Laboratory Evaluation: SENSIT SPOD (Ion XF-PID)

South Coast AQMD

AQ-SPEC
Air Quality Sensor Performance Evaluation Center

Background

Three **SENSIT SPOD Ion XF-PID** sensors (hereinafter **SENSIT SPOD;** units IDs: 1624, 1625, 1626) were evaluated in the South Coast AQMD Chemistry Laboratory under controlled Volatile Organic Compound (VOC) and interferent gas concentrations, temperature, and relative humidity. The sensor measurements were compared with two reference instruments (Thermo Fisher Scientific, Model 55i; hereinafter **Thermo 55i** and Agilent gas chromatograph with flame ionization detection, Model 6890N Network; hereinafter **GC-FID**).

SENSIT SPOD (*5 units tested*):

- VOC Sensor – PID (non-FEM)
  - VOC operable range: 0.1 – 30 ppm
  - Manufacturer stated Accuracy: ±0.2 ppm or 20%
  - Measurement interval: 1-min
- Measures: VOC (ppm)
- Unit cost: ~$3,213
- Units IDs: 1624, 1625, 1626

SENSIT SPOD

Thermo 55i

GC-FID

***Reference Instruments*:**

- **Thermo Fisher 55i**
  - Measures: methane (CH_4) and total non-methane hydrocarbon (NMHC)
  - Unit cost: ~$27,000
  - Specifications:
  - Measurement ranges: 0-50 ppm
  - Limit of Detection (LOD): 50 ppb
  - Analysis time: ~70 seconds
  - Accuracy: ±1% of range
  - Repeatability: ±2% of measured value or 50 ppb (whichever is larger)
  - Drift: ±2% of span over 24 hours
  - Ambient operating temperature: 15-35 °C
  - Sample temperature: ambient to 35 °C
- **Agilent Gas Chromatograph**
  - Flame Ionization Detection
  - Time Resolution: 22-min
  - Unit cost: ~ $100,000
  - Limit of Detection (LOD): dependent on the species, typically <1 ppb

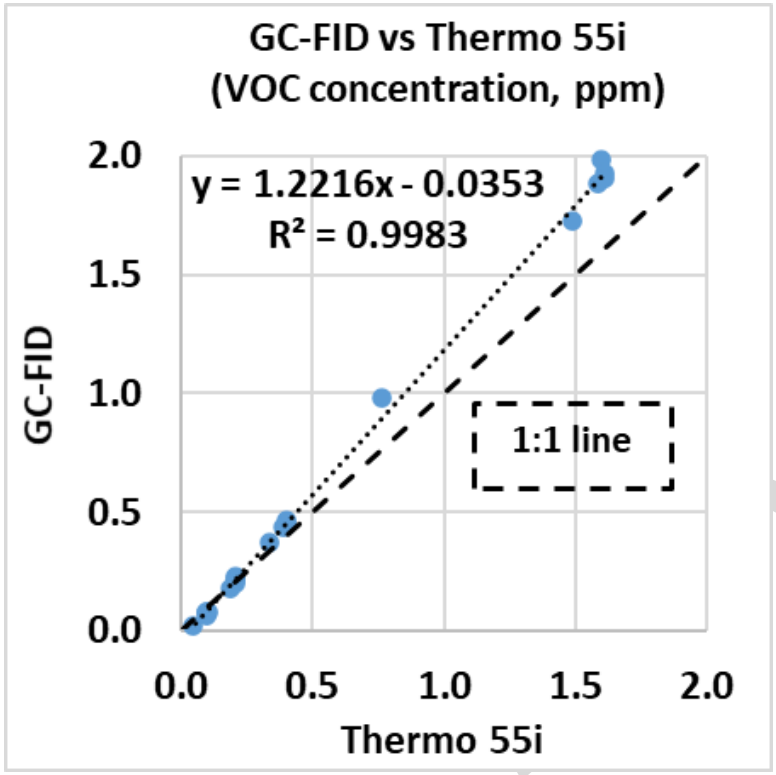
Outline

1. Reference instruments comparison
2. VOC blend results (Phase 1 through Phase 6)
3. Benzene-only results (Phase 2 and Phase 6)
4. Discussion

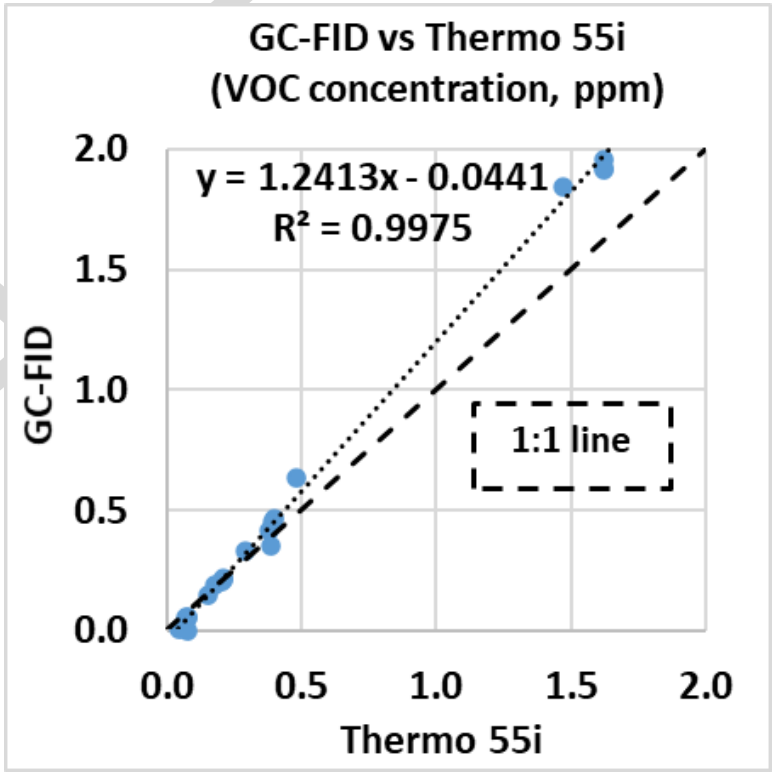
VOC Blend Results

GC-FID vs Thermo 55i: VOC Blend

Beginning of Evaluation



End of Evaluation

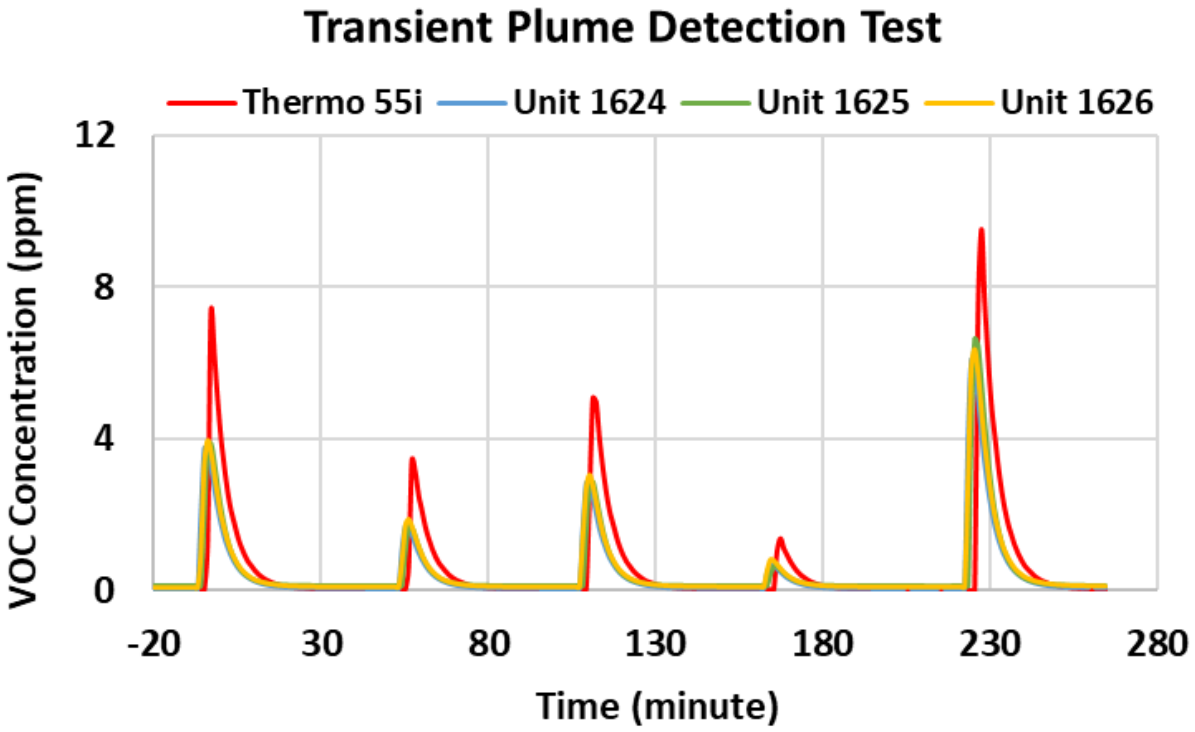


- Very strong correlations between the Thermo 55i and GC-FID ($R^2 > 0.99$).
- The two reference instruments reported similar VOC concentrations at both the beginning and the end of evaluation.

Phase 1: Transient Plume Detection

Testing Phase #1	Method	Parameters Evaluated
Transient Plume Detection	5 VOC plume events at various concentrations in randomized order	• Response time • % of peak detection

SENSIT SPOD vs Thermo 55i



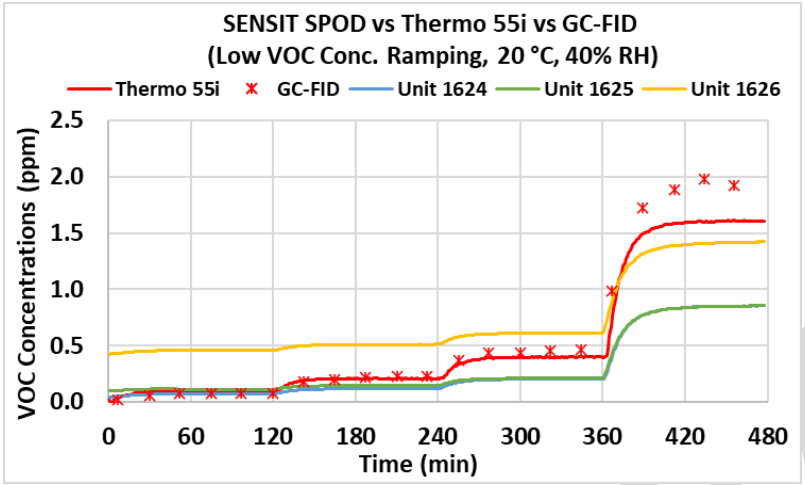
- The SENSIT SPOD sensors responded to 100% of the VOC peaks generated.
- The SENSIT SPOD sensors detected the peaks about 2 minutes earlier on average than the Thermo 55i; the apparent difference is due to different sampling times of the sensors vs. the reference instrument.

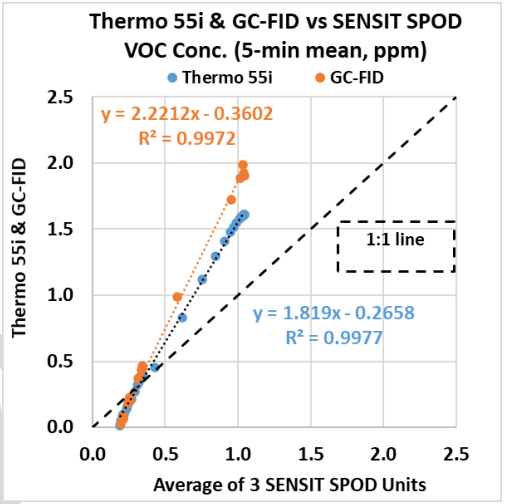
Phase 2:
Initial Concentration Ramping

Testing Phase #2	Method	Parameters Evaluated
Initial Concentration Ramping	• Low conc. ramping with VOC blend (0.06 to 1.6 ppm) • High conc. ramping with VOC blend (2 to 8 ppm) • Low conc. ramping with benzene-only (0.015 to 0.4 ppm) • High conc. ramping with benzene-only (0.5 to 2 ppm)	• Sensor Detection Limit, R^2, Accuracy, Precision, IMV, Data Recovery

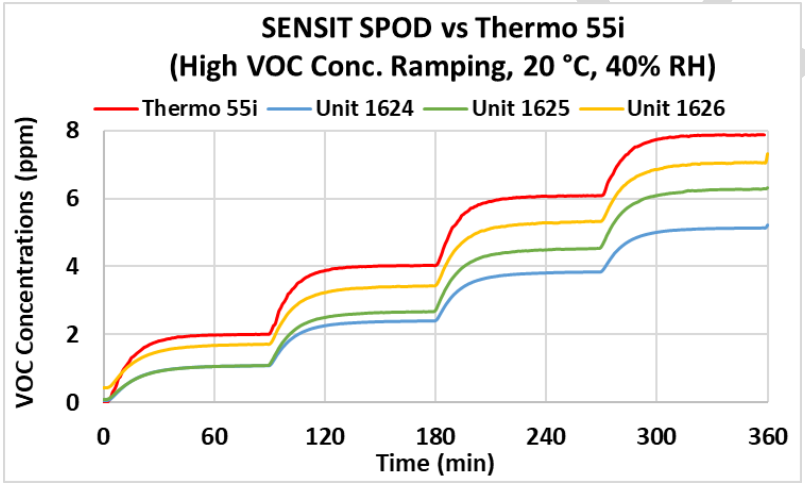
SENSIT SPOD vs Thermo 55i vs GC-FID

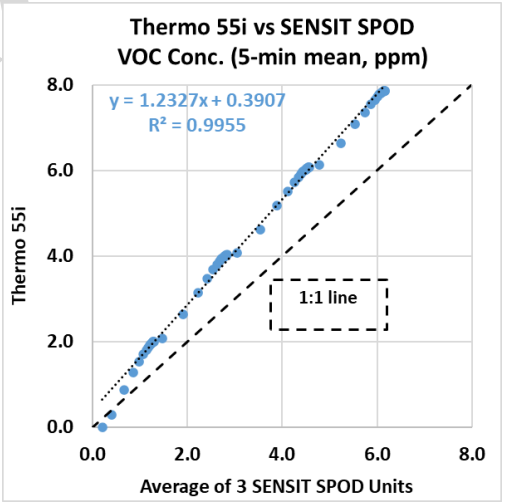
Low Ramp





High Ramp



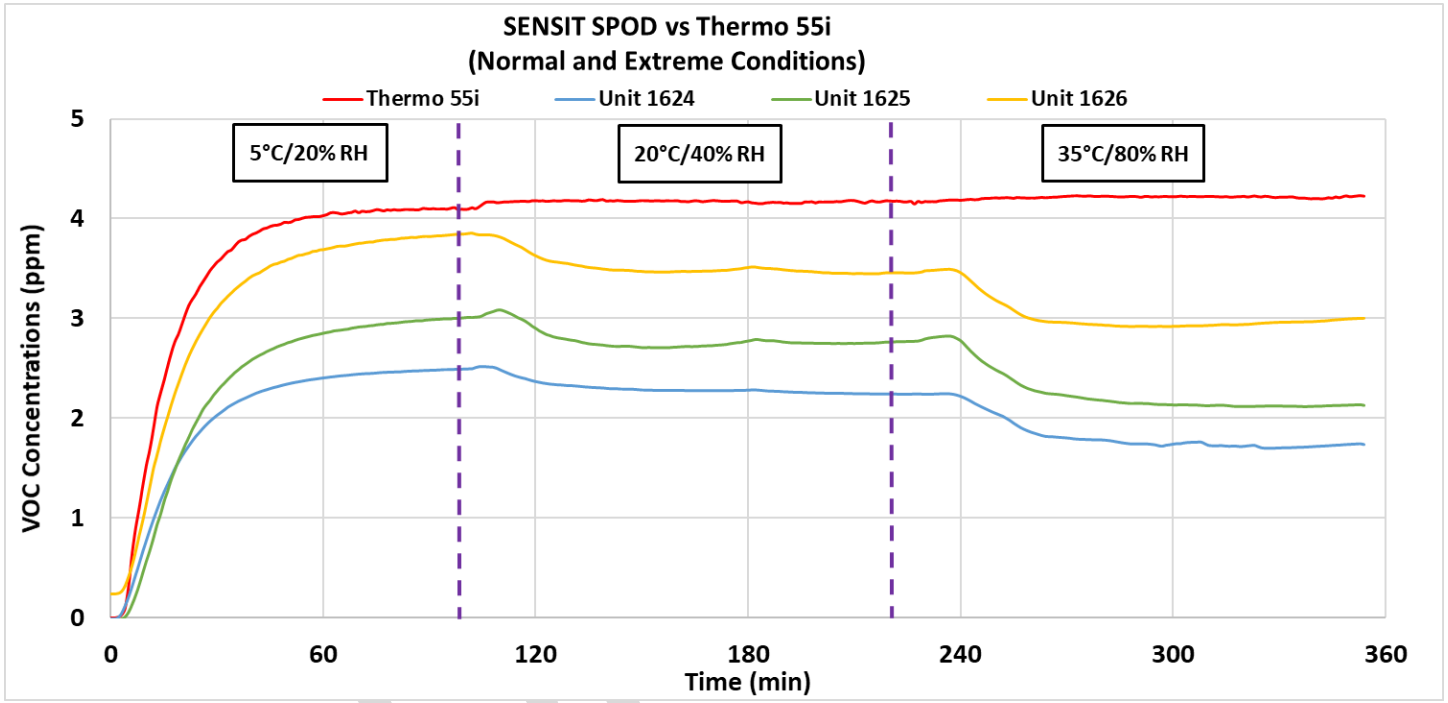


- The SENSIT SPOD sensors tracked the VOC concentration variation as recorded by the reference instruments.
- The SENSIT SPOD sensors showed very strong correlations ($R^2 > 0.99$) in both the low and high concentration ramps against the reference instruments
- The SENSIT SPOD sensors generally underestimated the VOC concentrations measured by the reference instrument except for Unit 1626 at VOC concentrations ≤ 0.5ppm.
- Unit 1626 generally showed a higher baseline compared to Units 1624 and 1625

Phase 3: Effect of Temperature and Relative Humidity

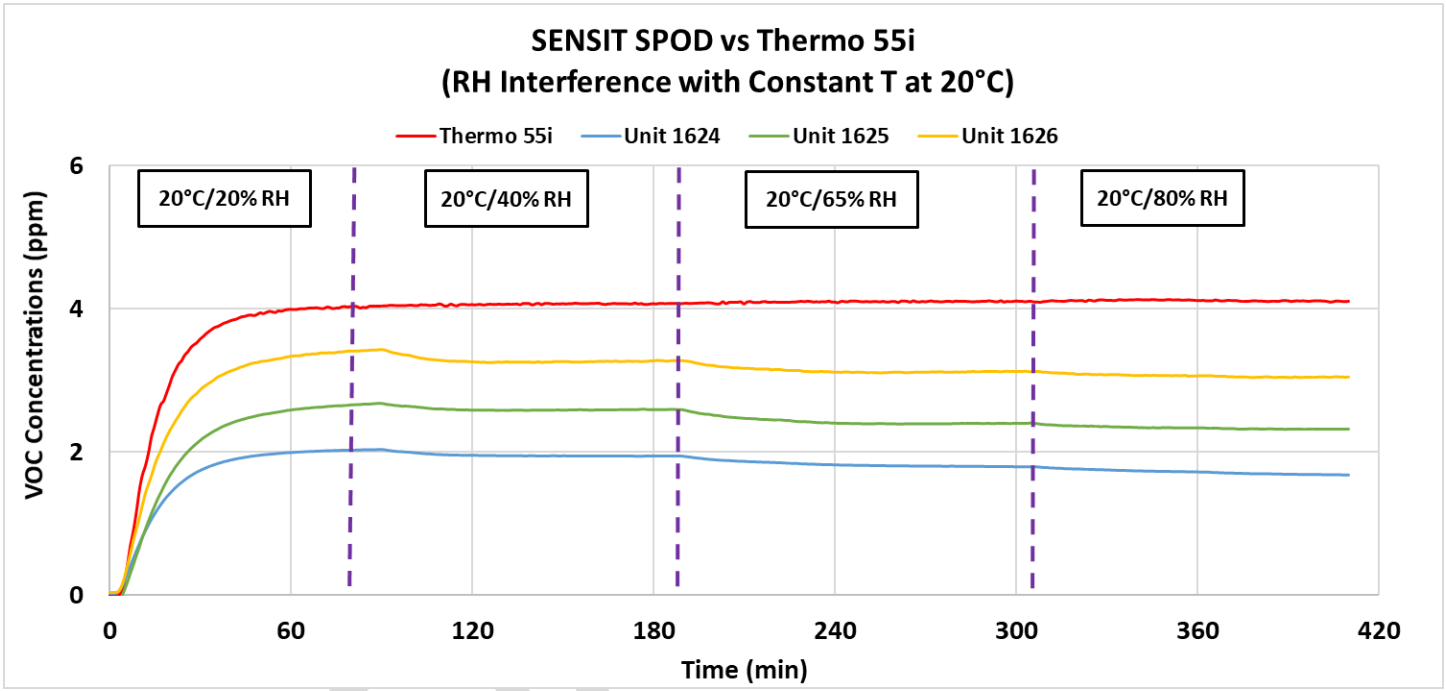
Testing Phase #3	Method	Parameters Evaluated
Effect of Temperature and RH	• Extreme Conditions: hot/humid; cold/dry and VOC = 4ppm • RH interference: 15% to 80% RH; T = 20°C and VOC = 4 ppm • T interference: 20°C to 10°C to 30°C to 20°C; RH = 40% and VOC = 4 ppm • *T interference: 20°C to 10°C to 30°C to 20°C; AH = constant and VOC = 4 ppm	• Climate susceptibility, Accuracy, Precision, IMV, Data Recovery

Normal and Extreme Conditions



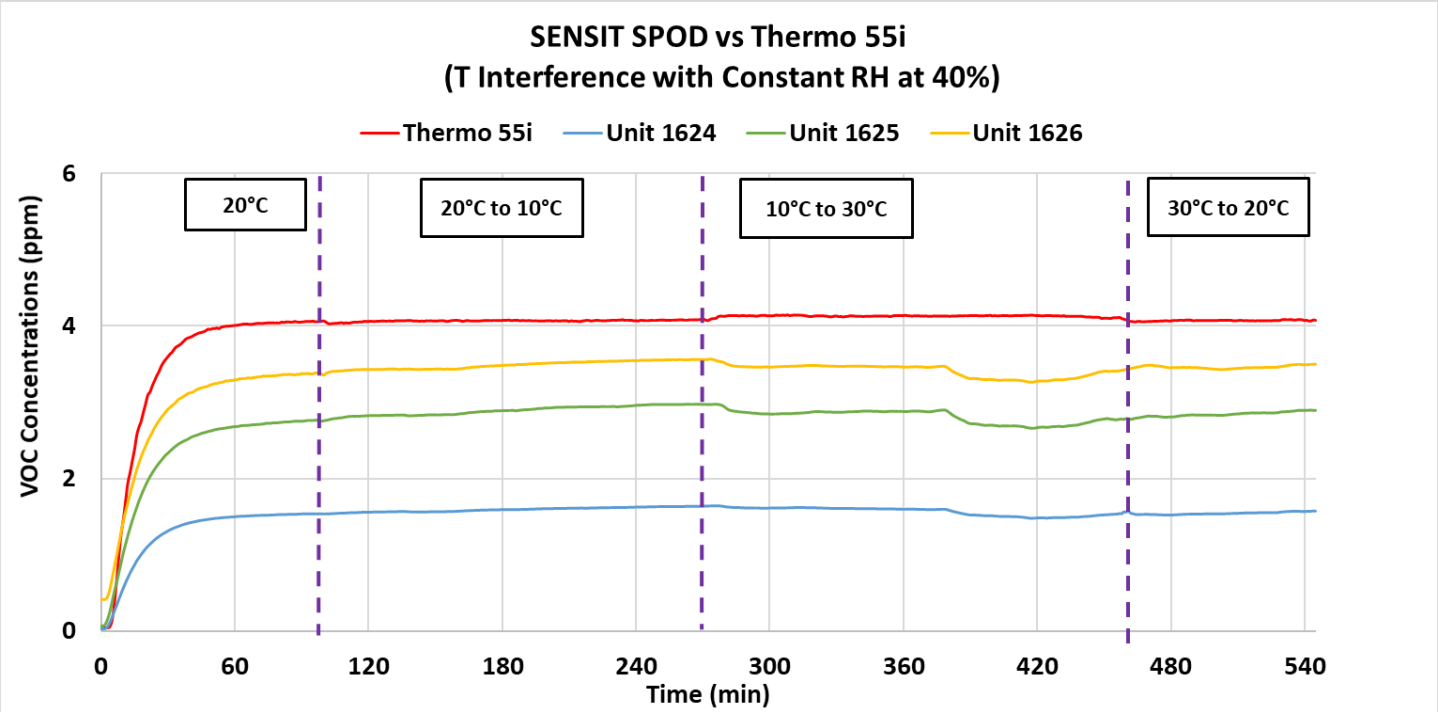
- The SENSIT SPOD sensors showed a decrease in mean VOC concentrations as T/RH increased from 5°C/20% RH to 20°C/40% RH, and then a larger decrease in mean VOC concentrations as temperature/RH was further increased to 35°C/80% RH.
- The SENSIT SPOD sensors' VOC concentrations decreased by ~20-30% at 35°C/80% RH as compared to the VOC concentrations at 5°C/20% RH.

RH Interference



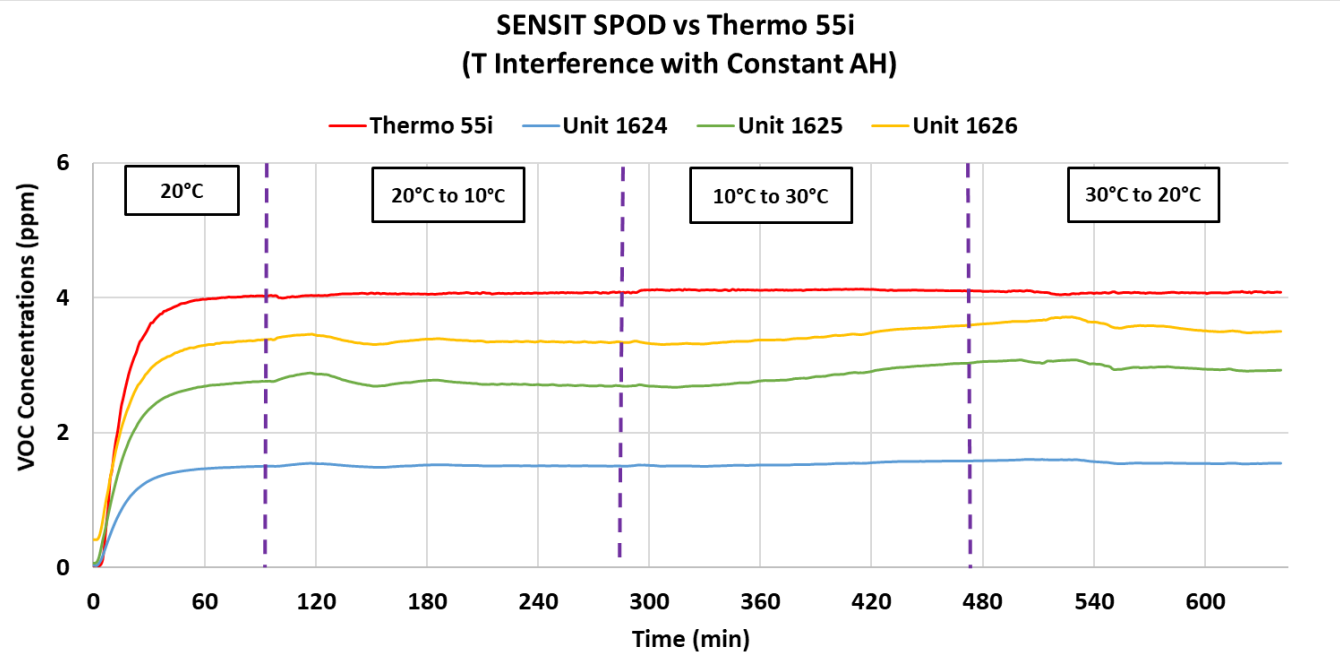
- The RH interference test was conducted at constant temperature of 20°C with RH increasing from 20% to 80%.
- RH had minimal effect on the VOC concentrations measured by the Thermo 55i.
- The SENSIT SPOD sensors' VOC concentrations decreased by ~10-16% as RH increased from 20% to 80%.

Temperature Interference at Constant RH



- The Temperature interference test was conducted at constant RH of 40%.
- T had minimal effect on the VOC concentrations measured by the Thermo 55i.
- A temperature change at constant RH appears to cause sensor response to move in the opposite direction, i.e. the sensors' VOC reading increases when temperature decreases and vice versa, after steady-state temperature and RH conditions are realized. The average change of VOC concentrations between the initial and final 20°C/40% RH conditions was ~3.8%.

Temperature Interference at Constant Absolute Humidity (AH)

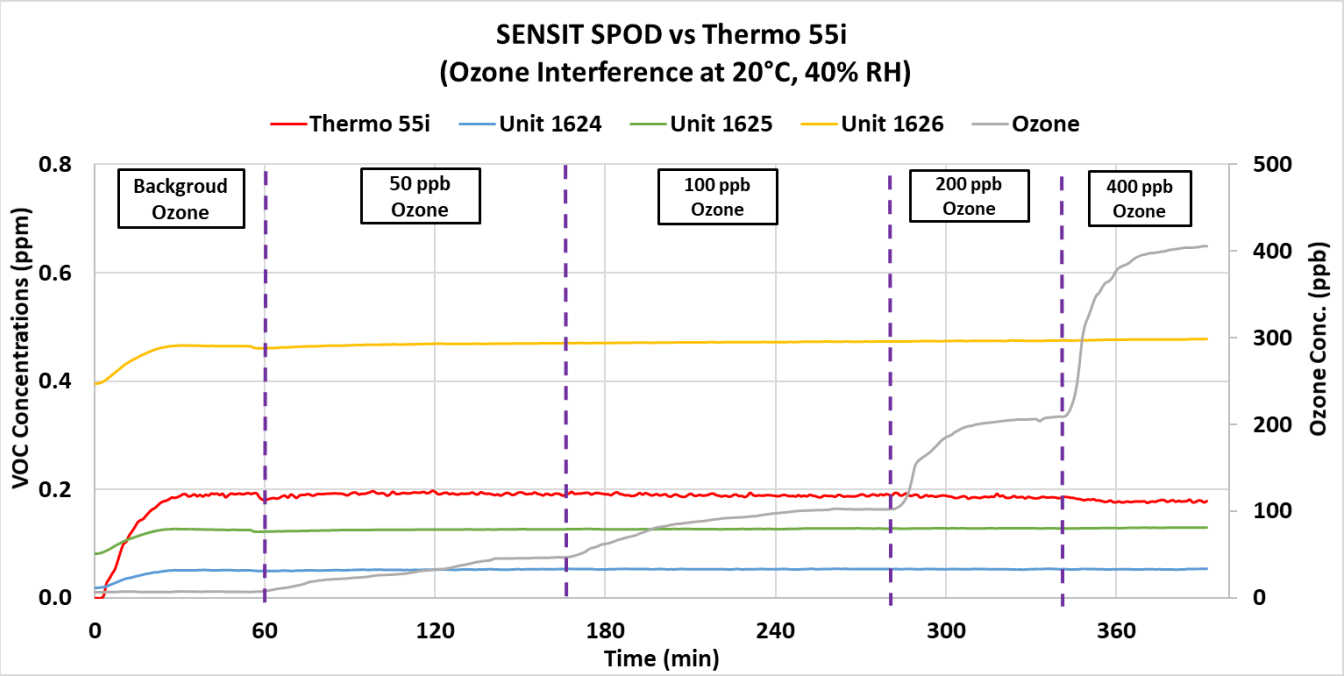


- The Temperature interference at constant AH setpoint was conducted at the moisture content corresponding to 20°C and 40% RH.
- T had minimal effect on the average VOC concentrations measured by the Thermo 55i.
- A temperature change at constant AH setpoint appeared to cause the sensor response to change in the same direction of temperature change. The average change of VOC concentrations between the initial and final 20°C with constant AH conditions was ~4.4%.

Phase 4:
Effect of Gaseous Interferents

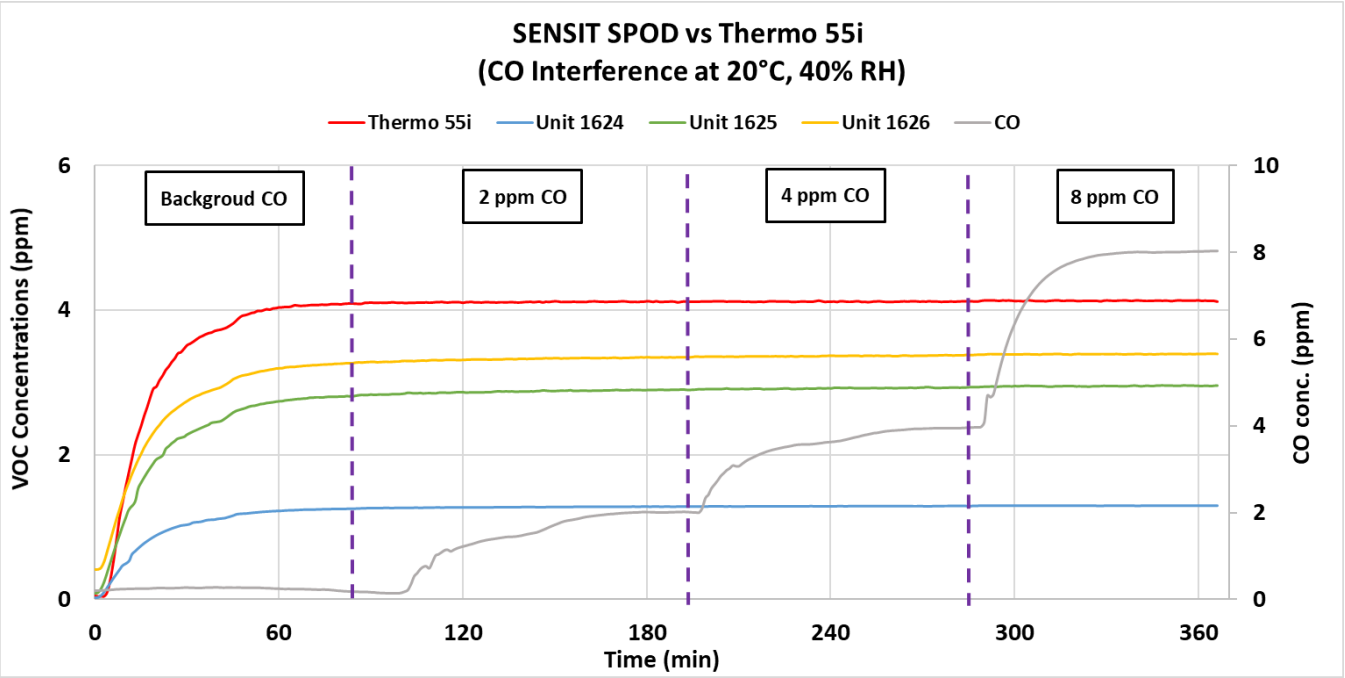
Testing Phase #4	Method	Parameters Evaluated
Effect of gaseous interferents	• Ozone (1 to 400 ppb; 20 °C/40% RH and VOC = 200 ppb) • Carbon Monoxide (background to 8 ppm; 20 °C/40% RH and VOC = 4 ppm) • Carbon Dioxide (background to 8000 ppm; 20 °C/40% RH and VOC = 4 ppm)	• Response to interferents, Accuracy, Precision, IMV, Data Recovery

Ozone Interferent



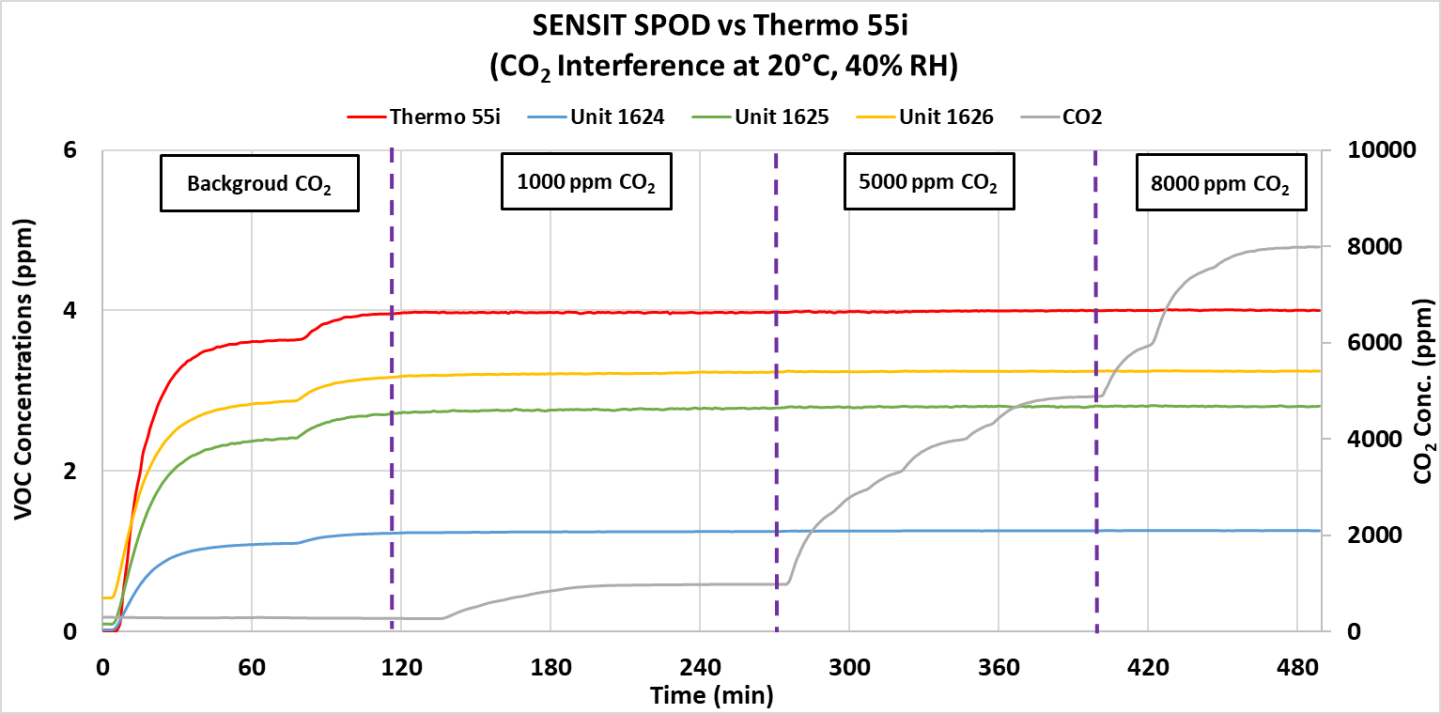
- Ozone interferent test: sensors were subjected to increasing ozone concentration from background level to 400 ppb while holding VOC concentration constant at 0.2 ppm.
- Ozone had minimal effect on the VOC concentrations measured by the Thermo 55i and the SENSIT SPOD sensors as O_3 increased from background to ~400 ppb.

CO Interferent



- CO interferent test: sensors were subjected to increasing CO concentration from background level to 8ppm while holding VOC concentration constant at ~4 ppm.
- CO had minimal effect on the VOC concentrations measured by the Thermo 55i and the SENSIT SPOD sensors as CO increased from background to ~8 ppm.

CO_2 Interferent

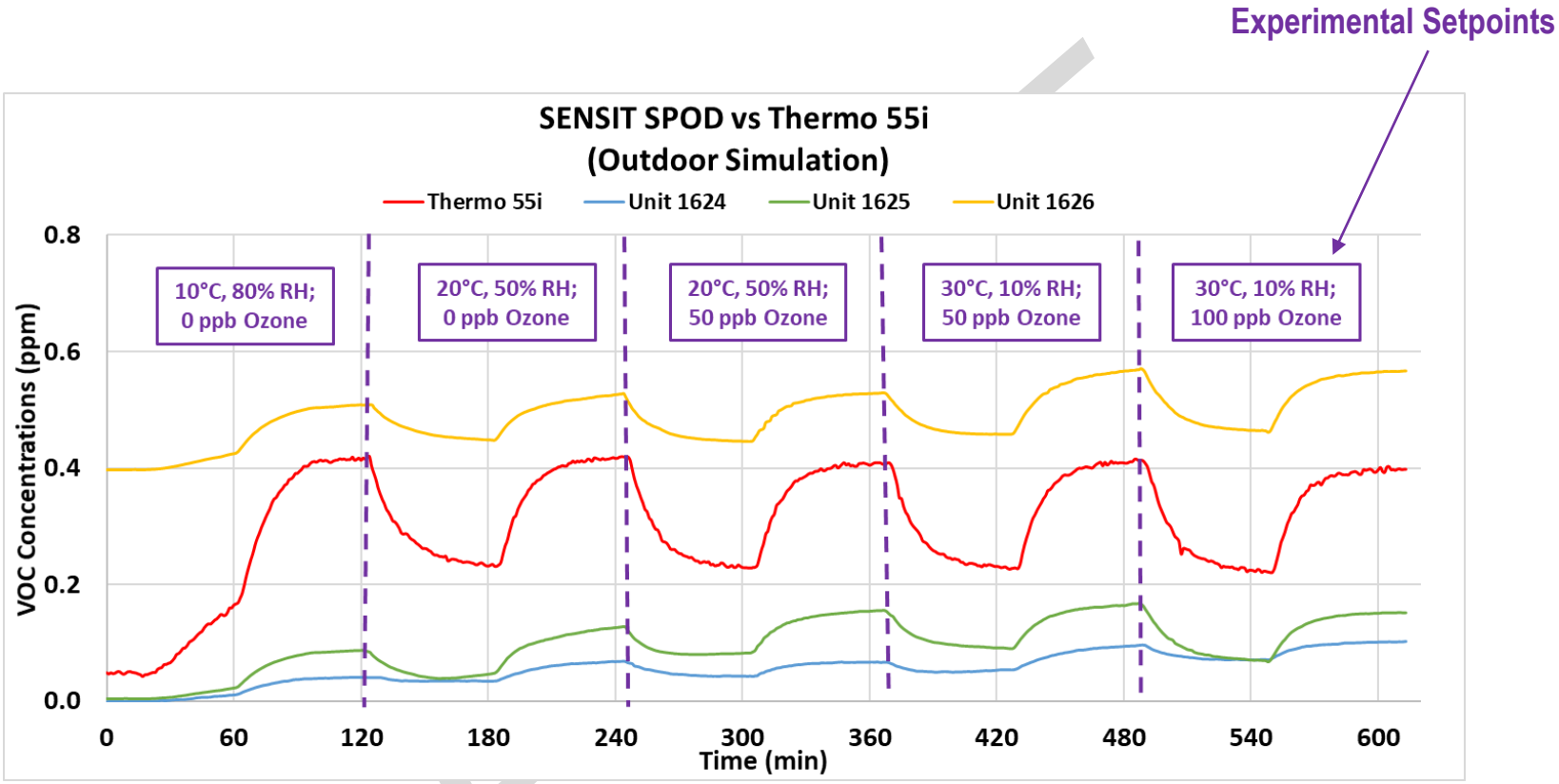


- CO_2 interferent test: sensors were subjected to increasing CO_2 concentration from background level to 8 ppm while holding VOC concentration constant at ~4 ppm.
- CO_2 had minimal effect on the VOC concentrations measured by the Thermo 55i and the SENSIT SPOD as CO_2 increased from a background value of ~280 ppm to ~8000 ppm.

Phase 5: Outdoor Simulation

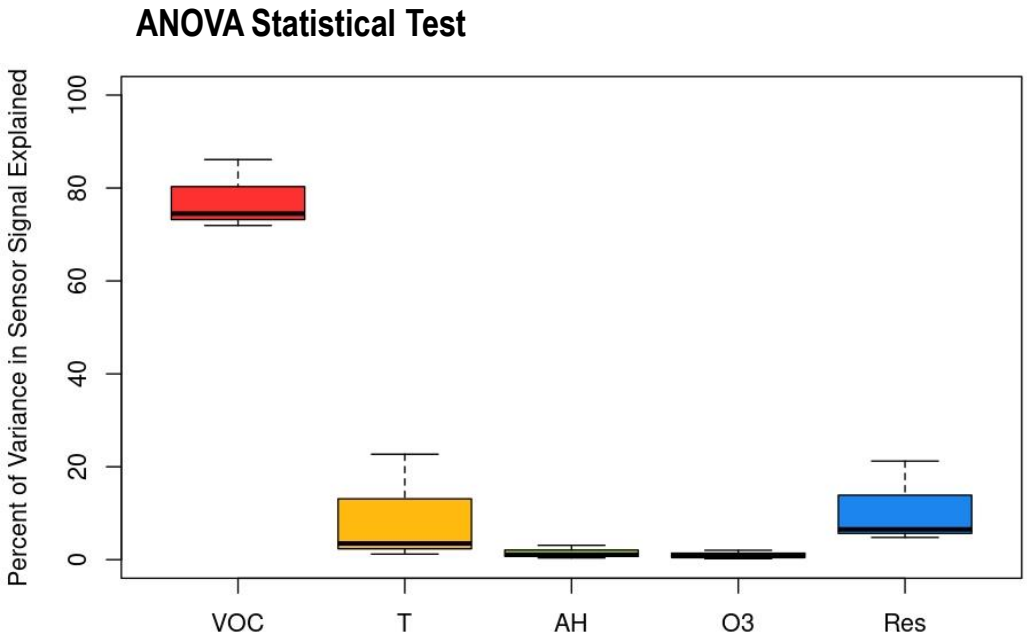
Testing Phase #5	Method	Parameters Evaluated
Outdoor Simulation	• Various combination of Ozone (0 to 100 ppb) and VOC (200 to 400 ppb) concentrations, T (10 to 30 °C) and RH (10 to 80%)	• Accuracy, precision, IMV, Data Recovery, Analysis of Variance (ANOVA),

Outdoor Simulation



- The SENSIT SPOD sensors generally tracked well with the VOC concentration variation as recorded by Thermo 55i.

Outdoor Simulation



	Variance explained by explanatory variables, %				
	REF	T	AH	OZONE	RES
Unit 1624	71.9	22.7	0.4	0.2	4.8
Unit 1625	74.5	1.2	1.1	2.0	21.2
Unit 1626	86.1	3.5	3.1	0.8	6.5

- VOC concentration as measured by the Thermo 55i explained ~ 78% of the SENSIT SPOD VOC readings on average in the ANOVA statistical test.
- **Temperature, AH and Ozone** explained a small percentage (<4%) of the variance when T, AH and ozone are included in the ANOVA statistical test, except for Unit 1624 where **T** explained about 23% of the variance.

Notes:
"REF" is the Thermo 55i reference VOC monitor reading
"RES" is the residual, or variance that is not explained by the other variables

Phase 6:
Final Concentration Ramping

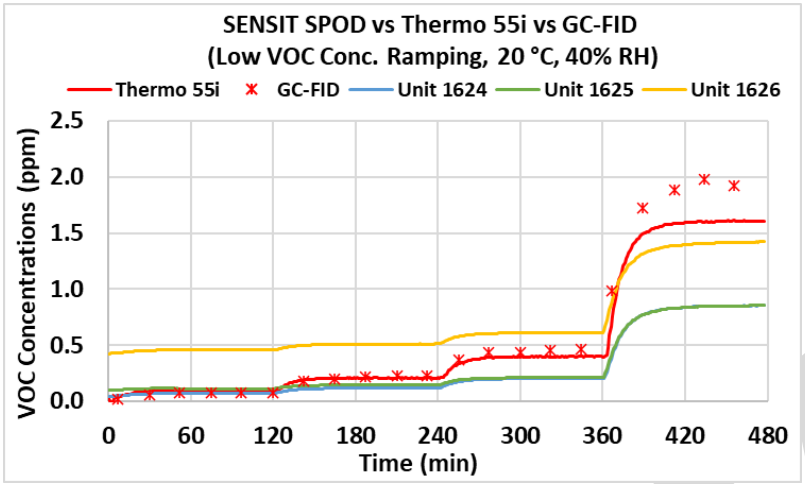
Testing Phase #6	Method	Parameters Evaluated
Final Concentration Ramping	• Low conc. ramping with VOC blend (0.06 to 1.6 ppm) • High conc. ramping with VOC blend (2 to 8 ppm) • Low conc. ramping with benzene-only (0.015 to 0.4 ppm) • High conc. ramping with benzene-only (0.5 to 2 ppm)	• Sensor Detection Limit, R^2, Accuracy, Precision, IMV, Data Recovery

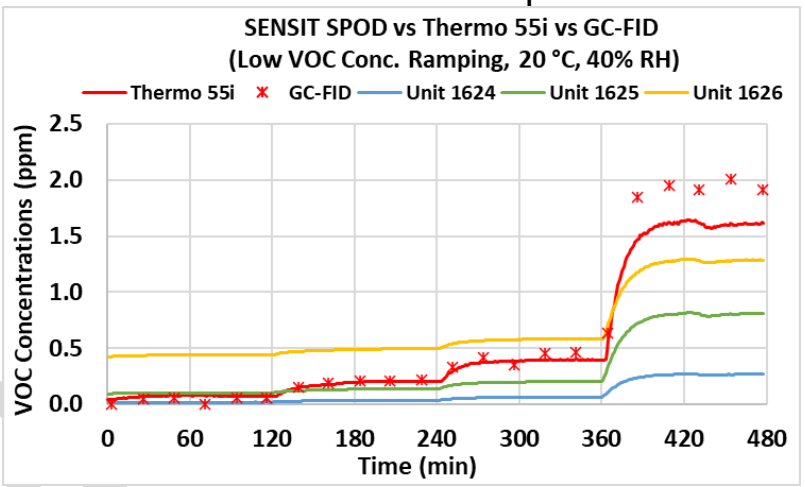
SENSIT SPOD vs Thermo 55i vs GC-FID

Initial Ramp

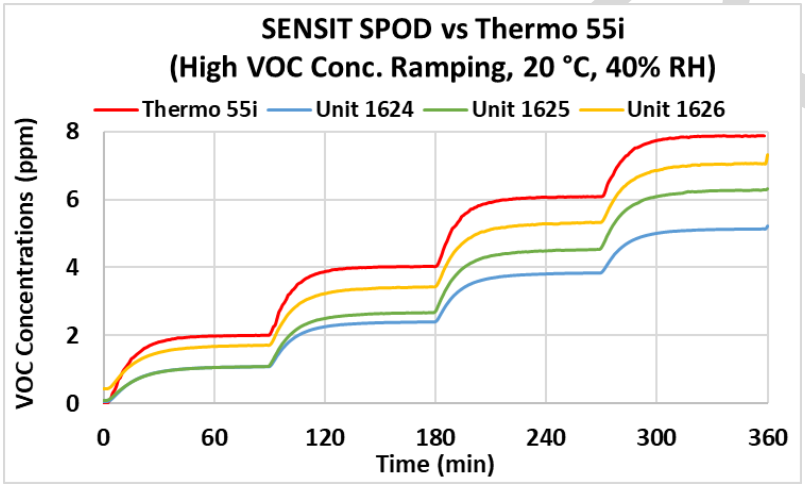
Final Ramp

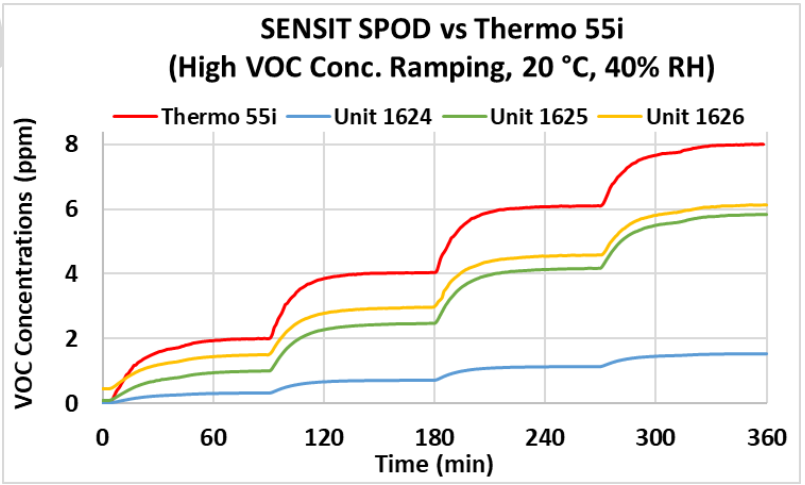
Low Ramp





High Ramp





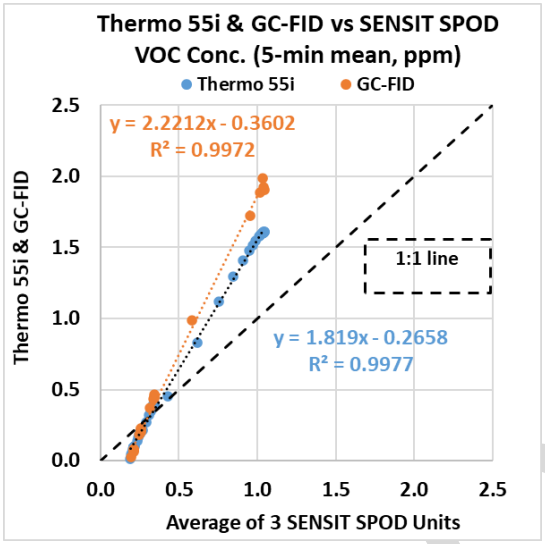
SENSIT SPOD vs Thermo 55i vs GC-FID

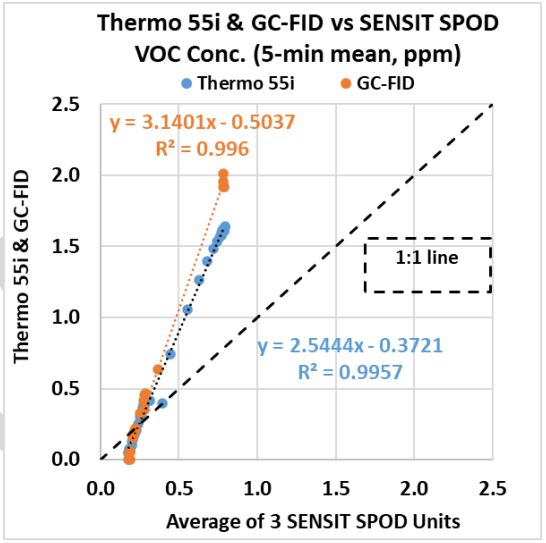
Initial Ramp

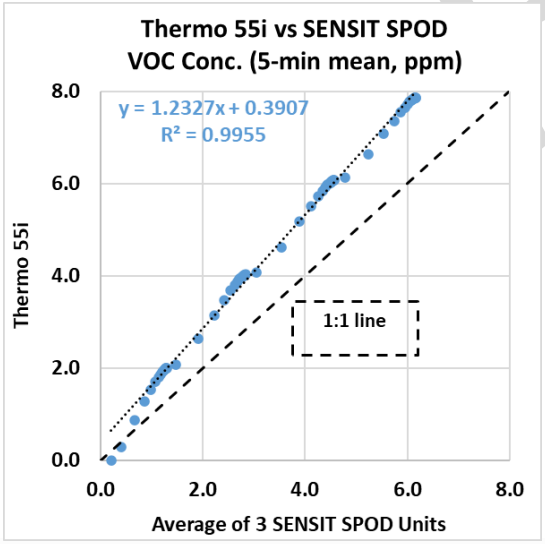
Final Ramp

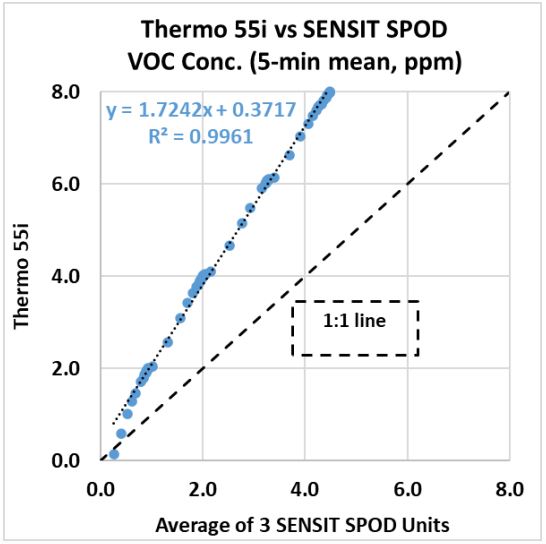
Low Ramp

High Ramp



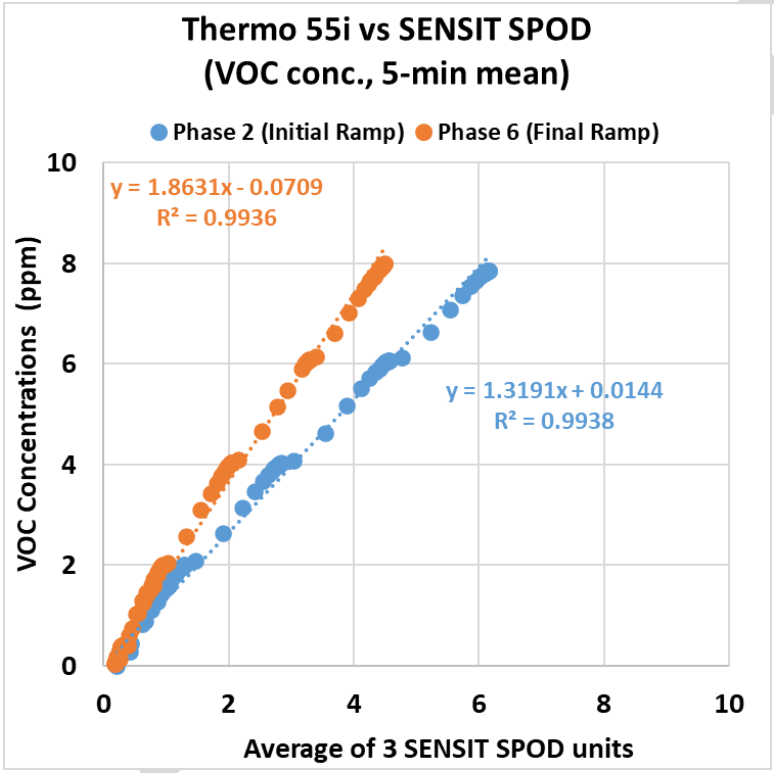






Short-Term Sensor Response Change

- Short-term sensor response change is characterized as the change in reference-sensor regression between the initial and final concentration ramping experiments



- Combining data from both low and high concentration ramps of the VOC blend, the slope of the final concentration ramping was higher, suggesting that the SENSIT SPOD sensors on average became less sensitive to unit changes in VOC concentrations compared to the initial concentration ramping.

Summary Statistics

Initial Ramp

Sensors					Thermo 55i			GC-FID		
Nominal VOC Conc., ppm	Avg, ppm	Precision, %	IMV, %	SDL, ppm	Ref avg, ppm	Sensor Bias Error, ppm	Sensor Accuracy, %	Ref avg, ppm	Sensor Bias Error, ppm	Sensor Accuracy, %
0.06	0.21	100	181.0	Unit 1624: 0.03-0.11	0.10	0.12	-22.0	0.08	0.13	-67.9
0.2	0.26	100	152.5	Unit 1625: 0.05-0.18	0.21	0.05	76.4	0.23	0.03	85.4
0.4	0.34	100	119.3		0.40	-0.06	86.2	0.46	-0.12	74.3
1.6	1.04	100	54.4	Unit 1626: 0.03-0.11	1.61	-0.56	64.9	1.91	-0.86	54.7
2	1.29	99.9	49.7		2.0	-0.7	64.3			
4	2.83	99.9	36.6		4.0	-1.2	70.2			
6	4.56	99.9	32.5		6.1	-1.5	75.0			
8	6.16	99.9	31.3		7.9	-1.7	78.4			

Summary Statistics

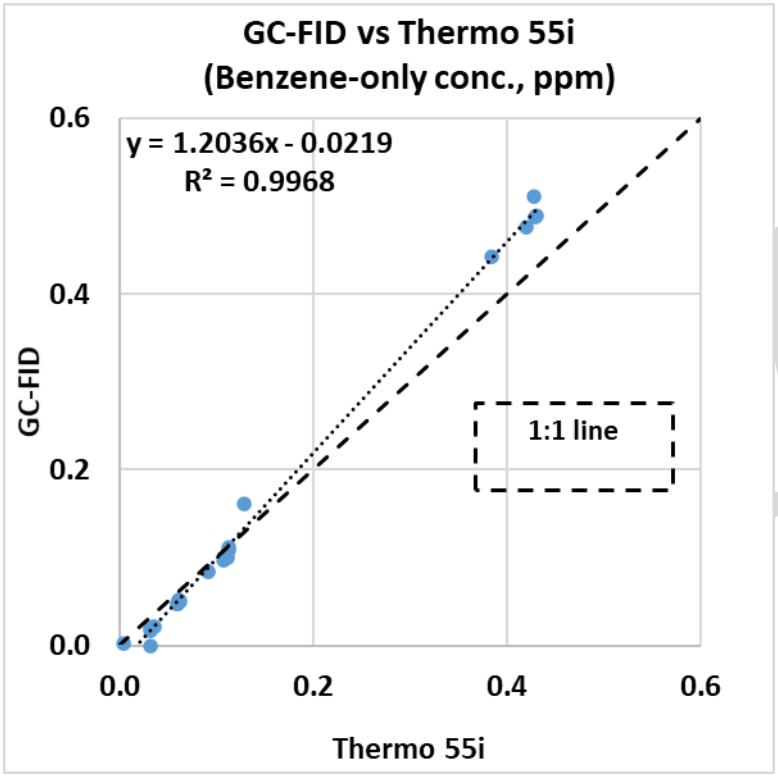
Final Ramp

Sensors					Thermo 55i			GC-FID		
Nominal VOC Conc., ppm	Avg, ppm	Precision, %	IMV, %	SDL, ppm	Ref avg, ppm	Sensor Bias Error, ppm	Sensor Accuracy, %	Ref avg, ppm	Sensor Bias Error, ppm	Sensor Accuracy, %
0.06	0.19	100	224.5	Unit 1624: 0.04-0.14	0.07	0.12	-66.2	0.05	0.13	-145.3
0.2	0.22	100	205.7	Unit 1625: 0.05-0.19	0.20	0.02	90.7	0.22	0.01	97.4
0.4	0.27	100	183.8		0.40	-0.12	68.8	0.47	-0.18	60.7
1.6	0.79	100	129.1	Unit 1626: 0.04-0.14	1.61	-0.82	48.9	1.92	-1.13	41.2
2	0.93	99.9	125.7		2.00	-1.07	46.6			
4	2.04	99.9	110.0		4.04	-2.00	50.6			
6	3.29	100.0	104.7		6.10	-2.81	53.9			
8	4.48	100.0	102.4		7.99	-3.51	56.1			

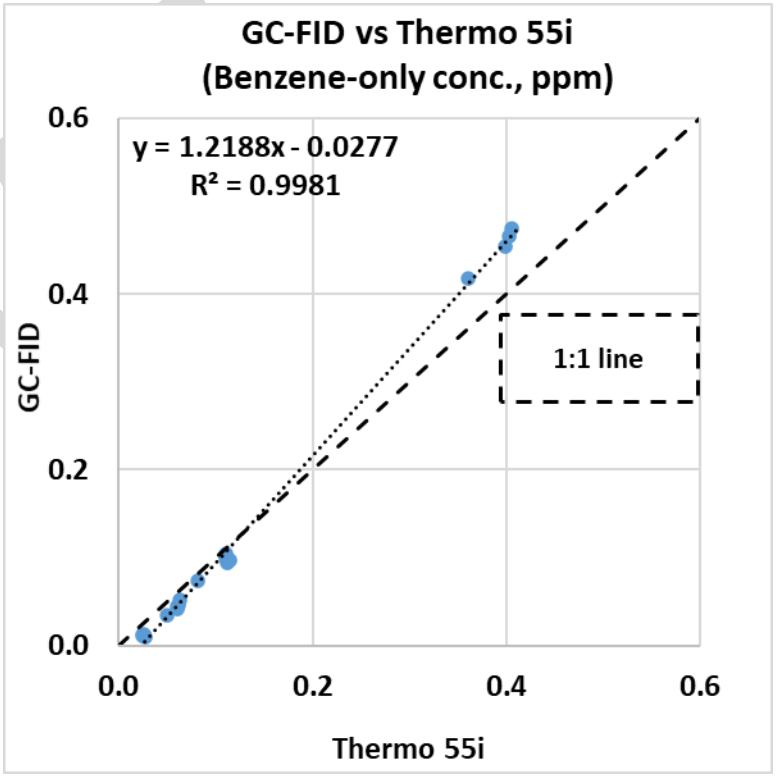
Benzene-Only Results

GC-FID vs Thermo 55i: Benzene-only

Beginning of Evaluation



End of Evaluation

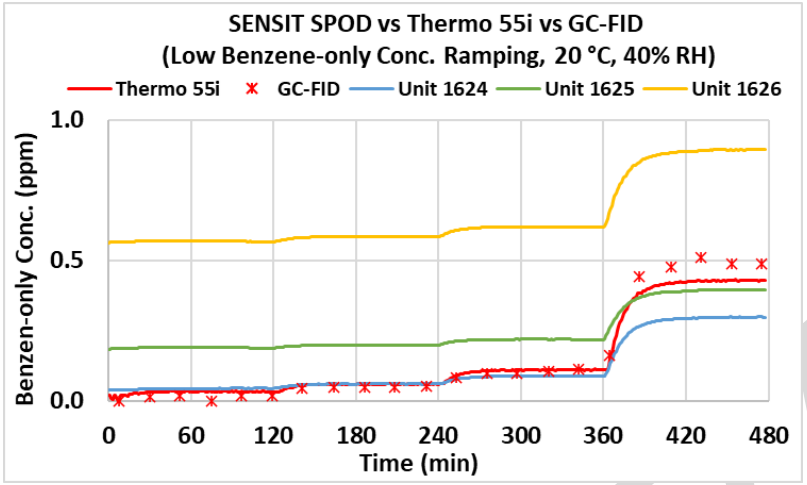


- Very strong correlations between the Thermo 55i and GC-FID (R^2 > 0.99).
- The two reference instruments reported similar VOC concentrations at both the beginning and the end of evaluation.

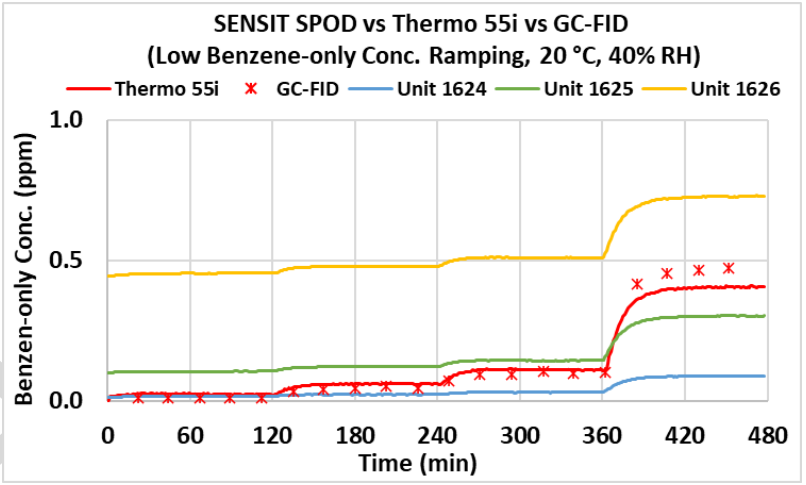
SENSIT SPOD vs Thermo 55i vs GC-FID

Low Ramp

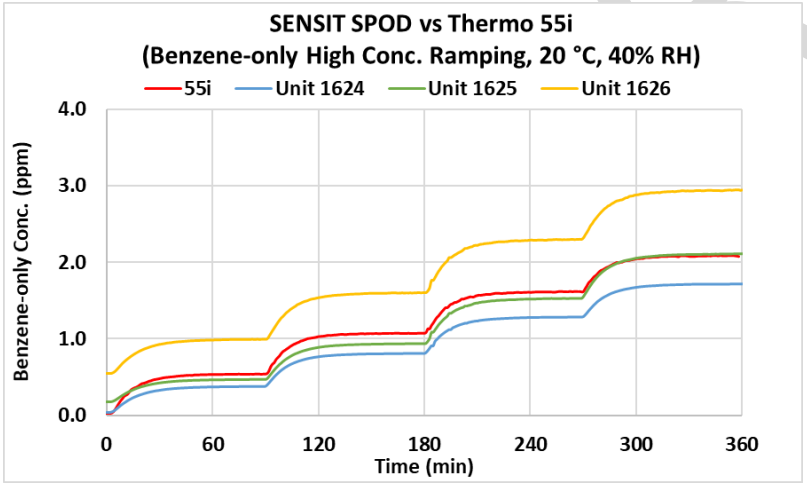
Initial Ramp

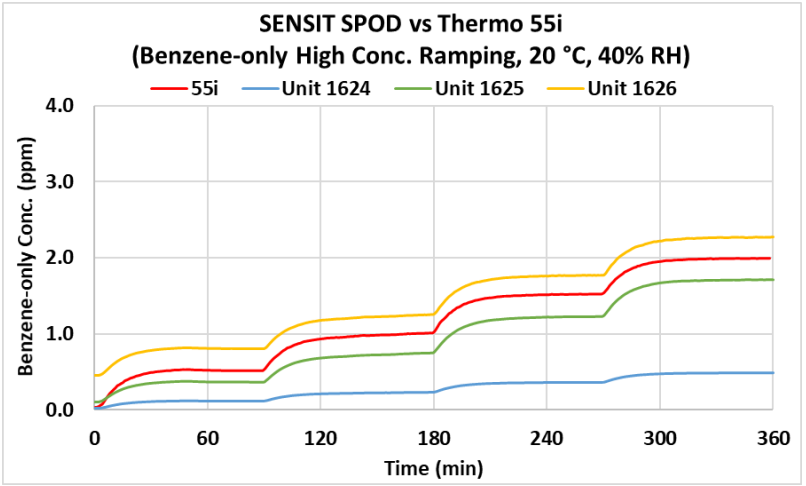


Final Ramp



High Ramp





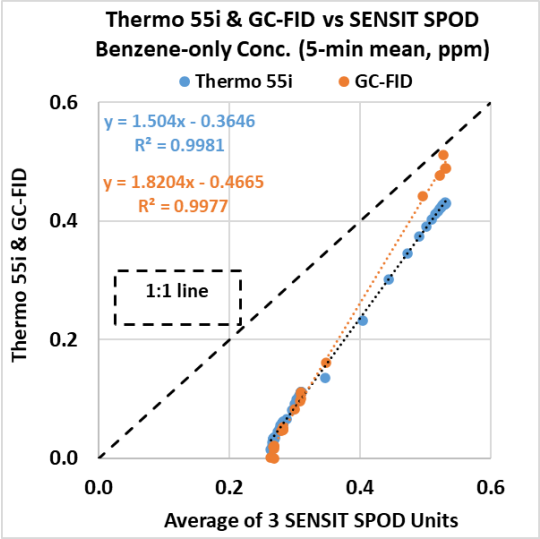
SENSIT SPOD vs Thermo 55i vs GC-FID

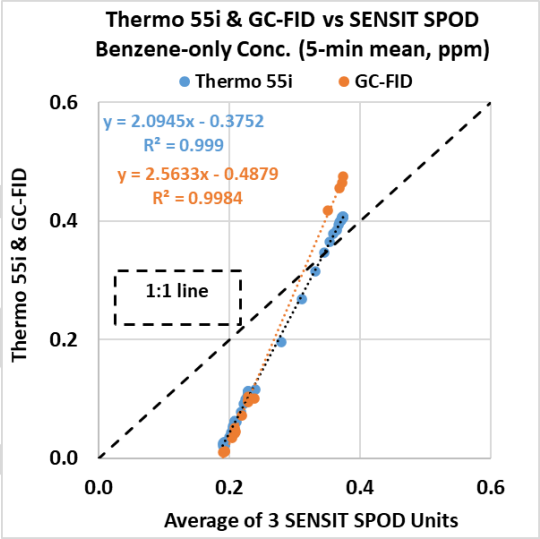
Initial Ramp

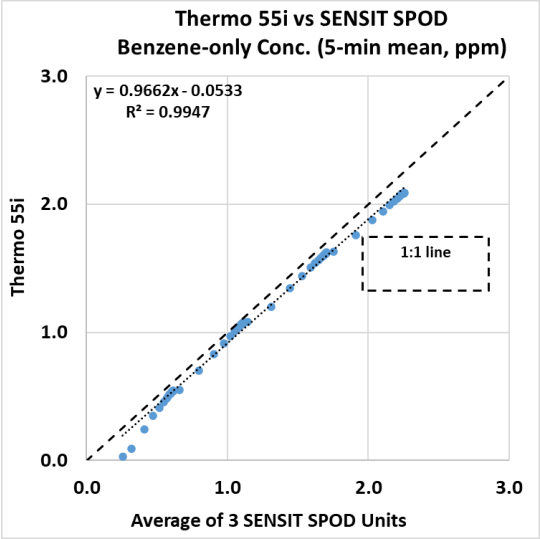
Final Ramp

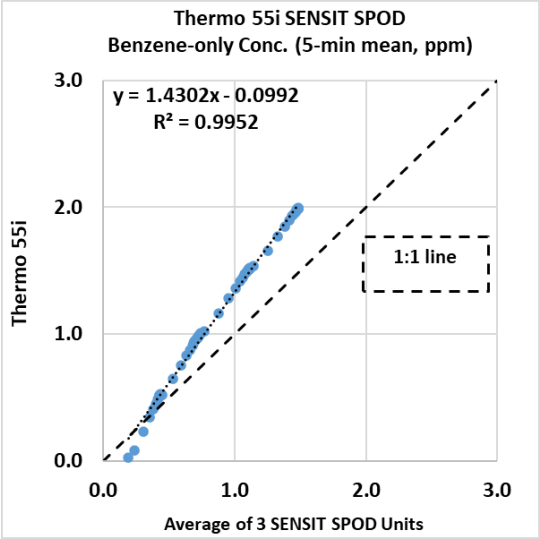
Low Ramp

High Ramp



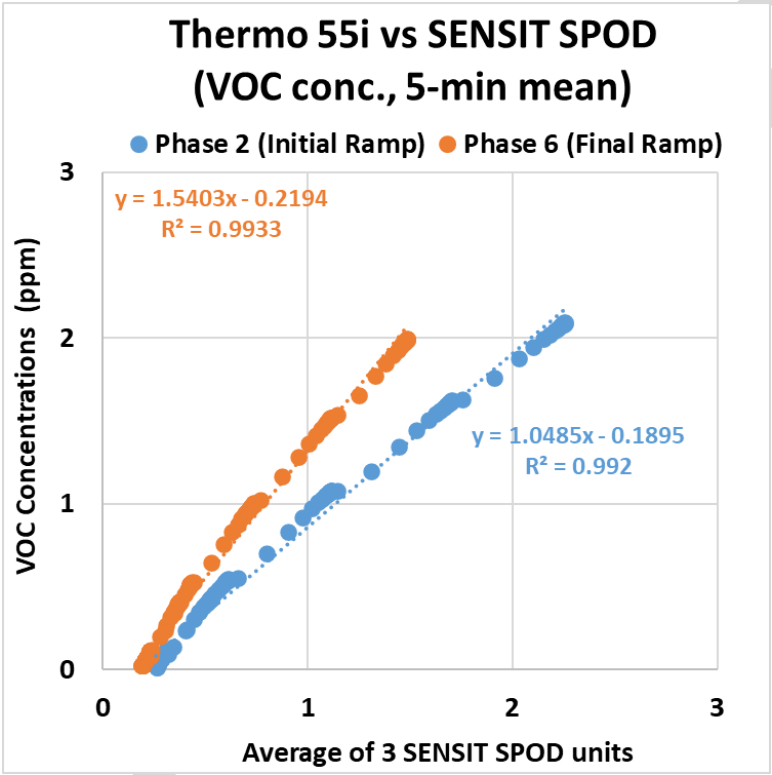






Short-Term Sensor Response Change: Benzene-only

- Short-term sensor response change is characterized as the change in reference-sensor regression between the initial and final concentration ramping experiments



- Combining data from both low and high concentration ramps of the VOC blend, the slope of the final concentration ramping was higher, suggesting that the SENSIT SPOD sensors on average became less sensitive to unit changes in benzene-only concentrations compared to the initial concentration ramping.

Summary Statistics – Benzene-only

Initial Ramp

Sensors					Thermo 55i			GC-FID		
Nominal VOC Conc., ppm	Avg, ppm	Precision, %	IMV, %	SDL, ppm	Ref avg, ppm	Sensor Bias Error, ppm	Sensor Accuracy, %	Ref avg, ppm	Sensor Bias Error, ppm	Sensor Accuracy, %
0.015	0.28	100	195.0	Unit 1624: 0.006-0.021	0.03	0.25	-650.5	0.02	0.28	-1283.4
0.05	0.28	100	185.8		0.06	0.22	-262.8	0.05	0.23	-337.6
0.1	0.31	100	171.4	Unit 1625: 0.01-0.033	0.11	0.20	-77.9	0.11	0.20	-76.1
0.4	0.53	100	112.3	Unit 1626: 0.008-0.028	0.43	0.10	76.8	0.49	0.04	91.4
0.5	0.61	100	99.8		0.54	0.07	86.9			
1	1.11	100	70.6		1.08	0.04	96.4			
1.5	1.70	100	59.2		1.62	0.08	94.9			
2	2.25	100	54.1		2.09	0.16	92.1			

Summary Statistics – Benzene-only

Final Ramp

Sensors					Thermo 55i			GC-FID		
Nominal VOC Conc., ppm	Avg, ppm	Precision, %	IMV, %	SDL, ppm	Ref avg, ppm	Sensor Bias Error, ppm	Sensor Accuracy, %	Ref avg, ppm	Sensor Bias Error, ppm	Sensor Accuracy, %
0.015	0.17	100	227.0	Unit 1624: 0.007-0.023	0.02	0.15	-515.5	0.01	0.20	-1606.4
0.05	0.21	100	218.6	Unit 1625: 0.007-0.023	0.06	0.15	-140.2	0.04	0.16	-274.2
0.1	0.23	100	209.1		0.11	0.12	-7.1	0.10	0.13	-33.7
0.4	0.37	100	171.4	Unit 1626: 0.007-0.024	0.41	-0.03	91.9	0.47	-0.10	78.8
0.5	0.43	100	162.0		0.51	-0.08	83.4			
1	0.74	99.9	138.3		1.00	-0.26	73.7			
1.5	1.11	100	126.4		1.52	-0.40	73.4			
2	1.48	100	120.2		1.99	-0.51	74.5			

Discussion

- **Data Recovery:** The SENSIT SPOD sensors showed near 100% data recovery for all experiments.
- **Intra-model variability:** Moderate to high variability was observed among the SENSIT SPOD sensors for all experiments. Generally Unit 1626 has significantly higher baseline compared to units 1624 and 1625.
- **Sensor Detection Limit (SDL):** The SDL of the SENSIT SPOD sensors ranged from 0.03 to 0.18 ppm in the initial VOC ramp and 0.04 to 0.19 ppm in the final VOC ramp; the SDL of the sensors ranged from 0.006 to 0.033 ppm in the Benzene-only ramps.
- **Phase 1: Transient Plume Detection**
  - The SENSIT SPOD sensors showed 100% plume detection recovery and detected the peaks about 2 minutes earlier than the Thermo 55i; the apparent difference is due to different sampling times of the sensors vs. the reference instrument.
- **Phase 2**: **Initial Concentration Ramping**
  - ***Coefficient of Determination – VOC Blend*:** The SENSIT SPOD sensors showed very strong correlations with the reference instruments for both low and high concentration ramps ($R^2 > 0.99$)
  - ***Coefficient of Determination – Benzene-only***: The SENSIT SPOD sensors showed very strong correlations with the reference instruments for both low and high concentration ramps ($R^2 > 0.99$)

Discussion

- **Phase 3: Effect of Temperature and RH**
  - ***Extreme Conditions:*** The SENSIT SPOD sensors showed a decrease in mean VOC concentrations as T/RH increased from 5°C/20% RH to 20°C/40% RH, and then a larger decrease in mean VOC concentrations as temperature/RH was further increased to 35°C/80% RH.
  - ***RH Interference at Constant Temperature:*** In this particular test, the SENSIT SPOD sensors generally showed a decrease of ~ 12% in VOC concentration as RH increased from 25% to 80% while temperature was maintained at 20°C.
  - ***Temperature Interference at Constant Relative Humidity:*** In this particular test, the SENSIT SPOD sensors generally showed a VOC response moving in the opposite direction of a change in temperature, i.e. the sensors' VOC reading increased when temperature decreased and vice versa. The average change of VOC concentrations between the initial and final 20°C/40% RH conditions was ~3.8%.
  - ***Temperature Interference at Constant Absolute Humidity:*** In this particular test, the SENSIT SPOD sensors generally showed a VOC response moving in the same direction of a change in temperature, i.e. the sensors' VOC reading increased when temperature increased and vice versa. The average change of VOC concentrations between the initial and final 20°C with constant AH conditions was ~4.4%.

Discussion

- **Phase 4: Effects of Gaseous Interferents**
  - **Ozone**
    - ***Responses to Ozone:*** The SENSIT SPOD sensors VOC readings generally remained constant as ozone concentration increased from background value to ~ 400 ppb.
  - **CO**
    - ***Responses to CO:*** The SENSIT SPOD sensors VOC readings generally remained constant as CO increased from background value to ~8 ppm.
  - **CO_2**
    - ***Responses to CO_2:*** The SENSIT SPOD sensors VOC readings generally remained constant as CO_2 increased from background value to ~8,000 ppm.

- **Phase 5: Outdoor Simulation**
  - The sensors' VOC values tracked well with the Thermo 55i VOC values when exposed to a combination of T, RH, ozone and VOC concentrations.
  - Overall, **VOC concentration** as measured by the Thermo 55i explained ~ 78% of the SENSIT SPOD VOC readings on average in the ANOVA statistical test.
  - **Temperature, AH and Ozone** explained a small percentage (<4%) of the variance when T, AH and ozone are included in the ANOVA statistical test, except for Unit 1624 where **T** explained about 23% of the variance.

Discussion

- **Phase 6**: **Final Concentration Ramping**
  - ***Coefficient of Determination – VOC Blend***: The SENSIT SPOD sensors showed very strong correlations with the reference VOC monitor data in both the low and high concentration ramp experiments ($R^2 > 0.99$)
  - ***Coefficient of Determination – Benzene-only***: The SENSIT SPOD sensors showed very strong correlations with the corresponding reference low benzene-only ramping data ($R^2 > 0.99$)
  - ***Short-term Sensor Response Change:*** In general, the slope of the final concentration ramping was higher, suggesting that the SENSIT SPOD sensors on average became less sensitive to unit changes in VOC and benzene-only concentrations compared to the initial concentration ramping.