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Full-scale Chamber Testing of Air Cleaner Performance for the Removal of Volatile Organic Compounds

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Introduction

ATMOSAIR has developed a new air cleaning technology that can be potentially applied in various indoor spaces to improve the indoor air quality. At the request of ATMOSAIR, BEESL has conducted full-scale chamber tests to evaluate the technology's performance. The test method and results are presented in this report.

Objective

The objective of the testing is to evaluate the performance of the new air cleaning technology for the removal of Volatile Organic Compounds (VOCs) under full-scale chamber conditions.

Method and Scope

A full-scale chamber with interior dimensions of 16 ft by 12 ft by 10 ft high was be used for testing under full-recirculation mode at 23+/-0.5 ºC, 45%+/-5% RH and 5 ACH total ventilation rate. Two ATMOSAIR air cleaner that is properly sized for the chamber volume were provided by ATMOSAIR, and tested in the tests. The units tested were set at maximum flow rate and ion output condition during each of the two tests conducted.

For each test, a mixture of 8 VOCs (hexane, 2-butanone, iso-butanol, toluene, hexanal, tetrachloroethylene, ethylbenze and decane) were vaporized in the chamber after the chamber had thermally stabilized at the test condition. After the VOC concentrations reached the steady state initial level, the air cleaner placed inside the chamber were turned on, and the concentration decays of the VOCs were determined by sorbent tube sampling followed by thermal desorption and GC/MS analysis. The Clean Air Delivery Rate (CADR) were calculated for each VOC based on the measured concentration decay, and are reported in the following section along with the measured concentration decay curves.

Test Results

The average CADR and standard deviations are listed in the **Table 1** as a summary of the test results. The average CADR from the two tests ranged from 12.0 cfm to 22.5 cfm, depending on the compounds. The standard deviation ranged from 0.1 cfm to 2.5 cfm, indicating a good repeatability of the tests and analysis performed. During the test, we also injected CO2 at 2000 ppm as a tracer gas to confirm that the chamber leakage rate was sufficiently low, if any. During both tests, the average relative humidity was 46.0% RH, and the average temperature was 74.4F.

Table1 Summary of test results:

VOC name	Test1-CADR (cfm)	Test2-CADR (cfm)	Average CADR (cfm)	Standard deviation
hexane	15.666	12.136	13.9	2.5
2-butanone	13.178	10.724	12.0	1.7
iso-butanol	18.120	17.919	18.0	0.1
toluene	21.112	17.414	19.3	2.6
tetrachloroethylene	15.767	13.178	14.5	1.8
hexanal	20.810	24.272	22.5	2.4
ethylbenzene	18.188	17.616	17.9	0.4
decane	18.356	16.910	17.6	1.0

Table 2 and **Table 3** are the detailed test results for each test. The initial concentration of the eight VOCs were between 100 ppb to 800ppb respectively. The best CADR is 24.272 cfm for Hexanal in Test2. The weakest is 10.724 cfm for 2-Butanone in Test2.

Table 2 Results of TEST1:

VOC name	Co (ppb)	N_total (ach)	CADR (cfm)*	R-square
hexane	764.6	0.478	15.666	0.9893
2-butanone	370.8	0.404	13.178	0.9656
iso-butanol	130.1	0.551	18.120	0.9906
toluene	384.8	0.640	21.112	0.9985
tetrachloroethylene	212.14	0.481	15.767	0.9897
hexanal	166.83	0.631	20.810	0.9137
ethylbenzene	333.06	0.553	18.188	0.9948
decane	191.60	0.558	18.356	0.9976

*The chamber leakage rate of 0.012ach has been subtracted from the total ACH.

Table 3 Results of TEST2:

VOC name	Co (ppb)	N_total (ach)	CADR (cfm)*	R-square
hexane	777.9	0.373	12.136	0.9989
2-butanone	393.0	0.331	10.724	0.9470
iso-butanol	125.1	0.545	17.919	0.9432
toluene	359.1	0.530	17.414	0.9992
tetrachloroethylene	205.15	0.404	13.178	0.9972
hexanal	165.93	0.734	24.272	0.9641
ethylbenzene	316.68	0.536	17.616	0.9992
decane	178.95	0.515	16.910	0.9962

*The chamber leakage rate of 0.012ach has been subtracted from the total ACH.

Table 4 and **Table 5** provided VOC reduction percentage rate during the 6 hour chamber test period.

Table 4 Test1 Reduction rate after turning on the air cleaner

Time from turn on AC (hr)	hexane	2-butanone	iso-butanol	toluene	tetrachloroethylene	hexanal	ethylbenzene	decane
0.000	100.0%	100.0%	100.0 %	100.0%	100.0%	100.0%	100.0%	100.0%
0.225	86.8%	84.8%	77.0%	83.6%	85.0%	78.8%	87.3%	90.7%
1.008	50.4%	48.6%	39.3%	46.2%	49.4%	33.3%	51.3%	53.9%
2.008	29.3%	30.9%	26.0%	23.3%	28.1%	10.1%	27.4%	30.5%
4.075	11.1%	12.9%	10.2%	6.4%	10.8%	3.3%	8.5%	8.9%
6.025	5.6%	8.9%	2.9%	2.0%	5.5%	2.5%	3.7%	3.6%

Table 5 Test2 Reduction rate after turning on the air cleaner

Time from turn on AC (hr)	hexane	2-butanone	iso-butanol	toluene	tetrachloroethylene	hexanal	ethylbenzene	decane
0.000	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
0.225	87.4%	84.3%	68.6%	87.1%	88.7%	79.6%	89.4%	93.7%
1.008	63.9%	63.8%	32.1%	57.4%	61.1%	36.9%	58.9%	65.6%
2.008	43.6%	36.6%	20.9%	31.9%	40.0%	12.9%	34.0%	36.3%
4.075	21.1%	25.7%	9.4%	11.2%	18.8%	5.1%	11.0%	12.4%

Conclusions

Test results showed good regression and repeatability between the two duplicate tests. Test indicated that the air cleaners reduced the concentrations in the chamber air (57.12 m^3 in volume) for Hexane by 94.6%, 2-Butanone by 91.1%, Iso-butanol by 97.1%, Toluene by 98%, Tetrachloroethylene by 94.5%, Hexanal by 97.5%, Ethylbenze by 96.3% and Decane by 96.4% over the 6 hours pull-down test period. These corresponded to the equivalent clean air delivery rate (CADR) for the two units tested to range from 12 cfm to 22.5 cfm, depending of the VOCs.

Appendix I Measured Concentrations over Time

Table 6 TEST1-10/07/2018 Concentration vs. Time

	hexane	2-butanone	iso-butanol	toluene	tetrachloroethylene	hexanal	ethylbenzene	decane
Time from AC on	CAS# 110-54-3	CAS# 78-93-3	CAS# 78-83-1	CAS#108-88-3	CAS# 127-18-4	CAS# 66-25-1	CAS# 100-41-4	CAS# 124-18-5
hour	ug/m^3	ug/m^3	ug/m^3	ug/m^3	ug/m^3	ug/m^3	ug/m^3	ug/m^3
0	2691.43	1093.99	394.23	1450.73	1438.30	682.34	1445.49	1115.12
0.225	2336.73	927.29	303.74	1213.49	1223.25	537.82	1261.33	1011.79
1.008	1357.42	531.28	155.10	670.88	710.36	227.26	740.91	601.22
2.008	789.90	338.05	102.53	338.03	404.19	68.61	395.34	339.60
4.075	299.66	141.25	40.31	92.90	155.93	22.50	122.28	99.61
6.025	151.24	97.20	11.52	29.65	78.64	17.29	52.93	40.05

Table 7 TEST2-10/08/2018 Concentration vs. Time

	hexane	2-butanone	iso-butanol	toluene	tetrachloroethylene	hexanal	ethylbenzene	decane
Time from AC on	CAS# 110-54-3	CAS# 78-93-3	CAS# 78-83-1	CAS#108-88-3	CAS# 127-18-4	CAS# 66-25-1	CAS# 100-41-4	CAS# 124-18-5
hour	ug/m^3	ug/m^3	ug/m^3	ug/m^3	ug/m^3	ug/m^3	ug/m^3	ug/m^3
0	2738.34	1159.43	378.99	1353.81	1390.93	678.65	1374.37	1041.52
0.225	2392.73	976.87	259.98	1179.51	1233.45	540.10	1229.13	975.61
1.008	1750.78	739.20	121.75	777.19	849.94	250.20	809.32	683.27
2.008	1193.58	424.58	79.12	431.70	556.96	87.25	466.92	377.72
4.075	577.14	298.11	35.63	152.30	261.31	34.50	151.05	128.80
6.025	N/A*							

*Lost Dyna5 data due to GC software error

Appendix II Regression Analysis Results

Figure 1 to **Figure 8** show the results of the regression analysis for each of the 8 compounds tested that provided the total air change rate coefficient, N_total, and R-square values in **Tables 2 and 3** above. The measured concentration data were normalized by the initial concentration before the regression analyses were performed.

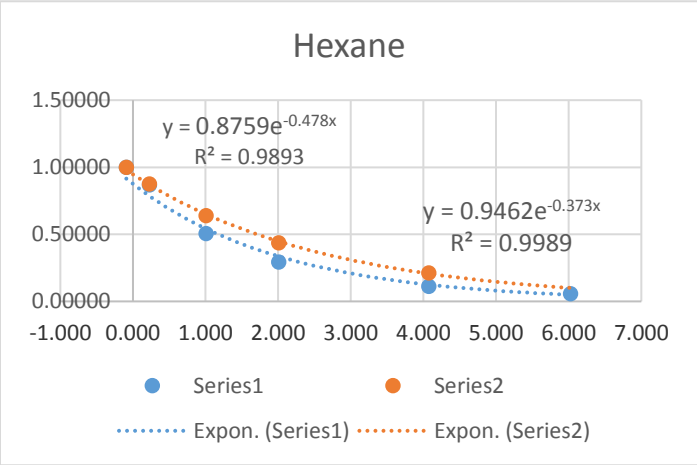

Figure 1: Hexane Data Curve Fitting Results

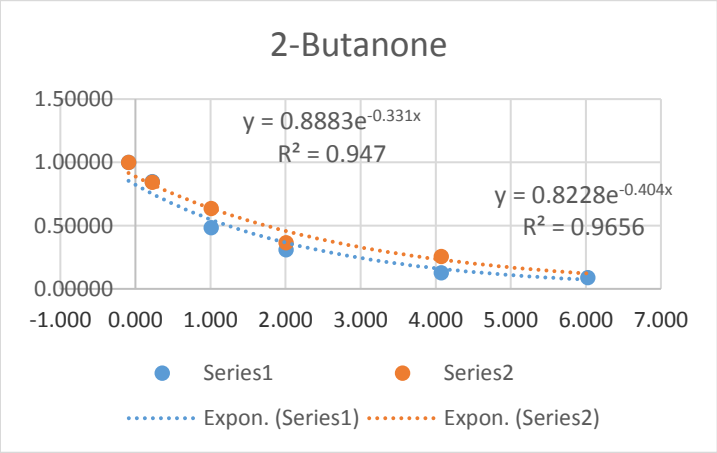

Figure 2: 2-Butanone Data Curve Fitting Results

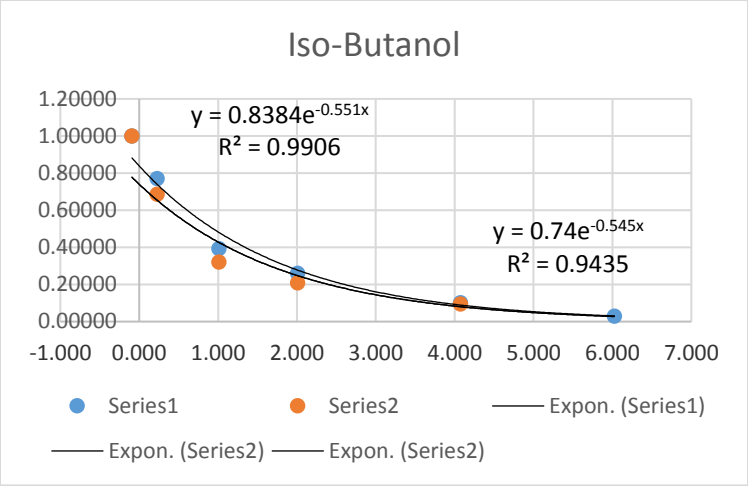

Figure 3: Iso-Butanol Data Curve Fitting Results

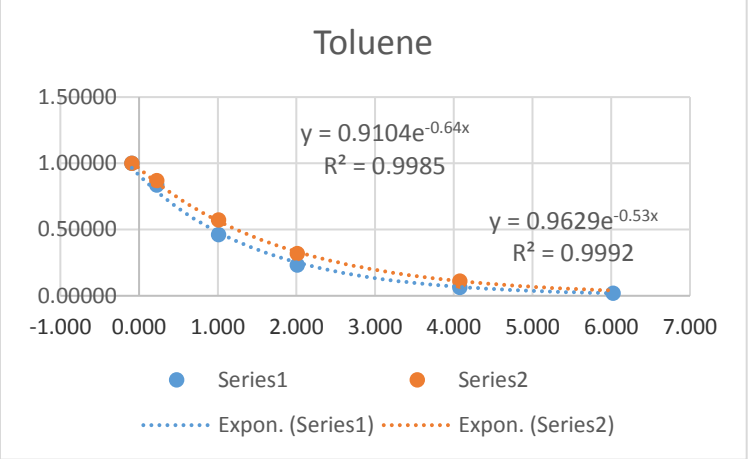

Figure 4: Toluene Data Curve Fitting Results

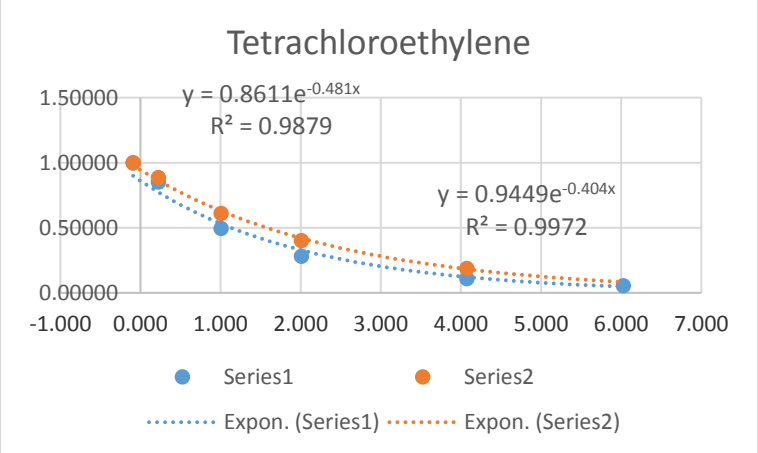

Figure 5: Tetrachloroethylene Data Curve Fitting Results

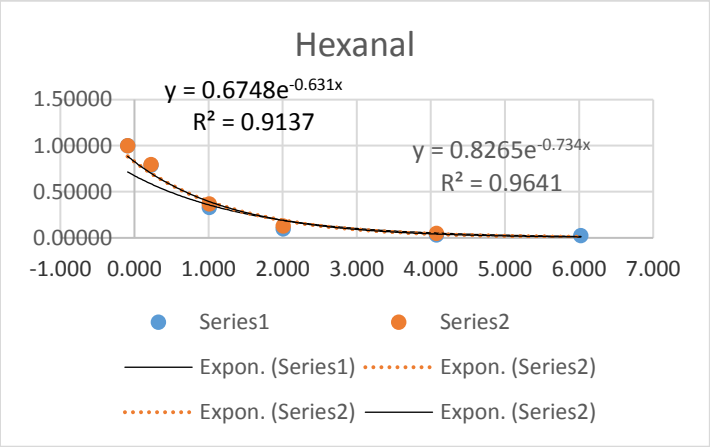

Figure 6: Hexanal Data Curve Fitting Results

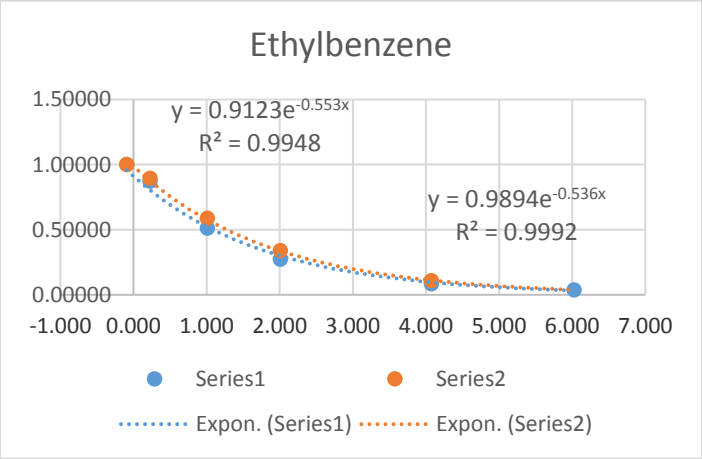

Figure 7: Ethylbenzene Data Curve Fitting Results

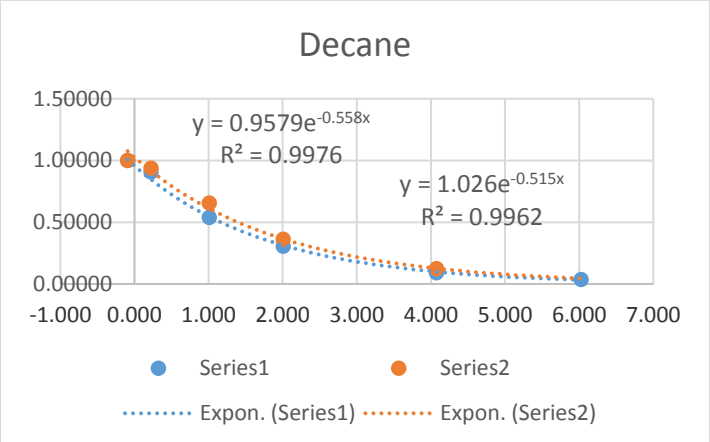

Figure 8: Decane Data Curve Fitting Results