Engineering, Test & Technology
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Effects of Heat Flux on Heat Release Peak, Total, and Peak Time

An OSU Study

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Agenda

- **Review Voltage vs Heat Flux Study**
- **Current Study Overview**
- **Results**
- **Data Analysis**
- **Voltage → Heat Release extension**
- **Summary and Next Steps**

Reminder of Voltage vs Heat Flux Study (Presented 6/2017)

Abstract

Input voltage change could cause OSU heat flux to be outside of spec limits

Procedure

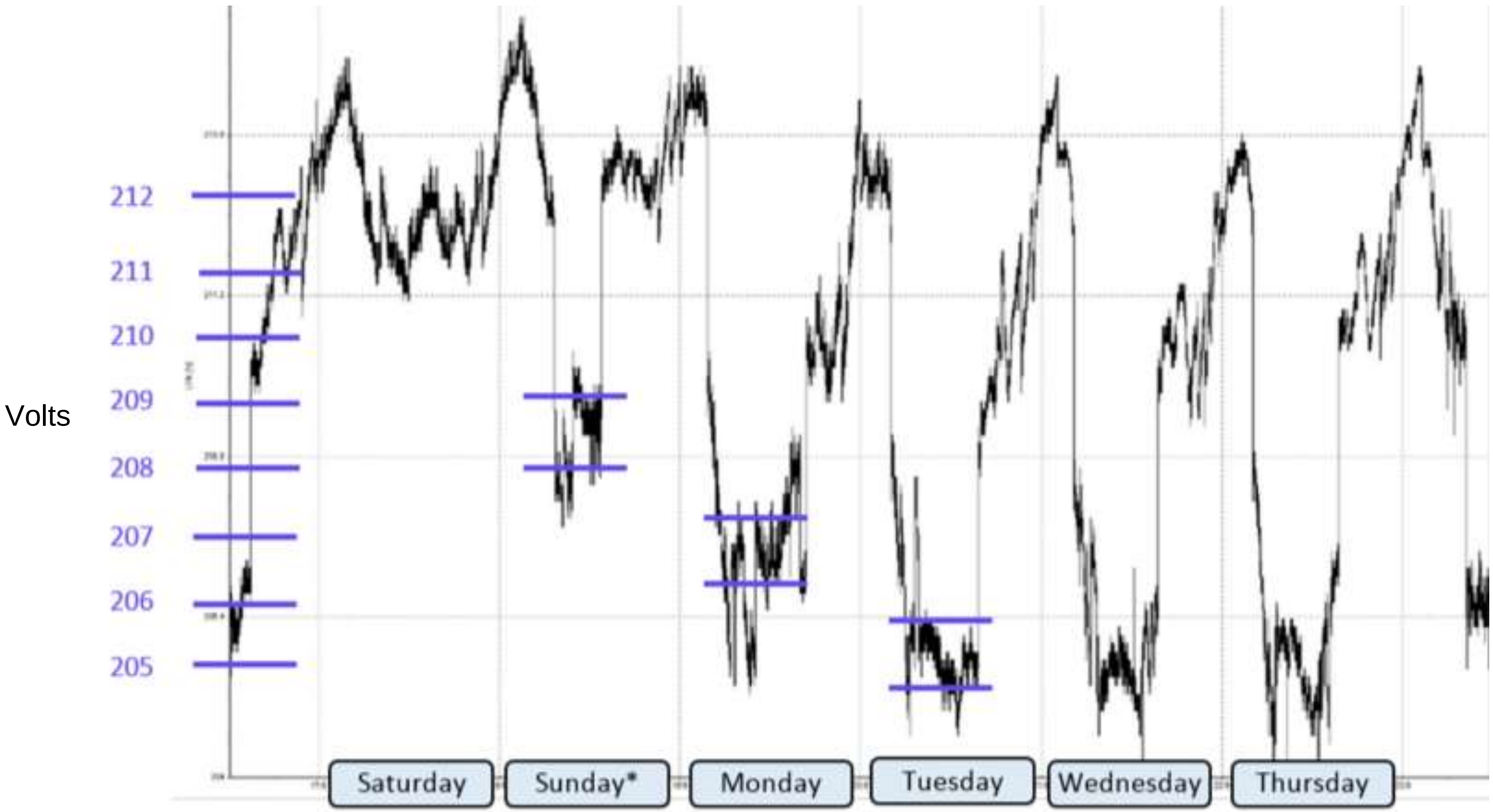
- Measure input voltage and resulting OSU heat flux
- Measure supply voltage changes over 3 days (Sunday, Monday, Tuesday) to capture a range of baselines and fluctuations
- Intentionally apply power load (lab equipment) to observe impact on OSU line voltage and resulting changes in OSU heat flux

Summary

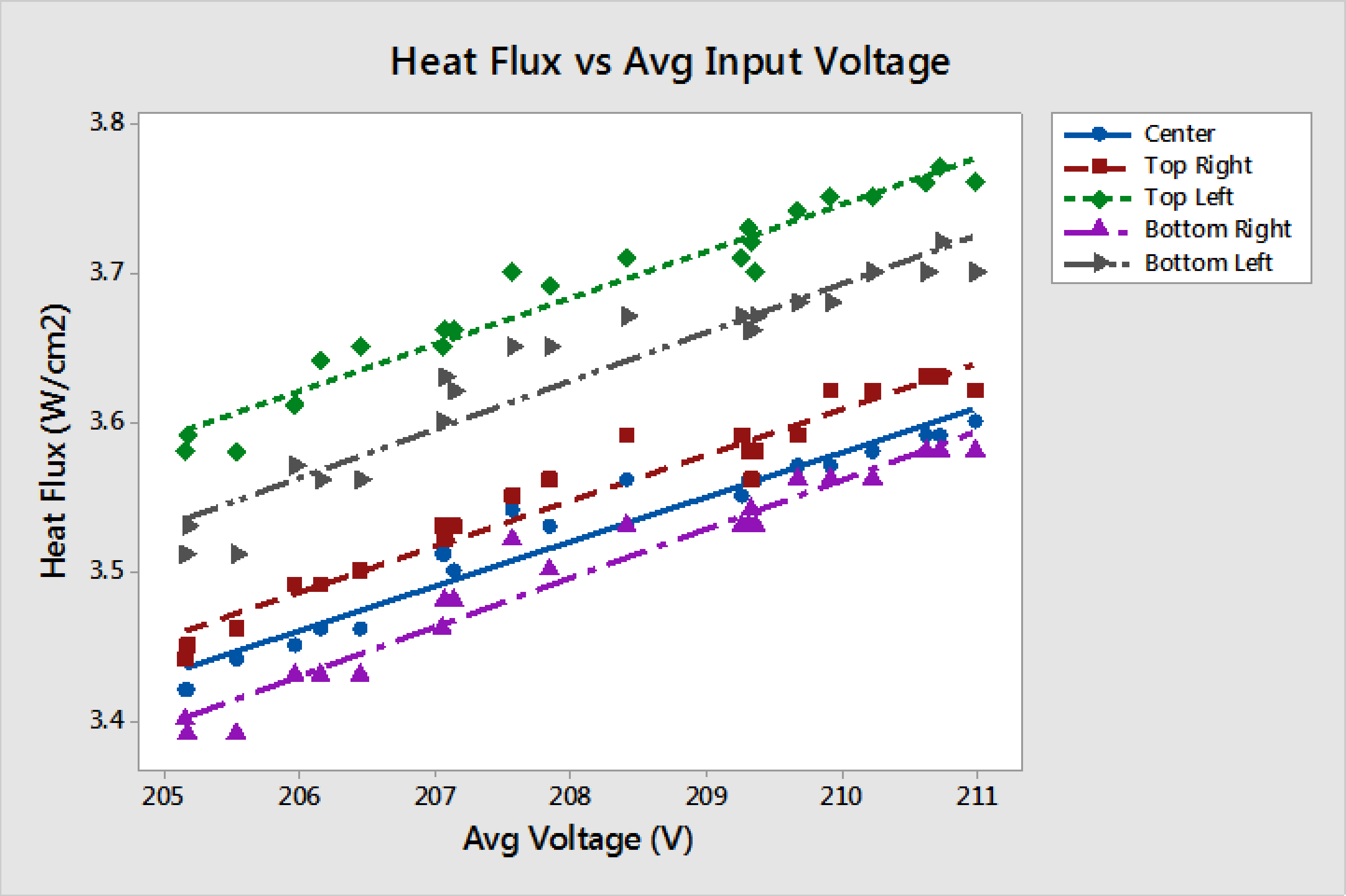
- Supply voltage fluctuated over a range of ~6 V in the 3-day period
- Heat flux changes linearly with voltage: 1 V change results in 0.024 to 0.033 W/cm^2 change in radiated heat flux
- For initial center heat flux value of 3.5 W/cm^2 to remain within specification, voltage change must be < ± 1.5 V during testing

Reminder of Voltage vs Heat Flux

- Notional relationship between Globar calibration power and time of day
- Specifications control heat flux but not voltage (ASTM E-906, Sec. F25.4)
- Initial voltage monitoring conducted indicated a dynamic supply voltage



Reminder of Voltage vs Heat Flux Study (Presented 6/2017)



Experimental Finding: Heat flux density changes linearly with voltage

1V change results in 0.024 to **0.033 W/cm²** in radiated heat flux

Overview of Heat Flux vs. Heat Release Study (Current)

Experiment

Study the effects of varying heat flux on HR peak, total, and peak time results. Conduct 27 total tests across three heat flux levels:

- $\leq$3.25 W/cm^2
- 3.5 W/cm^2
- $\geq$3.75 W/cm^2

Equipment

- OSU heat release unit
- Voltage logger installed and recording (10 sec sample interval)
- Multimeter monitored real-time supply voltage

Overview of Heat Flux vs. Heat Release Study (Continued)

Procedure

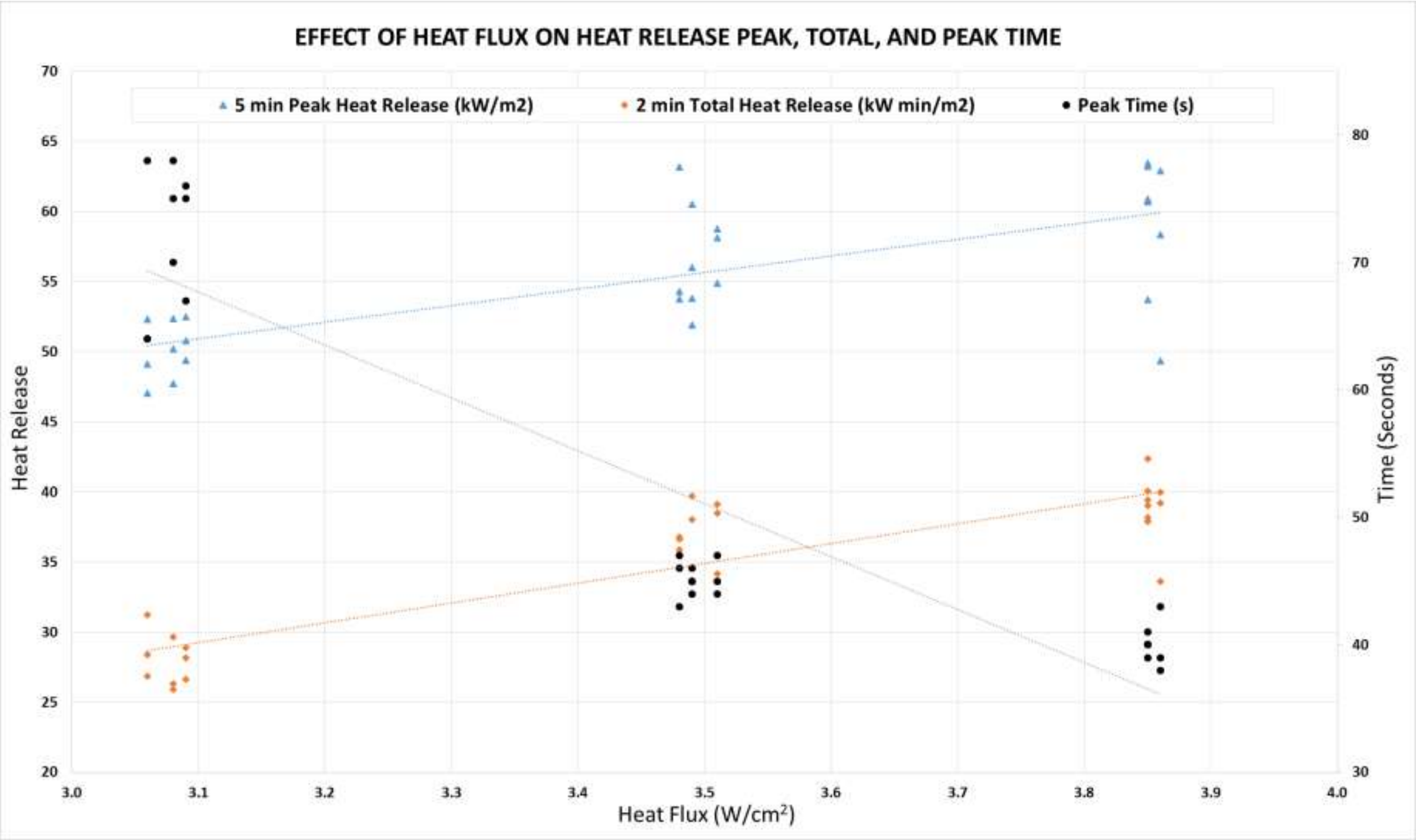
1. Standard OSU startup – allow 1.5 hours for mv output to stabilize
2. Heat flux calibration at 3.5 W/cm^2
3. Run 3 standard panels (prepreg / honeycomb sandwich)
4. Vary heat flux settings to produce ≤3.25 W/cm^2, 3.5 W/cm^2, and ≥3.75 W/cm^2 following a random order
5. At each heat flux level, run 3 standard panels before moving to the next level until a total of 27 tests results are generated – 9 at each of the three heat flux settings

Experimental Results

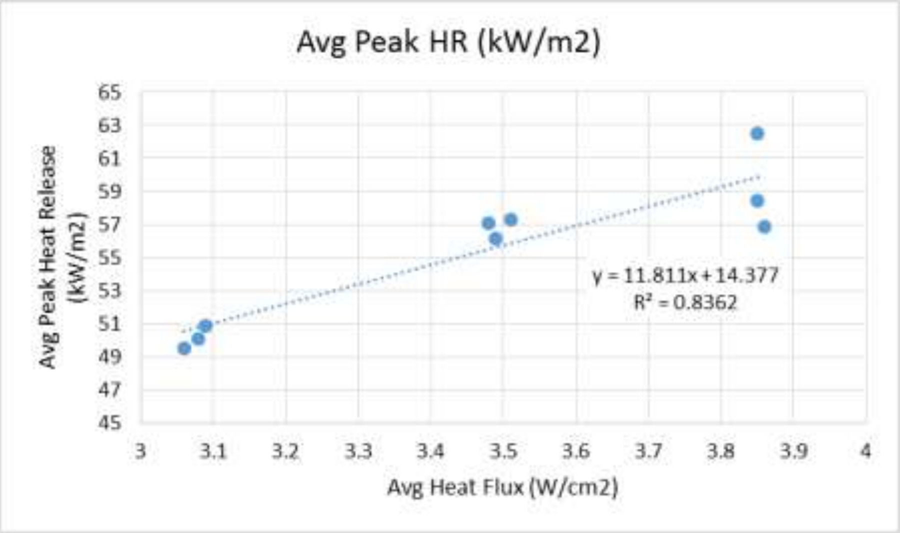
Data Tags					Heat Flux (W/cm2)						Supply Voltage (V)			Ambient Conditions		Air Pressure (mmHg)		Heat Release			
Data Point	Run #	SH	Date	Start Time	Initial Heat Flux	Target Heat Flux	Upper Bar Setting	Lower Bar Setting	Final Heat Flux	Average Heat Flux (i+f)/2	Initial Voltage	120s Final Voltage	Average 120s Logged Voltage	Temp (°C)	Humidity (%RH)	Initial Pressure	120s Final Pressure	Thermo-pile Baseline (mV)	Peak Heat Release (kW/m^2)	Peak Time (s)	Total Heat Release (kW min/m^2)
V_0	0		8/30	7:17 AM	3.49	3.50	53.5	65.0		*3.49*	206.9	206.7	206.6	22.7	56	197	198	26.2	53.81	46	33.55
V_1	1			7:27 AM	3.49						206.8	206.9	206.6	22.7	56	199	199	25.9	56.03	44	38.03
	2		8/30	7:48 AM		3.50	53.5	65.0		*3.49*	206.4	206.5	206.2	22.7	56	200	197	26.0	51.89	45	33.64
	3			7:56 AM					*		206.6	206.5	206.4	22.7	55	199	197	25.9	60.50	45	39.70
V_2	4	1		8:44 AM	3.10						207.1	207.0	207.0	22.8	55	200	199	24.1	49.40	75	26.62
	5	2	8/30	8:52 AM		3.25	49.2	59.8		3.09	206.9	207.2	206.9	22.7	55	198	201	23.9	52.50	76	28.17
	6	3		8:59 AM					3.08		207.2	207.4	207.1	22.7	55	200	200	23.9	50.77	67	28.87
V_3	7	4		10:04 AM	3.48						207.0	207.2	206.8	22.9	55	200	201	25.9	58.78	44	38.47
	8	1	8/30	10:11 AM		3.50	53.5	65.0		3.51	206.5	206.6	206.7	22.9	55	201	198	25.9	58.13	45	39.10
	9	2		10:18 AM					3.54		207.2	207.2	207.0	22.9	54	198	199	26.1	54.87	47	34.16
V_4	10	3		11:04 AM	3.86						206.2	206.4	206.1	23.1	54	200	202	27.4	49.35	43	33.61
	11	4	8/30	11:12 AM		3.75	57.8	70.2		3.86	206.1	206.2	206.0	23.1	54	202	202	27.2	58.37	39	39.99
	12	1		11:19 AM					3.86		206.1	205.9	206.0	23.1	55	202	200	27.2	62.90	38	39.22
V_5	13	2		12:16 PM	3.85						205.9	205.9	205.8	23.0	55	202	199	26.8	60.71	40	39.41
	14	3	8/30	12:22 PM		3.75	57.8	70.2		3.85	205.9	205.8	205.8	23.1	55	200	201	27.1	63.46	41	39.01
	15	4		12:29 PM					3.85		205.6	205.8	205.6	23.2	54	201	202	27.1	63.22	40	42.35
V_6	16	1		1:03 PM	3.12						206.2	206.0	206.0	23.4	55	198	200	24.4	50.22	78	25.91
	17	2	8/30	1:09 PM		3.25	49.2	59.8		3.08	205.8	205.9	205.6	23.4	55	200	201	24.2	52.36	75	26.31
	18	3		1:16 PM					3.03		205.7	206.1	205.8	23.2	55	200	202	24.1	47.71	70	29.66
V_7	19	4		2:05 PM	3.45						205.9	206.0	205.9	23.3	55	201	200	26.0	54.32	47	35.88
	20	1	8/30	2:12 PM		3.50	53.5	65.0		3.48	206.2	206.2	206.1	23.2	55	199	202	26.1	63.17	43	36.79
	21	2		2:18 PM					3.52		206.4	206.2	206.1	23.3	55	202	202	26.0	53.76	46	36.63
V_8	22	3		3:04 PM	3.82						206.0	206.0	205.8	23.3	55	203	200	27.2	53.73	40	37.91
	23	4	8/30	3:11 PM		3.75	57.8	70.2		3.85	205.8	205.6	205.6	23.3	55	200	200	27.2	60.68	39	40.07
	24	1		3:17 PM					3.88		205.7	207.0	205.4	23.2	55	201	202	27.4	60.88	40	38.16
V_9	25	2		4:16 PM	3.04						206.5	206.7	206.5	23.1	55	200	200	24.2	49.12	78	28.40
	26	3	8/30	4:22 PM		3.25	49.2	59.8		3.06	206.8	206.5	206.6	23.1	55	200	200	24.4	47.06	64	26.84
	27	4		4:29 PM					3.08		206.7	206.8	206.6	23.2	55	201	202	24.3	52.31	64	31.22

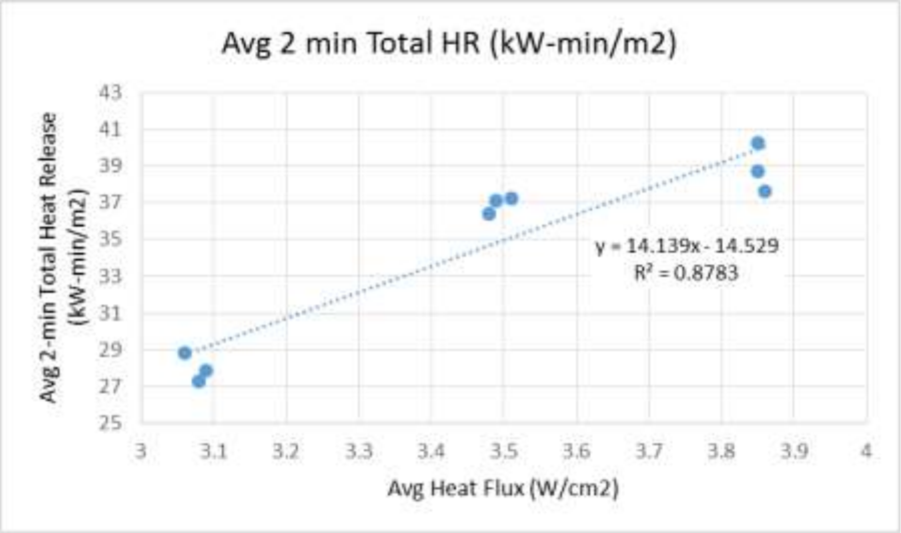
* Data point V_1 final heat flux not measured due to voltage jump of approx. 1V at end of 3rd run (did not affect results – occurred after measurement period)

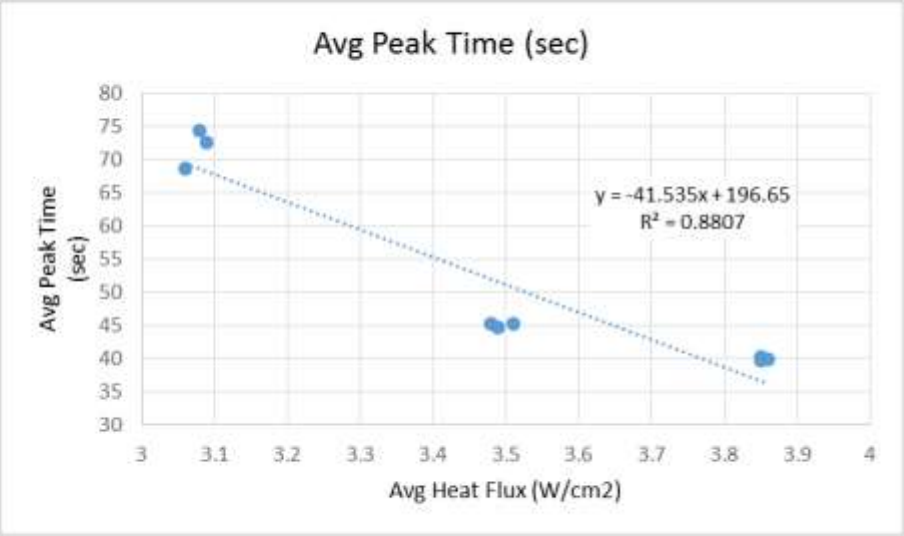
Data Analysis – Raw Data Scatter Plot



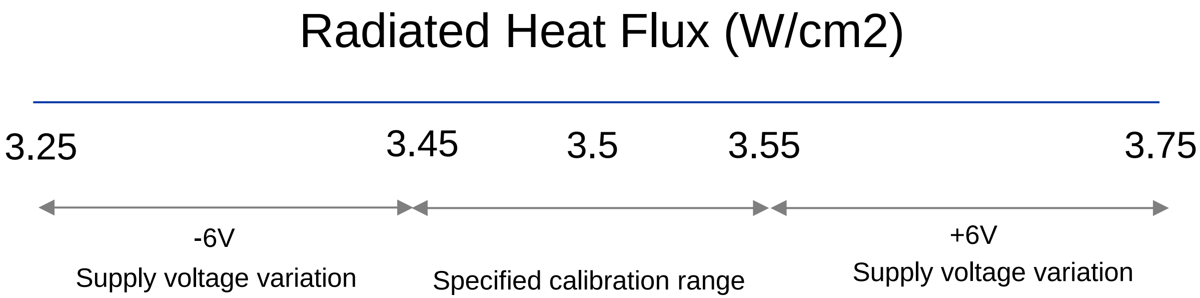
Regression Using 3-Point Data Averages







Heat Release Change Due to Supply Voltage Variation



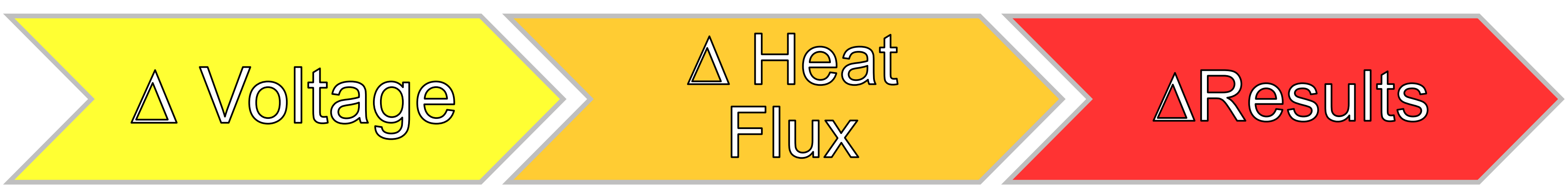
What impact could this have on coupon test results?

Heat Flux		Peak Heat Release
3.25	W/cm^2	62.1
3.45	W/cm^2	64.4
3.50	**W/cm^2**	**65.0**
3.55	W/cm^2	65.6
3.75	W/cm^2	68.0

6 point range

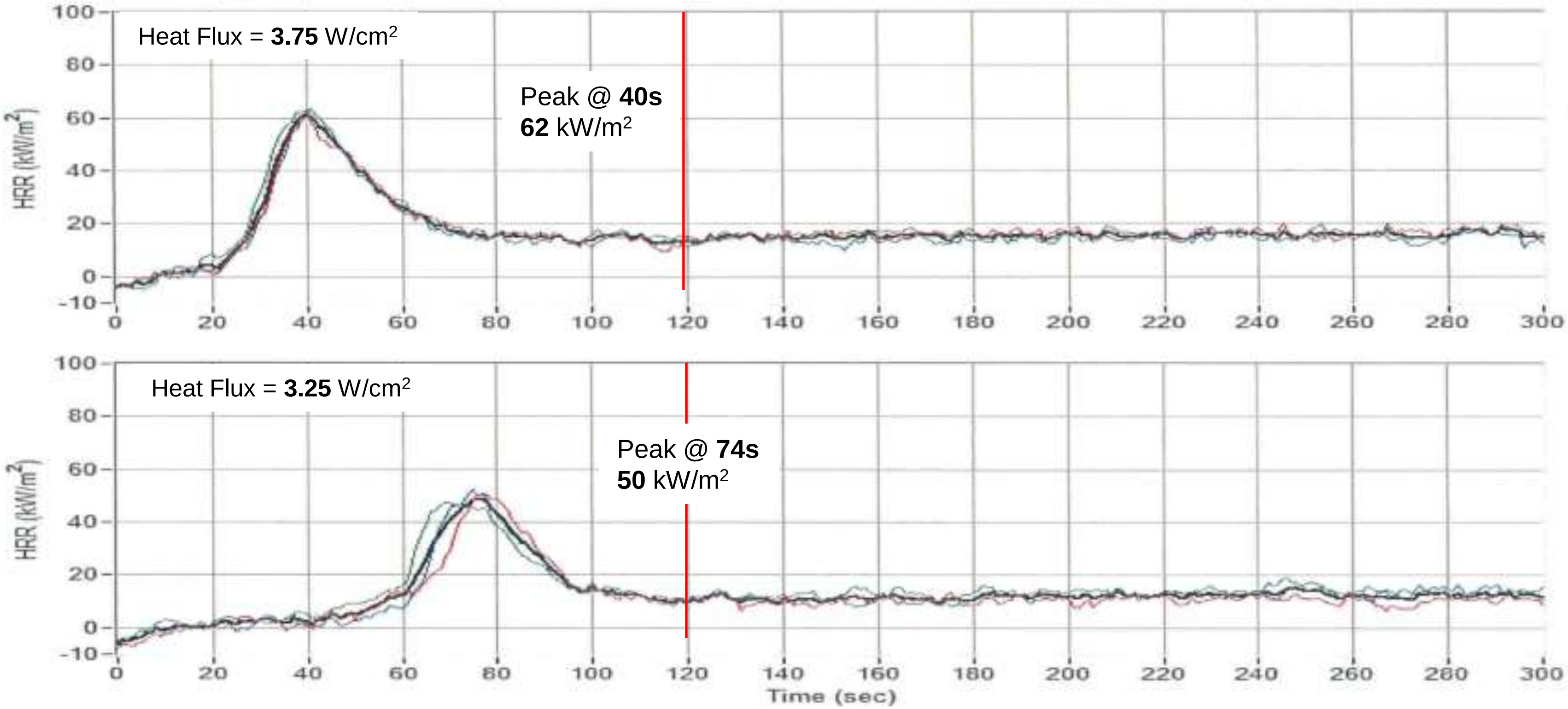
Heat Flux		2 min Total Heat Release
3.25	W/cm^2	61.5
3.45	W/cm^2	64.3
3.50	**W/cm^2**	**65.0**
3.55	W/cm^2	65.7
3.75	W/cm^2	68.5

7 point range



Heat Release Change Due to Supply Voltage Variation

Peak Shape / Timing



General Observations with Decreasing Heat Flux

- Lower peak values
- Lower 2 min total values
- Peaks shift right (starts and ends later)
- Wider peaks

Summary and Next Steps

Voltage fluctuations may cause significant variations in HR results

- Experiment focused on voltage as the prime variable – cognizant that other variables still exist and need to be studied further

Need voltage control limits in specifications (Handbook, HR2, etc.)

- Currently no voltage control in spec for OSU (Appendix F)
- HR2 draft specifies control within +/- 2.5% (+/- 5.2V at 208V supply)
- Need to consider the impact of heat flux over the range of materials

Power conditioners can provide up to +/-1% voltage control

- 15 kVA Single Phase Power Conditioner (~$11k)
  - May sufficiently isolate from ‘natural’ variation, but may still be susceptible to large local load cycling
- 15 kVA Single Phase UPS (~$15k)
  - Provides tighter voltage regulation than the Power Conditioner and immune to intra-day power swings
  - Yearly maintenance required, batteries require replacement every 5-10 years.