Building Energy and Environmental Systems Laboratory (BEESL)
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Evaluation of AL-PDA MOF Membrane:

Formaldehyde Test Results by Small Chambers

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Annex 86 expert meeting at DTU, Denmark on October 2, 2023

Overview

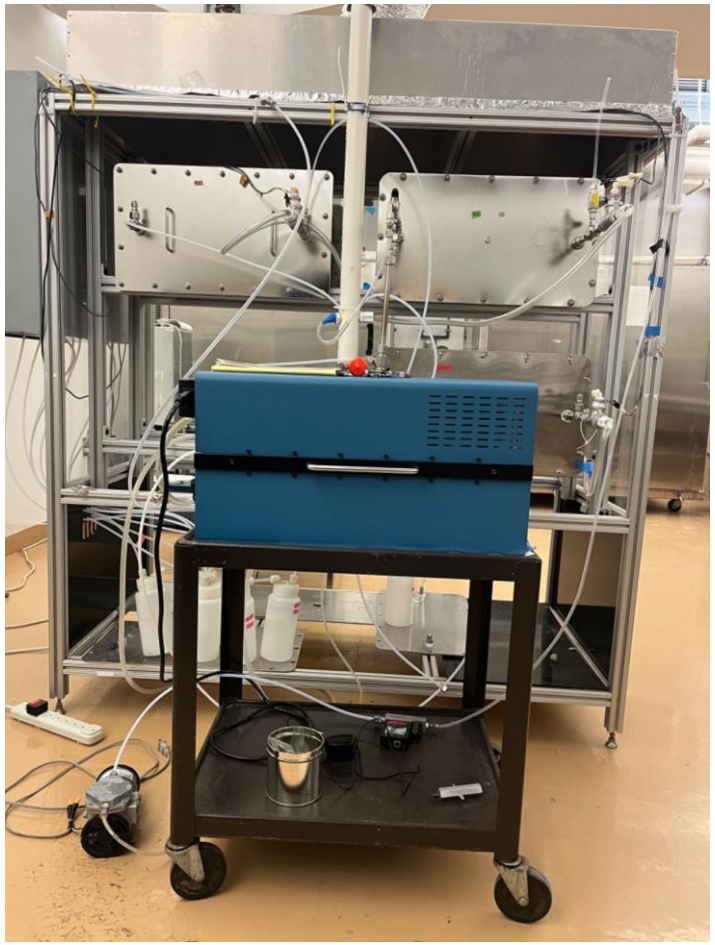
❑ Objectives

- ➢ Determine the removal efficiency of two pieces of MOF paper membranes
- ➢ Detect desorption
- ➢ Exam by-product if exists
- ➢ Provide data for modeling sorption and desorption process
- ➢ Inter lab comparison with NRC

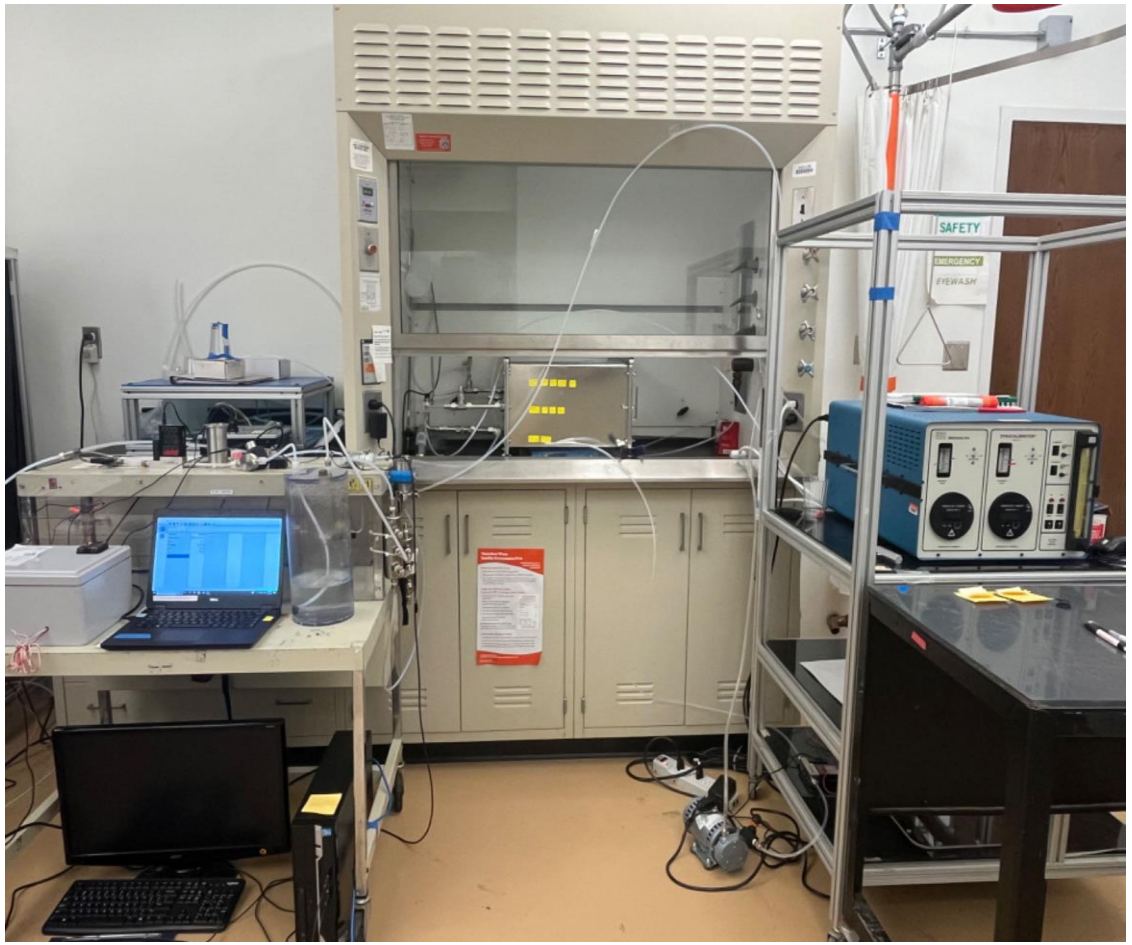
❑ Scope

- ➢ The MOF paper membrane specimens are provided by DTU, preconditioned, made by ….
- ➢ Tested in small chamber for 35 days
- ➢ DNPH samples and analyzed by HPLC
- ➢ Tenax sorbent samples followed by GCMS

Test Facilities

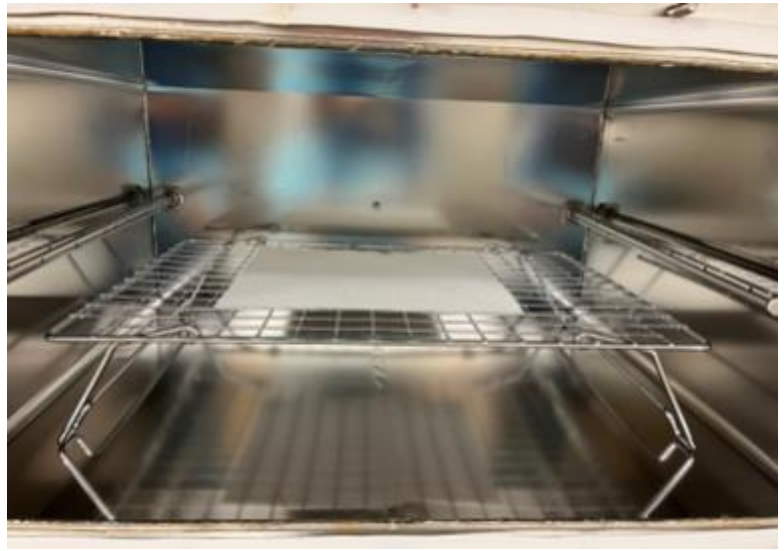


Chamber L (upper right): 93ppb



Chamber H: 260ppb

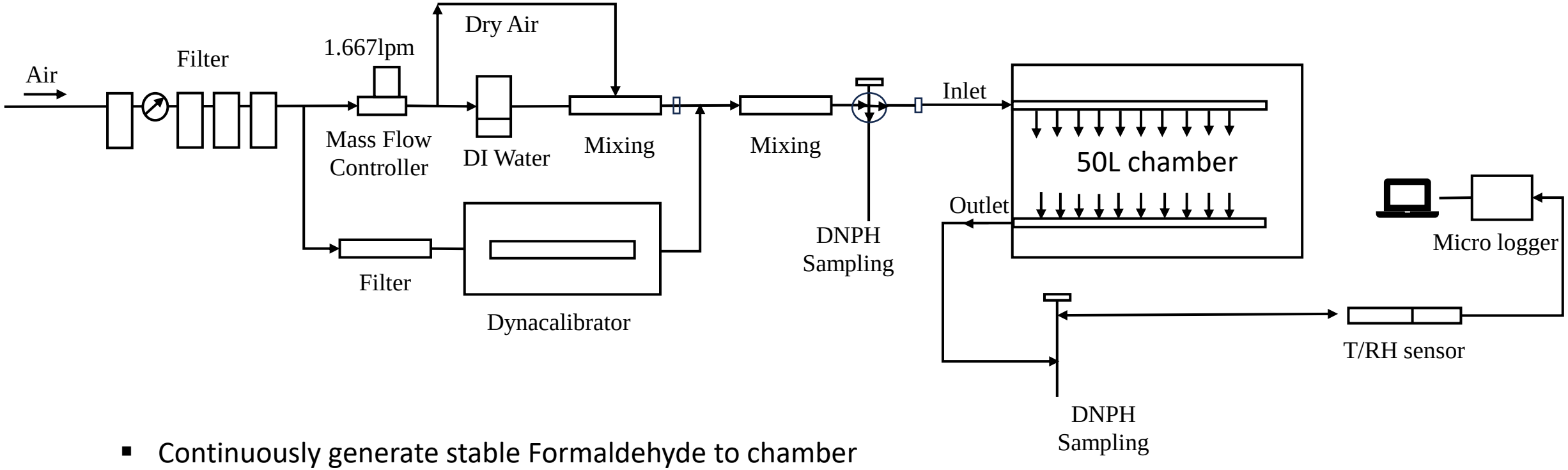
Specimen placement



Chamber L
Specimen size: 0.0450m^2

Chamber H
Specimen size: 0.0446m^2

Experimental Set Up



- Continuously generate stable Formaldehyde to chamber
- Continuous air flow with 50%RH
- Ensure Inlet and outlet sampling

Table1 Summary of the test condition and method

	Chamber L	Chamber H
Inlet concentration (ppb)	93 ppb	260ppb
Specimen Name	MOF membrane	MOF membrane
Size of Specimen (width x length)	22.5cm by 20cm	22.3cm by 20cm
History of Specimen	Received Date: Feb. 2023	Received Date: Feb. 2023
	Storage: 23°C (sealed in package)	Storage: 23°C (sealed in package)
Activation in vacuum oven	Static 104-107°C, Pressure 700 mbar, 4 hr	Static 104-107°C, Pressure 710-850 mbar, 4 hr
Chamber test condition	50L, T=23C, RH=50%, 1 ACH, 0.833LPM	50L, T=23C, RH=50%, 2 ACH, 1.667LPM
Formaldehyde generation	50C, permeation tube by Dynacalibrator	70C, permeation tube by Dynacalibrator
Sampling Method	Adsorption: day1,3,5,7,10,14,17,21,24,28	Adsorption: day1,3,5,7,10,14,17,21,24,28
	Desorption:1ac, 3 ac, 6 ac, day1, 3, 7	Desorption:1ac, 3 ac, 6 ac, day1, 3, 7
	Inlet check at Day 0 and Day27	Inlet check at Day 0 and Day27
	DNPH cartridge, 30 L	DNPH cartridge, 30 L
Analysis	HPLC analysis within 7 days of sampling	HPLC analysis within 7 days of sampling
By-product check	Tenax sorbent tube, GCMS analysis	Tenax sorbent tube, GCMS analysis
Test period	From 7/24 to 8/30/2023, 35days	From 7/24 to 8/30/2023, 35days

Chamber L&H: Plot of measured concentration (ppb) vs Time (hour)

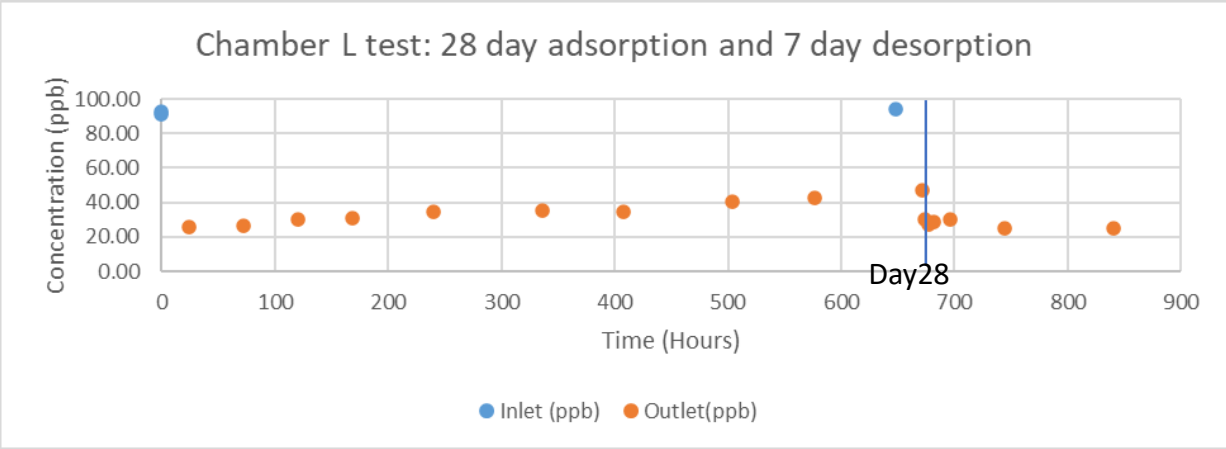


Figure 1: MOF membrane measured Formaldehyde concentration from Chamber L

Inlet: 93ppb
Outlet adsorption day28: 47ppb
Outlet desorption day7: 25ppb

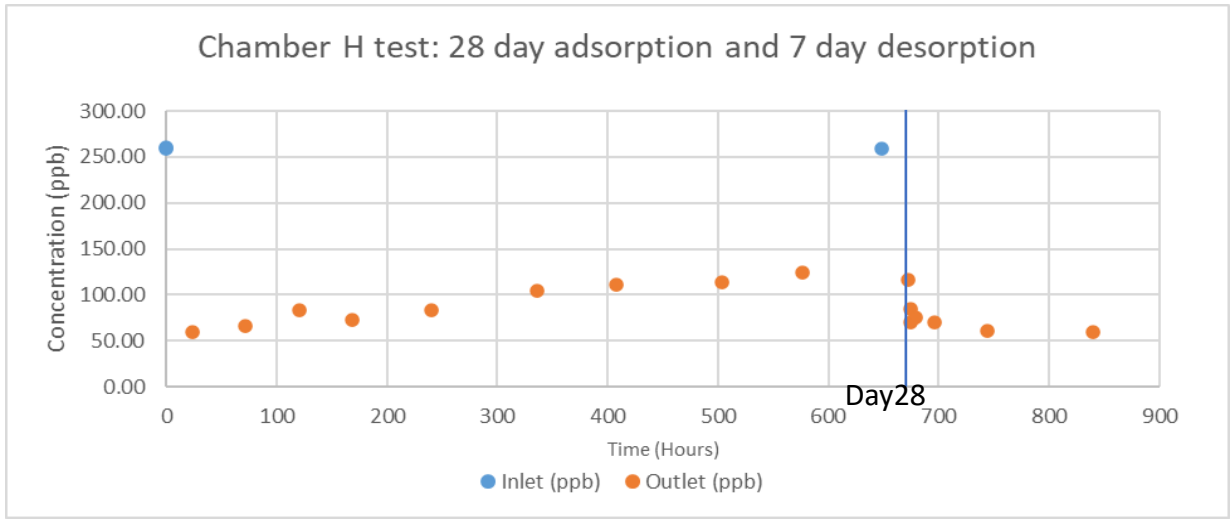


Figure 2: MOF membrane measured Formaldehyde concentration from Chamber H

Inlet: 260 ppb
Outlet adsorption day28: 116ppb
Outlet desorption day7: 60ppb

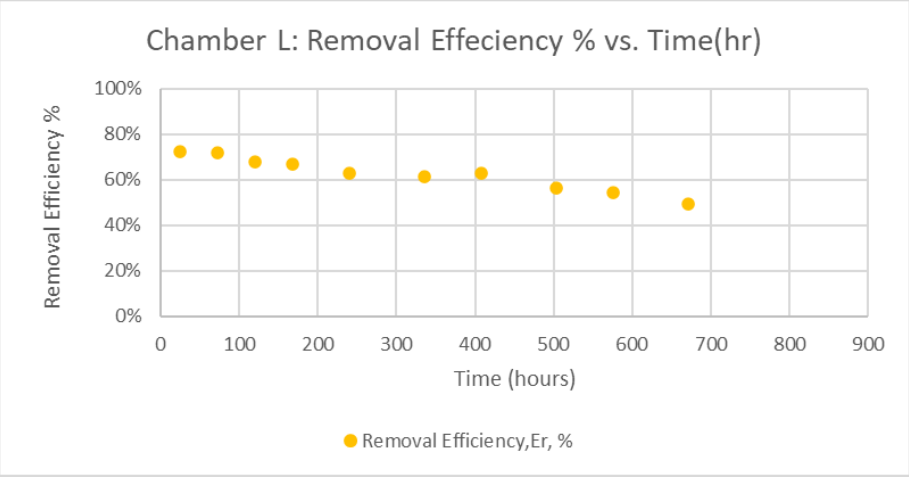
Table 2 Measured concentrations and calculation results from Chamber L

Chamber L	time (hour)	Inlet(ppb)	Outlet(ppb)	Breakthrough%	Removal Efficiency Er, %
inlet -1 hr	0	90.851			
Inlet 27day	648	94.311			
Inlet avg (ppb)	0	93			
day1	24		25.736	27.80%	72.20%
day3	72		26.252	28.36%	71.64%
day5	120		29.794	32.18%	67.82%
day7	168		30.738	33.20%	66.80%
day10	240		34.429	37.19%	62.81%
day14	336		35.628	38.48%	61.52%
day17	408		34.533	37.30%	62.70%
day21	504		40.389	43.63%	56.37%
day24	576		42.340	45.73%	54.27%
day28	672		47.159	50.94%	49.06%
1ac	674		30.236		
3ac	677		26.876		
6ac	682		28.446		
1day	696		29.785		
3day	744		25.003		
7day	840		24.955		

Table 3 Measured concentrations and calculations from Chamber H

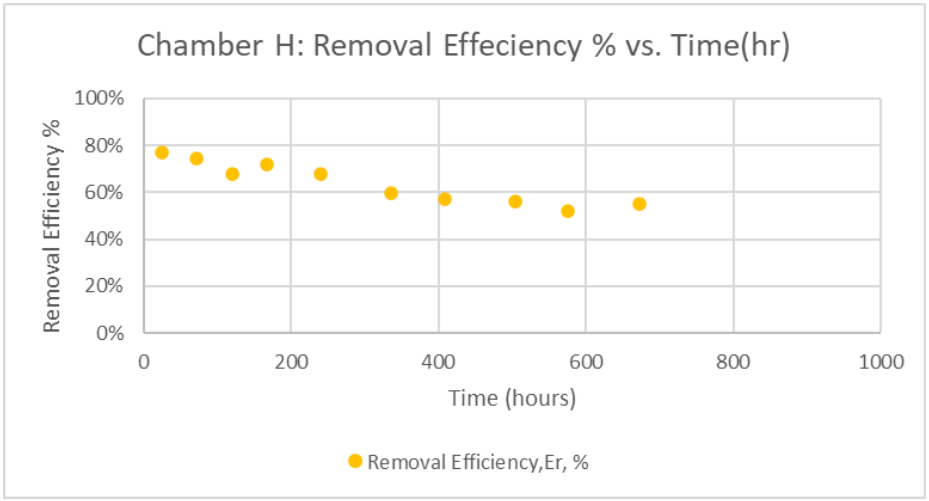
Chamber H	Time (hour)	Inlet (ppb)	Outlet (ppb)	Breakthrough %	Removal Efficiency Er, %
inlet 0 hr	0	259.77			
Inlet 27day	648	259.54			
Inlet avg (ppb)	0	260			
day1	24		59.63	22.96%	77.04%
day3	72		65.73	25.31%	74.69%
day5	120		83.77	32.26%	67.74%
day7	168		73.49	28.30%	71.70%
day10	240		83.51	32.16%	67.84%
day14	336		104.74	40.34%	59.66%
day17	408		111.74	43.03%	56.97%
day21	504		114.37	44.05%	55.95%
day24	576		124.44	47.92%	52.08%
day28	672		116.24	44.77%	55.23%
1ac	674		84.64		
3ac	675		70.39		
6ac	679		75.77		
1day	696		70.78		
3day	744		60.41		
7day	840		59.52		

Chamber L&H: Single-Pass Removal Efficiency (Er, %) vs. Time (hr)



- Chamber L inlet 93ppb
- Removal efficiency: 49% at 28 day (672 hour)
  72% initial at day1
  △ The efficiency reduced 23% over 27 days

Figure 3: MOF membrane 28-day adsorption removal efficiency Chamber L



- Chamber H inlet 260ppb
- Removal efficiency: 55% at 28 day (672 hour)
  77% initial at day1
  △ The efficiency reduced 22% over 27 days

Figure 4: MOF membrane 28-day adsorption removal efficiency Chamber H

Desorption test results

Chamber L:

Date/time	Time(hours)	Concentration without desorption (ppb)	Measured (ppb)
1ac	1	0.00	30.24
3ac	3	0.00	26.88
6ac	6	0.00	28.45
1day	24	0.00	29.79
3day	72	0.00	25.00
7day	168	0.00	24.95

Chamber H:

Date/time	Time(hours)	Concentration without desorption (ppb)	Measured (ppb)
1ac	1.5	4.63	84.64
3ac	2.5	0.63	70.39
6ac	4	0.03	75.77
1day	24	0.00	70.78
3day	72	0.00	60.41
7day	168	0.00	59.52

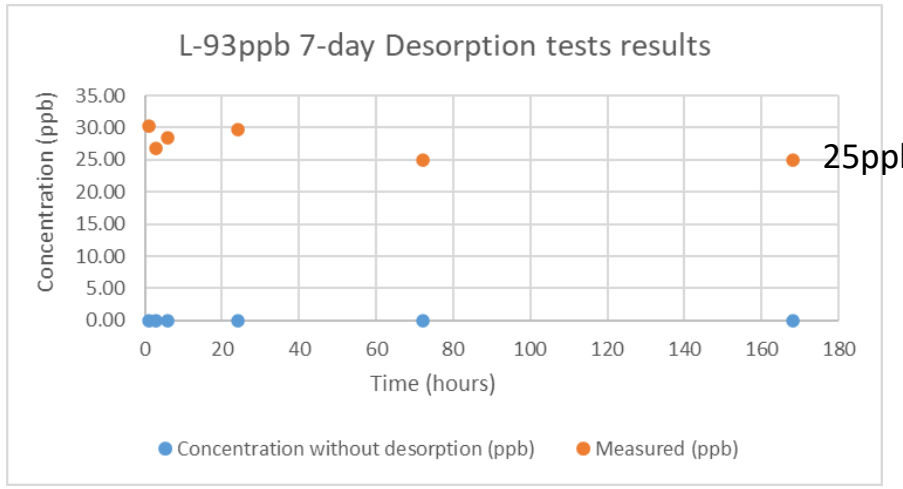


Figure 5 Desorption test result of Chamber L

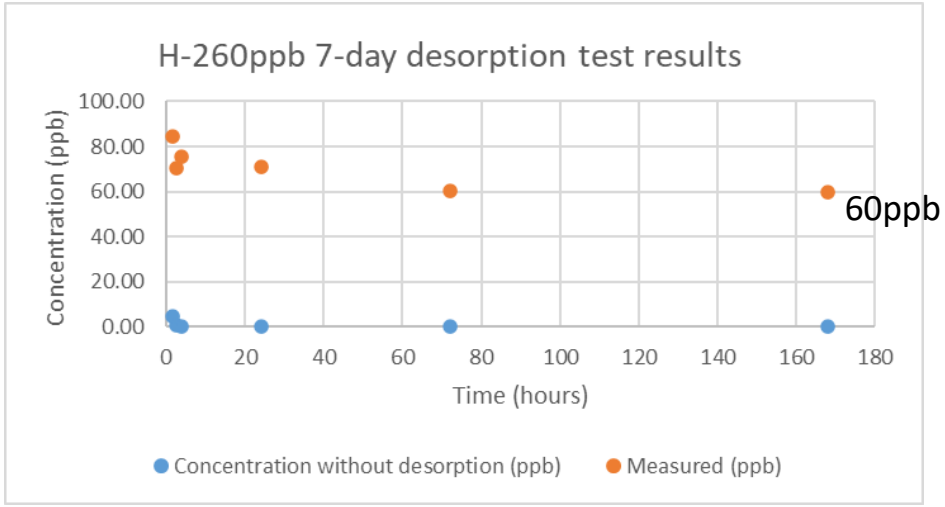


Figure 6 Desorption test result of Chamber H

- Desorption was observed after 7 days with 25 ppb (27% of inlet) and 60 ppb (23% of inlet) detected in L and H chamber, respectively.
- Reduced 6 ppb and 24ppb from 1 ac sample and 7-day sample

GCMS Tenax sample results

GCMS samples collected at time point: background, day1, day3 and day21.

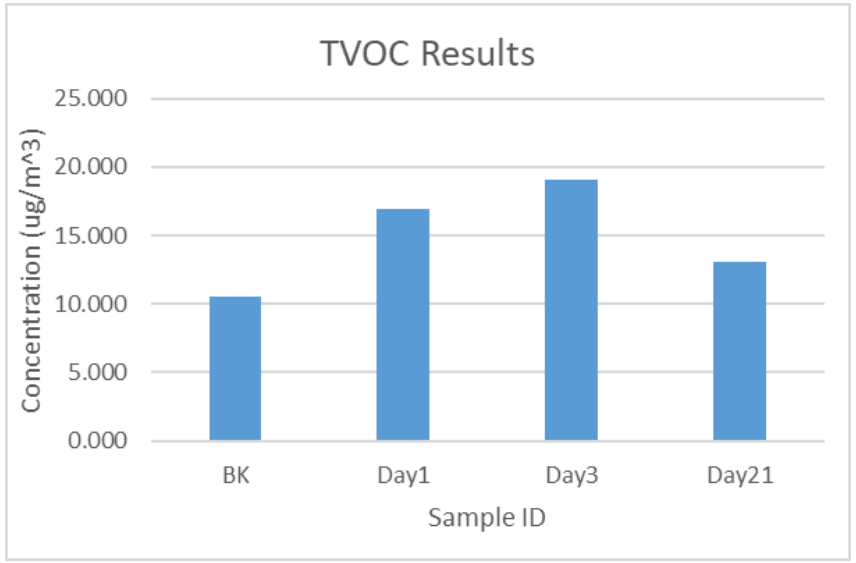


Figure 7 GCMS sample TVOC results from Chamber H

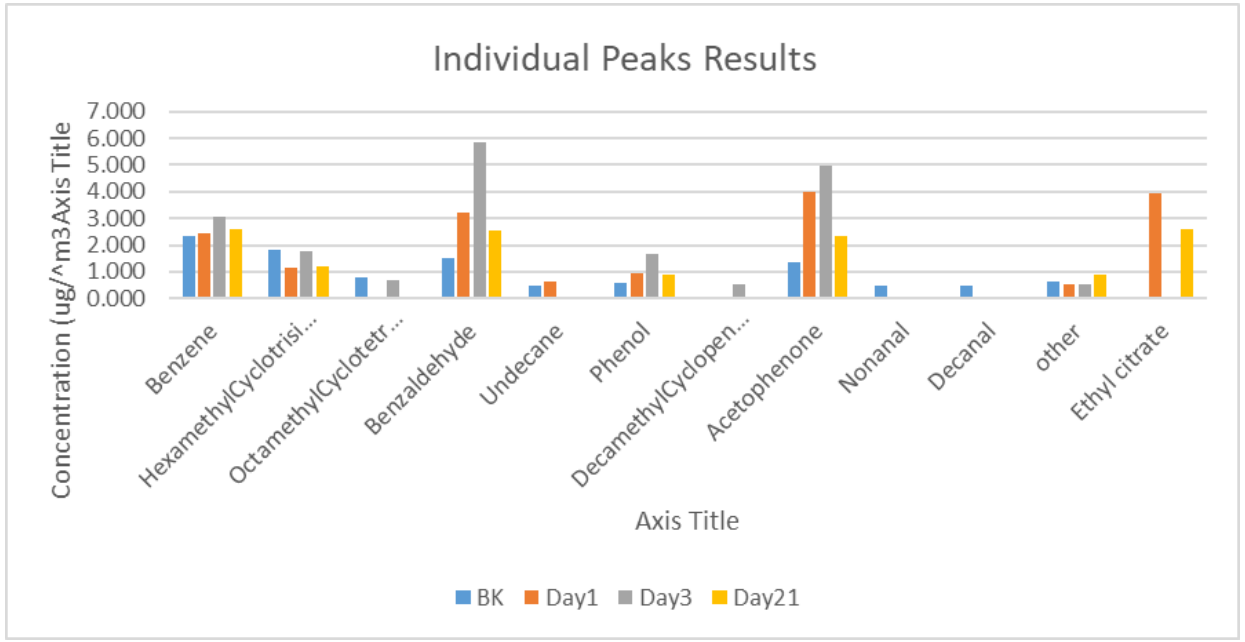


Figure 8 GCMS sample Individual peak results from Chamber H

- ❑ No significant new compounds found
- ❑ All the individual peaks concentration at very low level <6ug/m^3, and the differences overtime are within the measurement uncertainty
- ❑ The calculated concentration was quantified by Toluene standard

Conclusions

- ❑ No by-product found by small chamber test
- ❑ Removal efficiency: 72% at day1 and 49% at day28 under inlet concentration 93 ppb
- ❑ Removal efficiency: 77% at day1 and 55% at day28 under inlet concentration 260 ppb
- ❑ Reemission exists. Desorption was observed after 7 days with 25 ppb (27% of inlet 93ppb) and 60 ppb (23% of inlet 260 ppb) detected in L and H chamber, respectively.

Thanks, and Welcome to Syracuse!

Questions and comments?