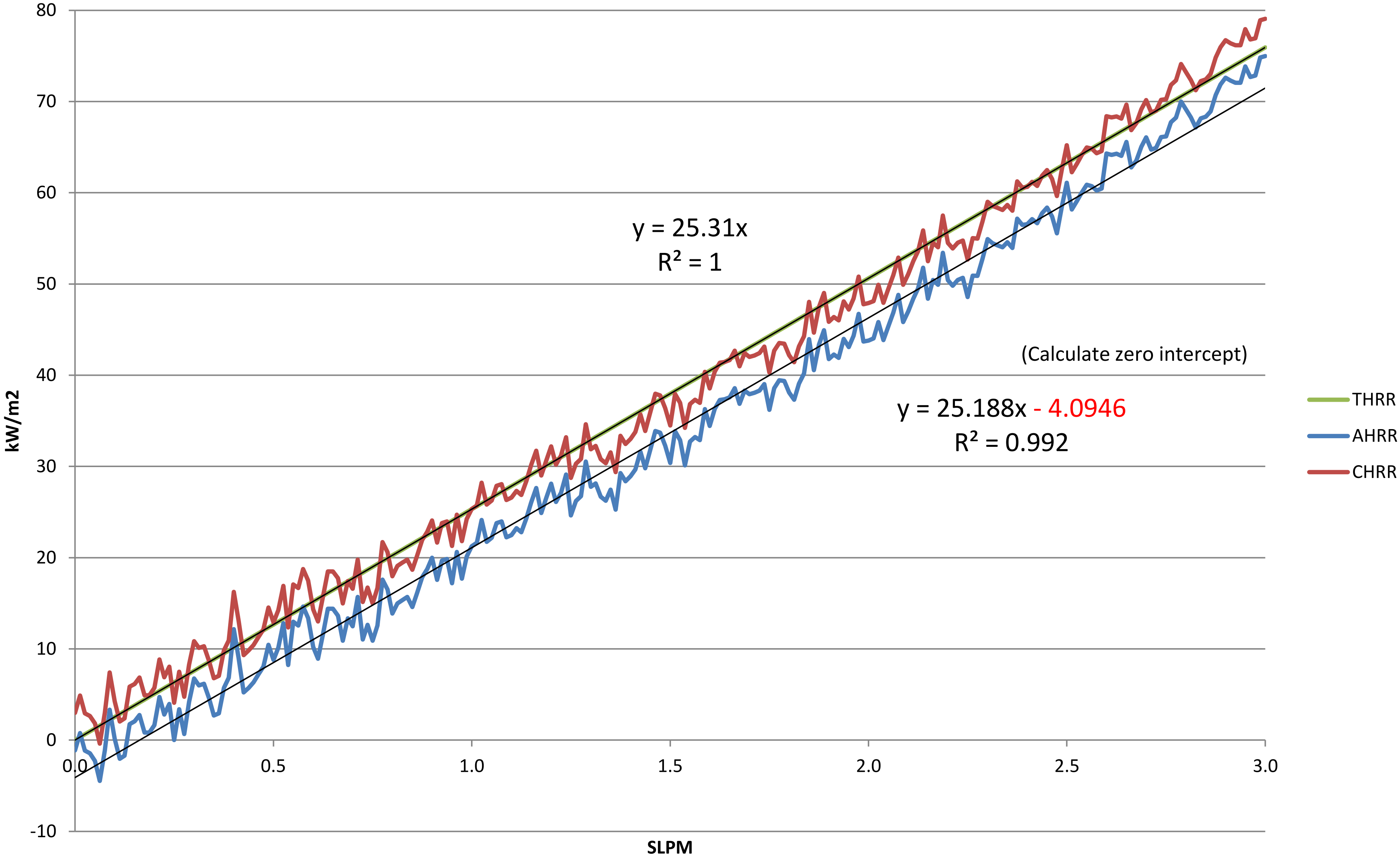
- $$\text{Theoretical HRR} = \frac{0.587914\ \frac{\mathrm{kW}}{\mathrm{L}}}{0.02323\ \mathrm{m}^2} = 25.31 = \frac{\frac{\mathrm{kW}}{\mathrm{L}}}{\mathrm{m}^2}$$

- $$\text{Theoretical HRR} = \text{Flow delta(L)} * 25.31 \frac{\frac{\mathrm{kW}}{\mathrm{L}}}{\mathrm{m}^2} = \frac{\mathrm{kW}}{\mathrm{m}^2}$$

Theoretical / Actual Heat Release Curve



Theoretical / Actual / Corrected HRR (2 minutes)



Calibration / System Validation Test (6 minutes Total Time Required)

Preheat / Calibration

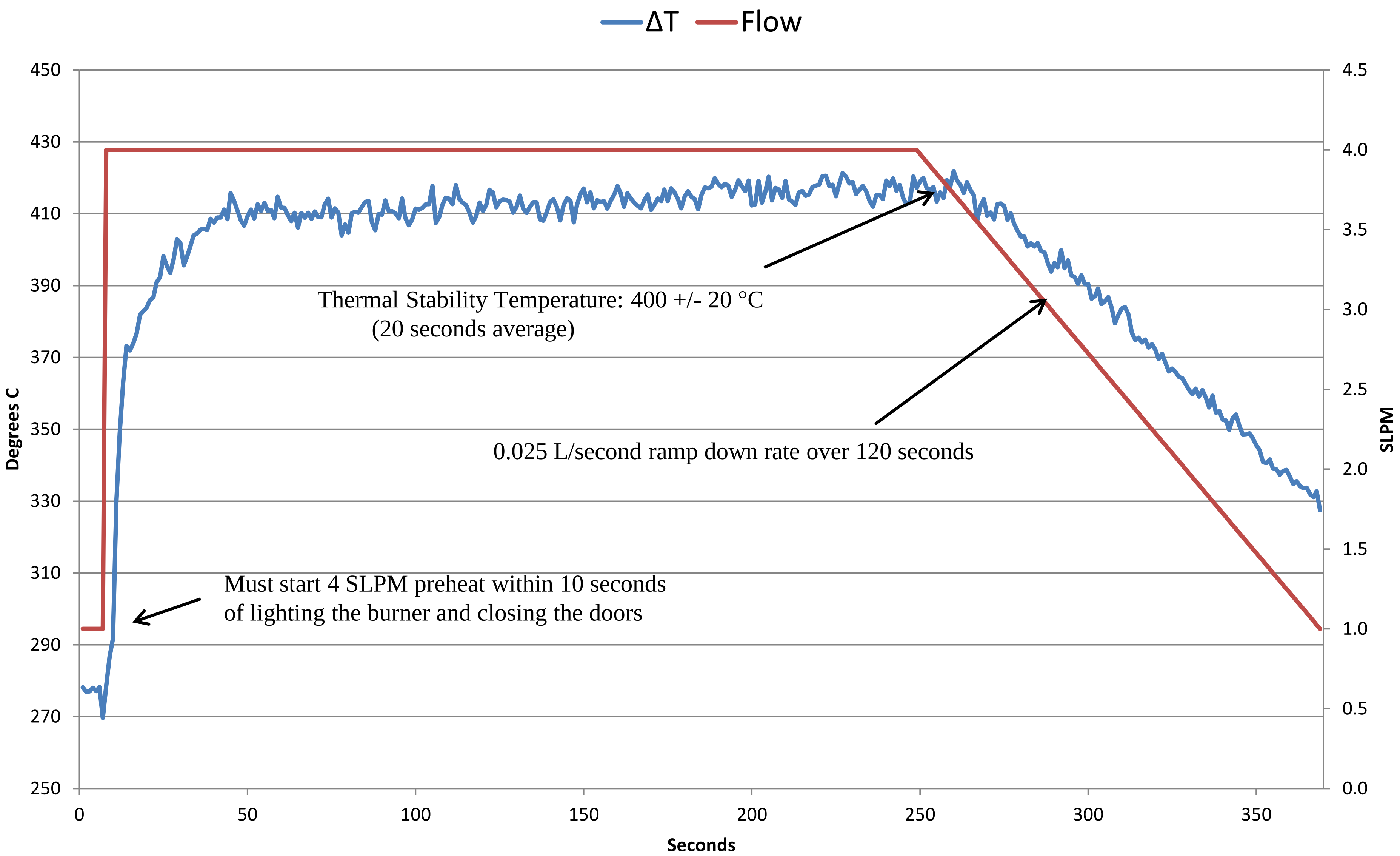
- Gas flow set to 1.0 SLPM
- Operator opens doors, lights burner, closes doors and presses a ‘START’ button within 10 seconds

  Note: Remote start option will be permitted (use of upper pilot igniter)
- Immediately gas flow increases to 4.0 SLPM
- The software program monitors the thermopile for 4 minutes recording the final 20 second average as the Thermal Stability Temperature (TST). This average temperature must be in the range of **400 ± 20 °C** in order to continue calibration.
- After 4-minute preheat is completed and the TST is within range the calibration can proceed.
- Starting at 4 SLPM at 0 seconds, the flow is ramped down to 1.0 SLPM at a rate of 0.025 L/second ending at 120 seconds.
- If a re-calibration is necessary the operator wait 15 minutes with no flames lit before attempting another calibration.

Calibration Factor Calculation

- Using the change in flow (0 – 3 L) and associated thermopile temperature, a slope is determined (L/°C) and used to calculate the calibration factor.
- The CF must be 17 ± 2 W/°C

Ramp Down Calibration Profile (6 Total Minutes)



Calibration / System Validation Test (Continued)

System Validation Test Using Theoretical Heat Release Rate Data

- Actual heat release rate (AHRR): ($TST_{\circ C}$ – $Tpile_{\circ C}$) * (Kh÷1000) /sample area (0.02323)
- Change in flow (flow delta): Initial flow (F_0) minus current flow (F_n)
- Theoretical heat release rate (THRR): Multiply flow delta by 25.31 kW/m^2
- Using flow delta, calculate the zero intercept for AHRR/L and subtract it from AHRR to get the Corrected HRR (CHRR)
- Calculate Peak Heat Release Rate (PHRR) and Total Heat Release (THR) for Theoretical and Corrected data
    - Theoretical Peak Heat Release Rate: 76 kW/m^2
    - Theoretical Total Heat Release: 76 $kW*min/m^2$
    - Calculate % Difference between Theoretical and Corrected heat release data

Calibration / System Validation Test (Continued)

Presentation of Data

When the calibration is completed the following information to be displayed:

- Thermal Stability Temperature (TST): 400 ± 20 °C
- Calibration Factor: 17 ± 2 W/ °C (Pass / Fail)

Theoretical / Corrected Heat Release data

- AHRR/L zero intercept value as $kW/m^2/L$
- PHRR (Theoretical & Corrected) kW/m^2
- THR (Theoretical & Corrected) $kW*min/m^2$
- % Delta (PHRR & THR)

	CHRR	THRR	% Delta
PHRR	79.06	75.93	4.1%
THR	75.9	76.23	-0.5%
Zero Offset	-4.0946	kW/m^2	

AHRR = ($TST_{°C}$ – $Tpile_{°C}$) * ((Kh÷1000) / 0.02323)

Cor HRR = AHR - Zero Offset (negative value)

Theo HRR = Flow Delta * 25.31

Zero Offset = AHRR / Flow Delta

Start Flow	4	SLPM
Stop Flow	1	SLPM
Ramp Time	120	Seconds
Rate	0.025	L/second
TST	416	°C
Slope	0.031	L/°C
CF	17.9	W/°C

DOE Test Plan (Round II)

- Randomize 4 main parameters
- No Materials Tested; Only looking at impact to Thermopile response

Parameter	DESCRIPTION	Min. (round I)	Avg.	Max. (round I)
System Air Flow rates	SCFM	19.6 (19)	20.0	20.4 (21)
Heat Flux (W/cm^2)	Center	3.60	3.65	3.70
Upper Pilot	Air (SLPM)	0.95 (0.8)	1.00	1.05 (1.2)
	Methane (SLPM)	1.47 (1.3)	1.50	1.53 (1.7)

Design of Experiment (DOE)

Data collection:

<u>Software</u>

- Time
- Thermopile Temperature (Real time)
- Thermopile Temperature (15 minute Running average)
- Center Heat flux (Real Time)
- Center Heat flux (60 second Running average)
- Inlet air Flow (SCFM)
- Inlet air temperature

Design of Experiment (DOE)

Data collection:

Manually recorded periodically

- Time
- Ambient Conditions
  - Room temp
  - Barometric Pressure
  - % Relative Humidity
- Inlet air % Relative Humidity

Design of Experiment (DOE)

Data collection:

Manually recorded periodically (Continued)

- % Power to Upper globars
- % Power to Lower globars
- Methane flow rate upper pilot burner
- Methane flow rate to lower pilot burner
- Air flow rate to upper pilot burner
- Air flow rate to lower pilot burner

Run Order	Series	Data Point	Airflow (SCFM)	Center Heat Flux (W/cm2)	Upper Pilot Flame Methane (L/min)	Upper Pilot Flame Air (L/min)
1	1	PRE	20.0	3.65	1.50	1.00
2	1	2	19.6	3.60	1.47	0.95
3	1	3	19.6	3.60	1.47	1.05
4	1	4	19.6	3.60	1.53	1.05
5	1	5	19.6	3.60	1.53	0.95
6	1	POST	20.0	3.65	1.50	1.00
7	2	PRE	20.0	3.65	1.50	1.00
8	2	2	19.6	3.70	1.47	0.95
9	2	3	19.6	3.70	1.47	1.05
10	2	4	19.6	3.70	1.53	1.05
11	2	5	19.6	3.70	1.53	0.95
12	2	POST	20.0	3.65	1.50	1.00
13	3	PRE	20.0	3.65	1.50	1.00
14	3	2	20.4	3.60	1.47	0.95
15	3	3	20.4	3.60	1.47	1.05
16	3	4	20.4	3.60	1.53	1.05
17	3	5	20.4	3.60	1.53	0.95
18	3	POST	20.0	3.65	1.50	1.00
19	4	PRE	20.0	3.65	1.50	1.00
20	4	2	20.4	3.70	1.47	0.95
21	4	3	20.4	3.70	1.47	1.05
22	4	4	20.4	3.70	1.53	1.05
23	4	5	20.4	3.70	1.53	0.95
24	4	POST	20.0	3.65	1.50	1.00

Design of Experiment (DOE)

Daily Calibration Routine

- Insert HFG calibration assembly in machine and set airflow and heat flux parameters at nominal values (See data point PRE).
- Allow machine to reach equilibrium
- Remove HFG calibration apparatus and close all doors.
- Conduct Methane gas calibration and record all values.

Design of Experiment (DOE)

Daily PRE Test Routine (Nominal Parameters)

- Light pilot burners and set as per data point PRE.
- Allow system to stabilize then record 5 minutes of data.
- Turn OFF upper and lower pilot burners.

Daily TEST Routine

- Insert HFG calibration assembly in machine and set air flow and heat flux parameters as per data point #2 for scheduled test day.

Design of Experiment (DOE)

<u>Daily TEST Routine (Continued)</u>

- Allow system to reach equilibrium.
- Remove the HFG calibration assembly.
- Light pilot burners and set as per data point #2 for scheduled test day.
- Allow system to stabilize then record 5 minutes of data.

Design of Experiment (DOE)

<u>Daily TEST Routine (Continued)</u>

- Systematically change inputs per Test Matrix recording the time of each change.
- Allow system to reach equilibrium at each step before recording 5 minutes of data.
- Turn OFF upper and lower pilot burners.

Design of Experiment (DOE)

Daily POST Test Routine (Nominal Parameters)

- Insert HFG calibration assembly in machine and set airflow and heat flux parameters at nominal values (See data point POST).
- Allow system to reach equilibrium.
- Remove the HFG calibration assembly.
- Light pilot burners and set as per data point POST.

Design of Experiment (DOE)

Daily POST Test Routine (Continued)

- Allow system to stabilize then record 5 minutes of data.
- Turn OFF upper and lower pilot burners.
- Repeat steps on following day until matrix is complete.

Material Testing

- TBD

HR2 Status

NEXT

- Manufacturers are currently working hardware/software changes (Marlin Engineering / DEATAK)
- Verification that everything is working properly
- Begin phase II of DOE

Questions?

Can a kangaroo jump higher than a house?

Yes! Because a house can’t jump.