Efficacy of Novaerus NV 1050 System against NO_2 and Formaldehyde Gases

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Background: This in vitro study characterized the removal efficacy of the toxic gases, NO_2 and formaldehyde, by the Novaerus NV1050 system. Novaerus's NV1050 system is designed to eliminate harmful gases in order to purify rooms and create safe environments for occupants. The study included three (3) trials and a control run against both NO_2 and formaldehyde.

Methods: In separate trials, NO_2 and formaldehyde gases were released into a sealed chamber while the monitoring of their concentrations were logged with specialized detectors. For the control trials, the NV1050 remained outside the chamber, and the gases were allowed to dissipate naturally over time. The NV1050 was moved inside the chamber for the test trials, the chamber was refilled with test gases and the NV1050 turned on once desirable concentrations of the gases had been reached. Chamber control trial data was subtracted from Novaerus trial data to yield net log reduction in the chamber for each challenge.

Results: The NV 1050 system was shown to be highly effective at removing NO_2 from its environment. At 6 minutes it showed a net LOG reduction of 2.29 LOG and would have been higher if not for the limited resolution of the NO_2 detector. The system was also successful at eliminating formaldehyde from the chamber, having an average net LOG reduction of 2.52 LOG. The detection limit was an order of magnitude greater for formaldehyde, however the starting chamber concentration was significantly lower compared to NO_2.

Overview

This study was conducted to evaluate the ability of the Novaerus NV1050 device, shown in **Figure 1**, by Novaerus Inc. to eliminate toxic gases. Testing was conducted in a controlled stainless steel chamber. The NV1050 device effectiveness was tested against Nitrogen Dioxide (NO_2) and Formaldehyde (HCHO), and was compared to control runs in order to evaluate the system's effective net LOG reduction of the toxic gases when compared to the control runs.

The test plan incorporated challenging the NV1050 device in a closed environmental chamber to determine the elimination rate of NO_2 and HCHO due to the NV1050 system.

Testing Chamber

A large sealed aerosol test chamber was used to replicate a potentially contaminated room environment and to contain any potential release of toxic gases into the surrounding environment.

The test chamber is constructed of 304 stainless steel and is equipped with three viewing windows and an air-tight lockable chamber door for system setup and

NOVAERUS

NV1050 Unit	
Picture:	
Device Features	
Manufacturer:	Novaerus Ltd.
Model:	NV1050
Notes:	Plasma Air Disinfection

Figure 1: *The NV1050 by Novaerus Inc.*

general ingress and egress. The test chamber internal dimensions are 9.1ft x 9.1ft x 6.8ft, with a displacement volume of 562 cubic feet, or 15,914 liters.

The chamber is equipped with filtered HEPA inlets, digital internal temperature and humidity monitor, external humidifiers (for humidity control), lighting system, multiple sampling ports, aerosol mixing fans, and a HEPA filtered exhaust system that are operated with wireless remote control.

For testing, the gas was released into the chamber through one of the sampling ports. A second sampling port was used to monitor gas levels. All other ports were sealed along with all HEPA filtered inlets.

The sample ports were inserted approximately 18 inches from the interior walls of the chamber to avoid wall effects and at a height of approximately 40 inches from the floor.

The test chamber is equipped with two high-flow HEPA filters for the introduction of filtered purified air into the test chamber during aerosol evacuation/purging of the system between test trials and a HEPA filtered exhaust blower with a 500 ft^3/min rated flow capability for rapid evacuation of remaining toxic gases.

A magnehelic gauge with a range of 0.0 +/- 0.5 inch H_2O (Dwyer instruments, Michigan City IN) was used to monitor and balance the system pressure during aerosol generation, aerosol purge and testing cycles. **Figure 2** shows a Flow Diagram of the pressure chamber.

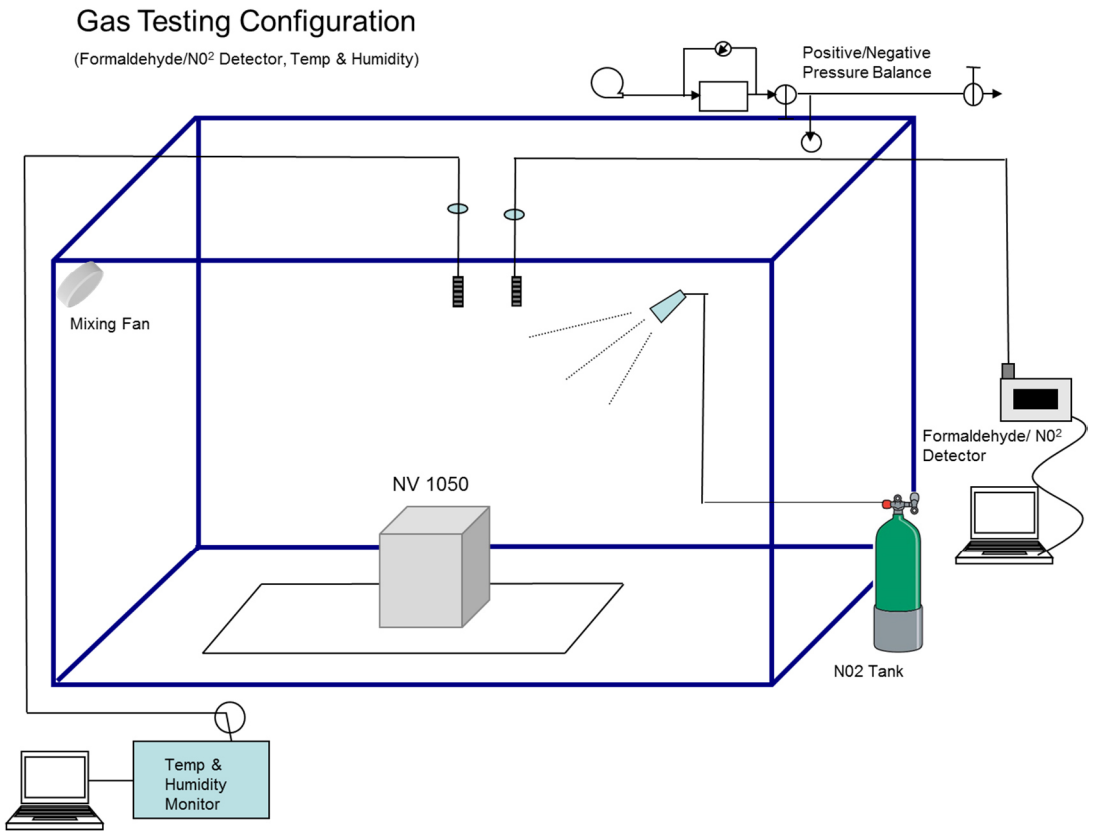

Figure 2: *Test Chamber Flow Diagram.*

NO_2 and HCHO Monitoring Systems

For NO_2, a MultiRAE monitor (RAE Systems Inc. Sunnyvale, CA) was used to determine chamber concentration. Calibration was successfully completed by Pine Environmental Services four days prior to testing began. The MultiRAE is equipped with a built in sample pump with an average flow rate of 250 cc/min. Its range of detection for NO_2 is 0 to 20 ppm with a resolution of 0.1 ppm. Measurements were datalogged every 30 seconds for the control test and the first NV1050 test, and then taken at 1 sec intervals for the final two NV1050 tests. The MultiRAE was kept outside of the chamber, connected to it via a sampling port.

A HAL-HFX205 meter (Hal Technology, Fontana, CA) was obtained to monitor formaldehyde. Like the MultiRAE, the HAL-HFX205 has a built in sample pump that was connected to a sample port outside of the pressure chamber. It has a formaldehyde detection range of 0 to 10 ppm with a resolution of 0.01 ppm. The unit was connected to a computer during testing and launched under *Logger Mode* in the associated *Data Downloader V2.0* software. Readings were set to occur every 5 sec in continuous mode. Originally the HAL-HFX205 was connected to a sample port of the chamber with plastic tubing, but due to the extreme reactivity of formaldehyde with the plastic, the resulting data was unreliable. To alleviate this, the monitor was directly connected to the sample port without the use of plastic tubing.

NO_2 and Formaldehyde Delivery Systems

A 500 ppm concentration tank of NO_2 was connected by a pressure regulator to a sample port on the chamber. Releasing 5 psi of pressure from the tank for 3 minutes increased the chamber concentration of NO_2 to 20ppm. Once 20ppm was reached the tank was shut off and testing began.

Like with the NO_2, a tank of Formaldehyde was acquired, however the tank came at a significant lower concentration (100 ppm) than that of the NO_2. An initial test of the system revealed an issue with reaching an

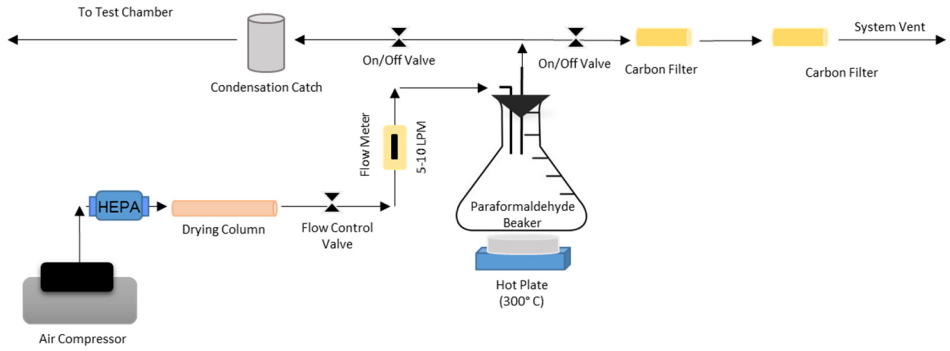

Figure 3: *Diagram showing the formaldehyde gas delivery system. Paraformaldehyde was heated to create formaldehyde vapor that traveled through a drying column and into the test chamber.*

adequate concentration of formaldehyde inside the chamber to proceed with testing. A new approach was required.

Reviewing old sterilization techniques revealed that formaldehyde gas can be formed from heating the solid powder paraformaldehyde. Deciding to employ this method, paraformaldehyde was purchased from Sigma. The system setup to heat and deliver the formaldehyde gas to the pressure chamber is diagramed in **Figure 3.**

An air compressor controlled with a needle valve and a flow meter, flowed through a drying tube and connected to the side arm of a filtering flask, which contained 100g of paraformaldehyde. A rubber stopper sealing the mouth of the flask had a stainless steel tube running through it, which created the escape path for the formaldehyde vapor. This tube then split, with one direction going to the chamber and the other running to a carbon filter. Both directions could be activated with inserted valves. The flask was put on a hot plate which was turned to 270°C. The route to the chamber was interrupted with a trap to catch any condensation. Once the desired concentration was reached in the chamber, the route to the chamber was shut, the flask was lifted from the heat, and the route to carbon filter was opened.

Control Testing

To accurately assess the NV1050 unit, a pilot control trial was performed with NO_2 overnight without the NV1050 inside the test chamber. The NO_2 tank was opened and 5 psi of pressure was released for 3 minutes to reach approximately 20 ppm of formaldehyde inside the chamber. Once 20 ppm was achieved, the tank was shut off and the MultiRAE was set to begin logging data. Due to the clearly sluggish decline in concentration of NO_2, the system was left to data log overnight. The following morning the meter was stopped and the data log was analyzed.

Formaldehyde dissipates faster than NO_2, so there was no cause to let the control test run overnight. The paraformaldehyde was heated and the chamber concentration of formaldehyde rose steadily until it began to level out at 5.3 ppm. The airflow into the flask containing paraformaldehyde was increased from 5 lpm to 10 lpm, but this had little effect on raising the concentration. Raising the hotplate temperature from 270°C to 300°C also had a marginal effect on the chamber concentration. It was deemed that 5 ppm would suffice and the paraformaldehyde source was cut off from the chamber and the meter was turned on and data logging began. The chamber reached 0.0 ppm in 2.3 hours, after which the meter was shut off and the data log was analyzed.

NV1050 Gas Testing Matrix

Trial	Run	System Tested	Species	Species Source	Target Starting Concentration	Chamber Volume (m^3)	Test Temperature	Temp Relative Humidity	Samplinjg Time (sec)	Monitoring System
1	Control	NV1050	Nitrogen Dioxide NO_2	500ppm Tanked gas	20.0 ppm	16	75° F	35%	30	MultiRAE *Rae Systems Inc.*
2	Challenge								30	
3	Challenge								1	
4	Challenge								1	
5	Control	NV1050	Formaldehyde *HCHO*	Formaldehyde Generator	5 ppm	16	75° F	35%	5	HAL-HFX205 *Hal Technology*
6	Challenge									
7	Challenge									
8	Challenge									
9	Challenge									

Table 1: *NV1050 Test Matrix.*

NV 1050 Testing

Before testing began for both NO_2 and formaldehyde, the Novaerus NV1050, fixed on its high setting, was moved inside the test chamber and connected to a remote controlled power source. The chamber door was shut and a final check was performed to ensure all filters and ports were sealed. A mixing fan was placed in proximity to the sample port for the purpose of establishing a homogeneous concentration of the gases in the test chamber.

For the NO_2 testing, the MultiRAE meter was turned on and the NO_2 tank was opened to 5 psi for 2:45 minutes. Once the NO_2 concentration stabilized inside the chamber, the mixing fan was turned off by remote and the exhaust vent was secured shut. At this point the NV1050 was powered on and NO_2 concentration was monitored until 0.0 ppm concentration was reached. The test was repeated for a total of three trials. **Table 1** shows a complete testing matrix for all testing conducted.

The formaldehyde testing proved more unpredictable compared to NO_2. Formaldehyde is more reactive in general and there were issues with establishing a consistent starting concentration inside the chamber. Once the paraformaldehyde began to heat, the concentration of formaldehyde in the chamber would rise steadily to a point until it would level off. This level at which it would level off would vary between trials.

Issues also arose with the HAL-HFX205 meter. The control test and first two NV1050 trials progressed as expected, but on the third trial the concentration in chamber had a much more gradual decline and never reached 0.00 ppm. The test was repeated several times with the same result. Initially it was thought that the carbon filter in the NV1050 was saturated, however a replacement filter produced the same results. The sample ports in the chamber were cleaned in case paraformaldehyde was off-gassing continuously, but that also had no effect on results. Attention turned to the meter, where it was observed that even when the meter was moved to an outside environment the concentration of formaldehyde continued to show the same gradual decline. Hal Technologies was contacted and a new meter was sent. With the new meter Trial 4 and Trial 5 were completed with results similar to Trials 1 and 2. For this report, the data from Trials 1, 2, 4, and 5 will be included.

In general the test trials were performed in the same manner as the control trial. The hotplate was turned on between 270°C to 300°C to heat the paraformaldehyde, while air flow into the flask would range between 5-10 lpm. The concentration inside the chamber reached 3.86 ppm for Trial 1, 2.44 ppm for Trial 2, 2.69 ppm for Trial 4, and 5.44 ppm for Trial 5. Once evident that a maximum concentration had been reached, the formaldehyde source was cut off from the chamber and the NV1050 was turned on. Formaldehyde was efficiently eliminated from the chamber, reaching a concentration of 0.00 ppm between 1.7 and 0.5 minutes for all four trials.

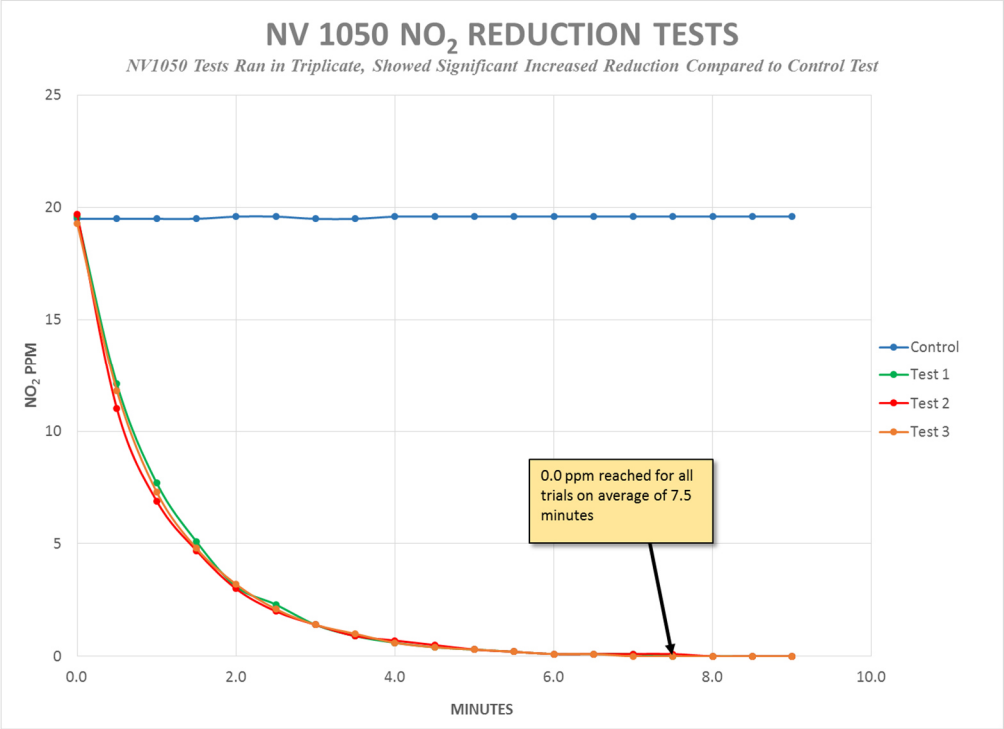

Figure 4: *NO_2 NV1050 Efficacy*

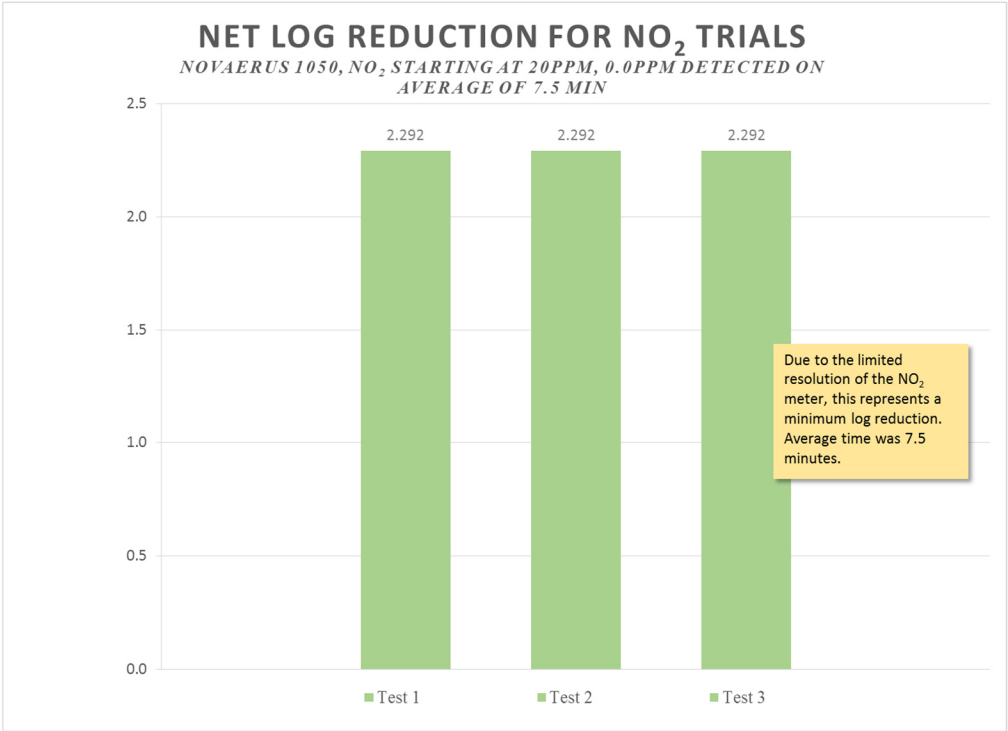

Figure 5*: NV 1050 net LOG Reduction of NO_2 for Tests 1, 2, and 3.*

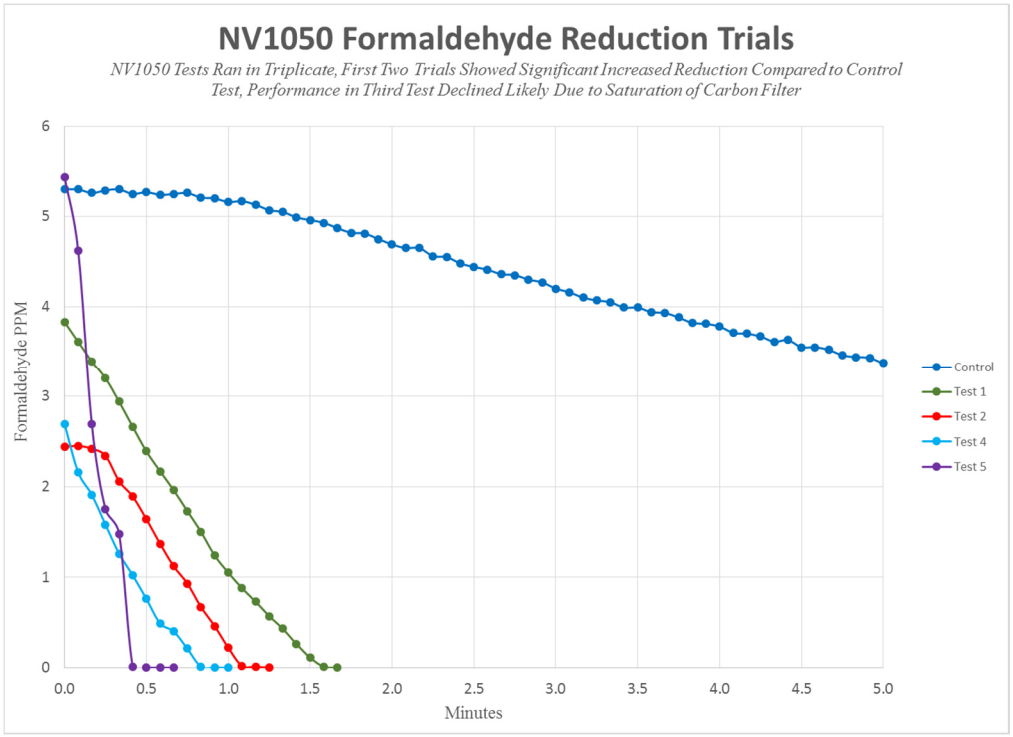

***Figure 6**: Formaldehyde NV1050 Efficacy*

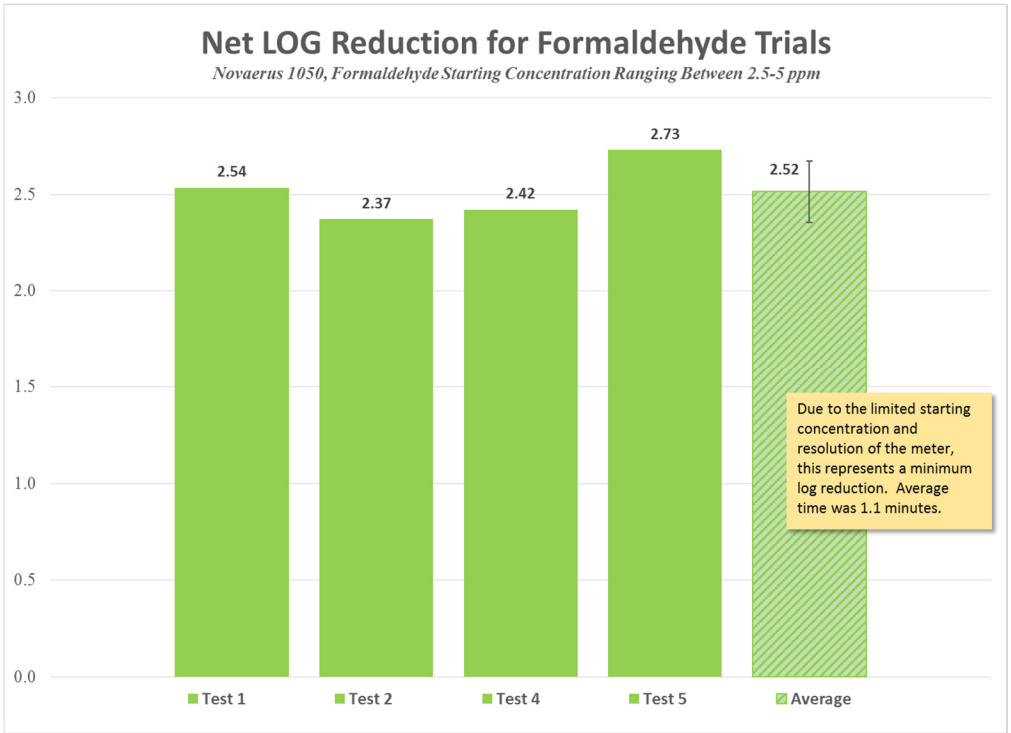

***Figure 7**: NV 1050 net LOG Reduction of formaldehyde for Tests 1, 2, 4, 5, and their average.*

Data Analysis

Results from the control trial were graphed and plotted to show natural viability loss over time in the chamber. These control runs served as the basis to determine the time required for the NV1050 to achieve a max net log reduction in the toxic gases, NO_2 and formaldehyde, above the natural losses from the control runs. All data is normalized with time zero (*t=0* minutes). Subsequent samples are normalized and plotted to show the loss of viability over time.

The equivalent air exchange rate (eqACH), clean air delivery rate (CADR), and the EPA's Energy Star Rating were calculated by plotting the natural logarithm of the concentration verses time for the control and test runs, and comparing the slopes of their linear trend models.

Summary of Results

The NV 1050 system was shown to be extremely effective at removing NO_2 from the air. At 6 minutes the NV 1050 system showed a net LOG reduction of 2.29 LOG for Trial 1, 2, and 3. If not for the limited resolution of the NO_2 meter, the net LOG reductions would have been greater. Within 7.5 minutes for all three trials, the chamber concentration was showing at 0.0 ppm. These results are represented in **Figures 4 and 5**. For NO_2, the NV 1050 system has an equivalent air exchange rate of 25.04 eqACH, a CADR of 235.85 cfm, and an EPA rating of 0.629 cfm/watt.

The NV1050 also proved to be exceedingly effective at removing formaldehyde from its environment. The four tests had an average net LOG reduction of 2.52 LOG and formaldehyde levels reached 0.00 ppm in an average of 1.1 minutes. In this instance, the main cause preventing a greater net LOG value was the lower starting concentration. The results for the formaldehyde tests are shown in **Figures 6 and 7.** For formaldehyde, the NV 1050 system has an equivalent air exchange rate of 641.21 eqACH, a CADR of 6038.10 cfm, and an EPA rating of 16.10 cfm/watt.

Overall the NV 1050 system is extremely effective at eliminating NO_2 and formaldehyde from room environments. The results show that at least 99.5% of the gases were removed in 7 minutes and less.

A summary of the results is represented in **Table 2.** The NV 1050 system ratings for each of the gases is outlined in **Table 3.**

Average NET LOG and Percent Reduction of Gases

Trial	Run	Gas	Starting Conc. (ppm)	Ending Conc. (ppm)	Time to Reach Ending Conc. (min)	Net LOG Reduction	Net Percent Reduction
1	Control		19.5	8.4	944.0		
2	Challenge	Nitrogen Dioxide	19.6	0.0	7.5	2.29	99.487%
3	Challenge	NO_2	19.7	0.0	7.0	2.29	99.487%
4	Challenge		19.3	0.0	7.0	2.29	99.487%
Challenge Average			19.5	0.0	7.2	2.29	99.487%
Challenge Std. Deviation			0.2	0.0	0.3	0.00	0.000
5	Control		5.30	0.00	142.0		
6	Challenge	Formaldehyde	3.83	0.00	1.7	2.54	99.712%
7	Challenge	*HCHO*	2.44	0.00	1.2	2.37	99.573%
8	Challenge		2.69	0.00	0.9	2.42	99.620%
9	Challenge		5.44	0.00	0.5	2.73	99.814%
Challenge Average			3.6	0.0	1.1	2.52	99.680%
Challenge Std. Deviation			1.4	0.0	0.5	0.160	0.001

Table 2: Average Net LOG and Percentage Reduction of Gases.

Gas	Equivalent Air Exchange Rate (eqACH)	Clean Air Delivery Rate (CADR)	Energy Star Rating (R_{EPA})
NO_2	25.04 eqACH	235.85 cfm	0.629 cfm/w
Formaldehyde	641.21 eqACH	6038.10 cfm	16.10 cfm/w

Table 3: The NV1050 rating for Equivalent Air Exchange Rate, Clean Air Delivery Rate, and its Energy Star Rating.

References

L. Taylor, M. Barbeito, G. Gremillion et al. *Paraformaldehyde for Surface Sterilization and Detoxification.* Applied Microbiology, Vol. 17, No. 4, 1969, pp. 614-618

Appendix A: eqACH, CADR, and EPA Ratings

The figures below show the natural logarithms of the gas concentrations plotted versus time. The slopes of the linear trend models were used to calculate the equivalent air exchange rate (eqACH), the clean air delivery rate (CADR), and the EPA's Energy Star Rating certification in the highlighted boxes. The volume of the chamber at 16m^3 was also used in the calculations. Because the NO_2 trials were almost identical, the concentrations were averaged before calculating the natural logarithms. The formaldehyde trials all had different starting concentrations and therefore it was necessary to plot the trials separately and take an average of their slopes.

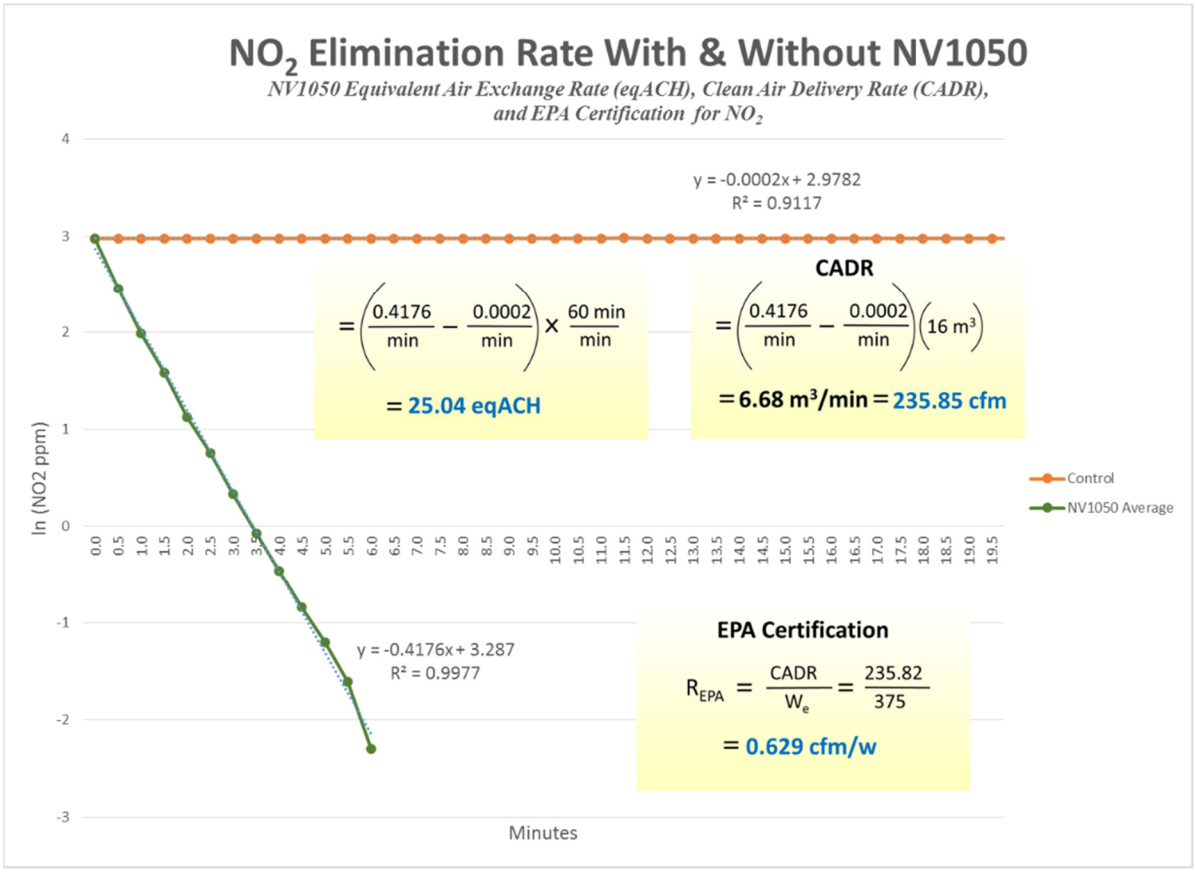

Figure A.1: Natural log of NO_2 concentration versus time for the control and averaged NV1050 test runs. Calculations derived from the slopes of the linear trend models for the eqACH, CADR, and EPA rating shown in highlighted boxes.

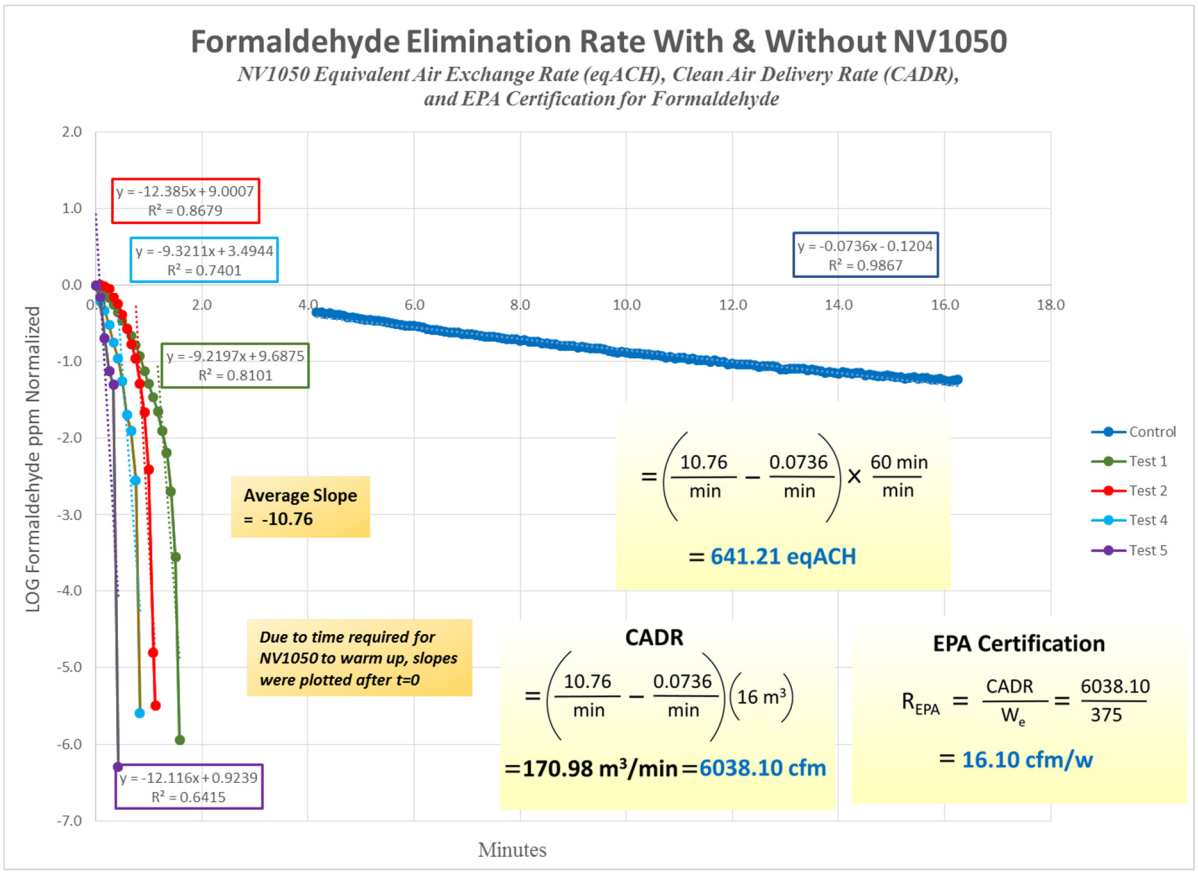

Figure A.2: Natural log of formaldehyde concentration versus time for the control and the four NV1050 test runs. Calculations derived from the slopes of the linear trend models (averaged for tests) for the eqACH, CADR, and EPA rating shown in highlighted boxes.

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GLP Statement

We, the undersigned, herby certify that the work described herein was conducted by Aerosol Research and Engineering Laboratories in compliance with FDA Good Laboratory Practices (GLP) as defined in 21 CFR, Part 58.

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