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CerroZone Mobile VOC Destruction Efficacy Testing

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REPORT APPROVAL

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Article Info

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· *Indoor Air Quality*

Conflict of Interest:

Aerosol Research and Engineering Laboratories, Inc. have no affiliations with, or involvement in any capacity, with CerroZone's financial interests such as membership, employment, stock ownership, or other equity interest.

Purpose: The purpose of this study was to assess the CerroZone Mobile air purification device for its ability to destroy volatile organic compounds (VOCs) in room air and measure and identify potential byproducts.

Background: The CerroZone Mobile device was designed to destroy potentially harmful VOCs and improve indoor air quality. This study was performed to show the destruction efficacy of the CerroZone Mobile device operated at 226 +/- 40 cubic feet per minute (CFM) and monitor for any potential byproducts from the treated room air. Commonly found VOCs were selected as challenges in this study and they were as follows: Limonene, Formaldehyde, Toluene, Acetic Acid, and Formic Acid. High concentration challenges were performed to assess destruction efficacy and byproduct identification. Lower concentrations testing was then performed to verify efficacy over a range of possible exposure environments and assess the byproduct degradation if measurable. Control tests were also run for each type of compound to measure the natural decay or half-life in the test chamber.

Methods: The CerroZone Mobile device was placed in the center of a 16 m^3 stainless steel chamber with two small mixing fans and purged overnight with a carbon filter. A spectral background was taken with the Thermo Fisher MAX-IR Fourier Transform Infrared (FTIR) spectrometer for quantification of ambient gas concentrations in the chamber. Challenge VOCs were vaporized and let equilibrate in the chamber. Once gas concentrations were stable the CerroZone device was powered on and monitored with the FTIR spectrometer. The FTIR was capturing infrared spectral scans every 6 seconds with a sample flow rate of 2 liters per minute (lpm) through the gas sample cell, which was kept at 191 °C for all tests. Spectral data was analyzed using the MAX Analytics Software and concentration data exported to Microsoft Excel for tabulation and graphing.

Results: The CerroZone Mobile was effective at destroying all challenge VOCs. The Clean Air Delivery Rate (CADR) for all gas types tested ranged from an average of 72.8 to 147.8 cubic feet per minute (CFM) across the five different gas types tested.

Conclusion: In conclusion, the CerroZone Mobile was effective at destroying all challenge VOCs in the test chamber and all measurable byproducts were identified.

Overview

The purpose of this study was to evaluate the VOC destruction efficacy of the CerroZone Mobile room air purifier in a controlled test environment against hazardous VOCs. The CerroZone Mobile is an air purification system that uses proprietary ozone technology. Air is passed through a pre-filter then exposed to a chamber of ozone producing ultraviolet bulbs for inactivation. The air then passes through a catalyst filter which converts the ozone back to oxygen before exiting the device through a post-filter.

The test device is designed to be used in a variety of settings and applications. Testing was conducted in an environmentally controlled stainless steel bioaerosol test chamber. The test chamber was constructed with 304 stainless steel and designed to simulate a small room environment (10' L x 10' W x 7' H). The testing environment was maintained at ambient temperature and humidity inside of the testing chamber. Control trial data, or natural losses, were subtracted from test trial data and multiplied by the chamber volume to calculate the clean air delivery rate (CADR) attributable to the device.

The device's efficacy for destroying potentially hazardous chemicals was evaluated using commonly found VOCs. The test matrix is presented in **Figure 1,** and it lists the challenge VOCs used in the study. High concentrations challenges were performed first in order to identify any possible byproducts or intermediaries from the room air treated by the CerroZone Mobile device. Gas measurements were taken using the Thermo Fisher MAX-IR FTIR Spectrometer for all tests. Next, lower concentration challenges were performed to further validate the destruction potential of the test device.

Trial No.	Test Device	Sample Flow Rate (lpm)	Challenge VOC	Challenge Conc. (ppb)	Byproduct Identification	Quantification Method
1	NA	2	Limonene	10000	N	MAX-IR FTIR
2	CerroZone Mobile	2	Limonene	60000	Y	MAX-IR FTIR
3	CerroZone Mobile	2	Limonene	4000	Y	MAX-IR FTIR
4	CerroZone Mobile	2	Limonene	2000	Y	MAX-IR FTIR
5	NA	2	Toluene	8000	N	MAX-IR FTIR
6	CerroZone Mobile	2	Toluene	45000	Y	MAX-IR FTIR
7	CerroZone Mobile	2	Toluene	10000	Y	MAX-IR FTIR
8	CerroZone Mobile	2	Toluene	2000	Y	MAX-IR FTIR
9	NA	2	Formaldehyde	10000	N	MAX-IR FTIR
10	CerroZone Mobile	2	Formaldehyde	70000	Y	MAX-IR FTIR
11	CerroZone Mobile	2	Formaldehyde	10000	Y	MAX-IR FTIR
12	CerroZone Mobile	2	Formaldehyde	2000	Y	MAX-IR FTIR
13	NA	2	Acetic Acid	13000	N	MAX-IR FTIR
14	CerroZone Mobile	2	Acetic Acid	50000	Y	MAX-IR FTIR
15	CerroZone Mobile	2	Acetic Acid	4000	Y	MAX-IR FTIR
16	NA	2	Formic Acid	24000	N	MAX-IR FTIR
17	CerroZone Mobile	2	Formic Acid	100000	Y	MAX-IR FTIR
18	CerroZone Mobile	2	Formic Acid	20000	Y	MAX-IR FTIR

Figure 1.VOC Destruction Test Matrix.

CerroZone Mobile

The CerroZone Mobile air purifier is described by the manufacturer as an air purification system using proprietary ozone technology. Air is passed through a pre-filter then exposed to a chamber of ozone producing ultraviolet bulbs for inactivation. The air is then fed through a catalyst filter which converts the ozone back to oxygen before exiting the device through a post-filter. The device was tested while operating at 226 +/- 40 CFM throughout testing. A picture of the device can be found in **Figure 2**.

Major Equipment Used

Overview

The equipment used in this study was calibrated and certified prior to the start of testing. The calibration is performed either in house or by the manufacturer as applicable.

Test Chamber

The test chamber (**Figures 3 and 4**) is constructed of 304 stainless steel and is equipped with three viewing windows and an air-tight lockable chamber door for system setup and general ingress and egress. The chamber is equipped with filtered HEPA inlets, digital internal temperature and humidity monitors, multiple sampling ports, 2 mixing fans, and a carbon-filtered exhaust system that are operated with wireless remote control. Gas samples were collected via Polytetrafluoroethylene (PTFE) tubing passed through one of the four 3/8-inch diameter stainless steel probes projecting into the chamber about 18” from the nearest sidewall and at a height of approximately 40 inches from the floor.

Figure 2. CerroZone Mobile Test Device.

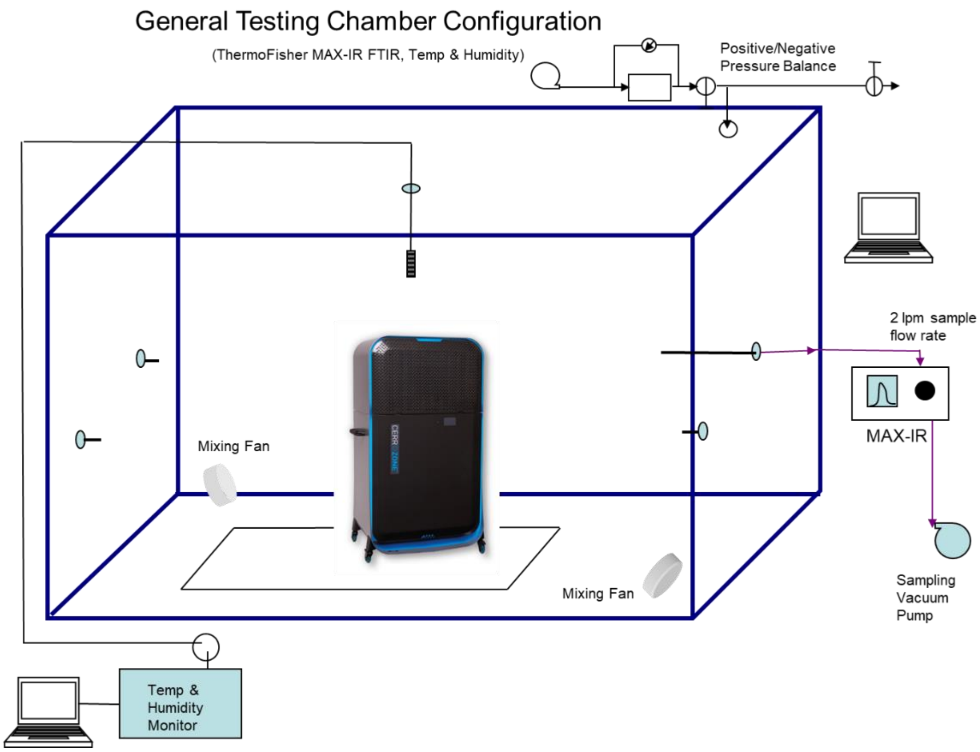

Figure 3. *Test Chamber Flow Diagram.*

The test chamber is equipped with high-flow carbon filters (Can-Filters Vancouver, WA, USA) for removal of background VOCs. These were used to purge the chamber between test trials. Additionally, it has a high efficiency particulate air (HEPA) filtered exhaust blower with a 500 ft^3/min rated flow capability for rapid evacuation of any remaining contaminants.

Figure 4. Testing Chamber External View *The environmental test chamber used to replicate a small room environment.*

A Magnehelic® gauge (Dwyer instruments, Michigan City, IN), with a range of 0.0 +/- 0.5-inch H_2O, is used to monitor and balance the system pressure during gas generation, purge, and testing cycles.

Thermo Fisher MAX-IR FTIR Spectrometer

The Thermo Fisher MAX-IR FTIR Spectrometer (Thermo Fisher Waltham, MA) was used for all gas sampling. The MAX-IR uses the Fourier-transform infrared spectroscopy technique to obtain high resolution spectral data from 500 to 5000 cm^{-1} wavenumbers with 1 cm^{-1} resolution. Figure 5 on the following page shows an internal and external view of the gas analyzer.

The spectrum collected MAX-IR is a two-dimensional plot of the intensity and frequency of the sample absorption. This data is then used for qualitative and quantitative analysis of samples being as each chemical functional group absorb at different frequencies.

The MAX-IR is capable of quantifying over 100 VOCs, and the software allows for comparison of spectra of over 1000 different compounds, if any unknowns are present in the sample. The test chamber was sampled using an oil-free vacuum pump pulling a constant flow of 2 liters per minute (lpm) through the spectrometer.

Figure 5. *Thermo Fisher MAX-IR FTIR Spectrometer was used to measure gas concentrations of all chemical compounds in the air. The front of the gas analyzer is shown on the left, and the rear and internal picture is shown on the right.*

Gas Species Selection/Justification

There were six different challenge chemicals used in this study which are commonly found indoor VOCs, and some are used for assessment of air purification devices. Compounds were purchased from Spectrum Chemical Mfg. Corp. (New Brunswick, NJ). Each compound was high purity to mitigate interference of other solvents commonly used when preparing the chemicals. In addition to the six challenge compounds, different classes of chemical species were monitored in order to identify possible products. A list of the monitored species can be found in **Figure 6.**

Gas Compound	Odor Threshold (ppb)	TWA (ppb)	STEL (ppb)
Limonene	38	NA	NA
Formic Acid	49	5,000	10,000
Acetone	20	250,000	750,000
Acetic Acid	1000	10,000	15,000
Toluene	8000	10,000	150,000
Formaldehyde	100	750	2,000
O-Cresole	1	5,000	NA
CO2	NA	5,000,000	30,000,000
CO	NA	25,000	200,000
2-Butanone	5400	200,000	300,000
Methanol	100	200,000	250,000

Figure 6. Standard Odor threshold and exposure limits for common VOCs and compounds detected in this study.

Chamber Pre-Trial Preparation

Prior to testing, the interior walls, ceiling, and floor of the testing chamber were wiped down with warm soap water. After the initial wipe down was complete, the chamber was cleaned again with a 91% Isopropyl Alcohol to remove any soap residue. Next, the chamber was treated with 50 ppm ozone for one hour then left overnight for further oxidation of any possible VOCs present. The following day the chamber was purged of ozone and a new carbon filter recirculated for 1 hour prior to taking a background spectral reference for testing that day.

Vaporization Method

Each challenge compound was heated in a dedicated glass dish for each chemical on a hot plate for vaporization. The hot plate was set to 200°C for rapid vaporization of each chemical. Once the compound was completely vaporized, the hot plate was powered off via remote, and a 10-minute mixing period allowed for homogeneity. The stability of the chamber concentration was verified prior to powering on the challenge device for a good representation of the challenge environment.

Pre-Testing

To assess possible byproducts both qualitatively and quantitatively, high concentrations of the challenge VOCs were tested for theoretically higher concentrations of any byproducts being formed. Higher gas concentrations increase the absorbance detected by the spectrometer and allow for identification of any unknown compounds being produced.

Once the byproducts were identified for each challenge compound a custom acquisition method was utilized for all testing with the specific compound. This allows for real-time concentration monitoring of the chemical compounds of interest. If there are any unknown spectral peaks the software includes a peak identification tool to compare reference spectra with collected spectra and verify.

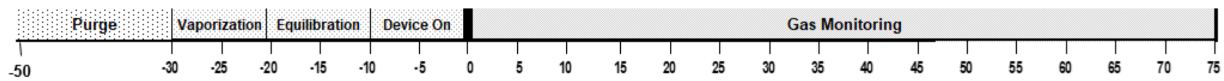

Figure 7. *General Timeline for the Test Trials. The solid highlighted area above represents the sampling period. The bottom line represents a time scale in minutes for reference.*

VOC Destruction Testing Method

Control Testing

In order to determine CADR of each gas by the CerroZone air purification unit, independent control trials were performed with each challenge gas to quantify the natural decay without the device in operation. The same general timeline found in **Figure 7** was used for all tests. The natural decay rate of the measured gaseous compounds was subtracted from the rate of reduction with the device in operation to calculate net reduction achieved by the CerroZone Mobile device.

Challenge Testing

Prior to each trial, the spectral background was taken to improve the signal to noise ratio. Once the background was taken, the standard procedure of vaporization, equilibration, and device activation was followed while sampling with the MAX-IR spectrometer. The VOC destruction of each compound and the measurable byproducts were monitored for each trial. Once gas concentrations reached background levels, the CerroZone device was powered off, and the chamber prepared for the next trial.

Post-Testing Chamber Purge Procedure

Between each test, the chamber was airflow evacuated/purged for a minimum of 20 minutes and analyzed with the MAX-IR for gas concentration decrease to baseline levels. The chamber was recirculated between tests with a high velocity carbon filter for capture of any background VOCs.

For all testing, the device remained in the test chamber for consistency with test runs. During both control and test device trials, two low velocity Honeywell HT-900 mixing fans, located in the corners of the bioaerosol test chamber, were turned on for the duration of trial to ensure a homogenous environment within the test chamber.

Quantitative Analysis

The analytical method used for quantification of compounds followed the ordinary least squares regression method. Background values were subtracted from the concentration calculation values and signals above those were used. Each analyte was assessed for interferences from other compounds including water and carbon dioxide. Each calibration curve used a specific spectral region when calculating concentrations, and these regions can be affected by different compounds. To account for this, the analytics software allows for compounds to be marked as interferents and accounted for in concentration calculations.

Once all compounds were checked for interferents, the quant method was saved. The quant method was then used for its specific challenge gas type. After analysis with the MAX-IR software, results were exported to Microsoft Excel for tabulation and graphing. The CADR for the CerroZone device was calculated by subtracting the natural log of the natural decay rate of concentration over time from the decay rate with the CerroZone Mobile device activated. This net reduction rate was multiplied by the volume of the test chamber to determine the volumetric rate at which VOCs were removed from the chamber air.

Results

The challenge chemical species were destroyed at various rates, depending on their chemical structure. During the destruction process, some low-level byproducts were detected for each of the challenge volatile organic compounds (VOCs). The results are categorized based on the challenge compound being observed as the source of the byproduct formation during its destruction by the CerroZone Mobile. However, none of these detected byproducts reached concentration levels of concern. Moreover, since the conditions and byproducts varied, a customized analysis method was employed for each gas type testing in each corresponding trial.

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Limonene Results

Limonene Challenge Results

All challenge compounds were destroyed by the CerroZone Mobile at different rates depending on the chemical species. Some chemical compounds require different conditions to undergo oxidation, this can depend on temperature, pressure, activation energy, and the presence of a catalyst. The more complex VOCs were observed being reduced at a slower rate, but overall, very consistent over different challenge concentrations.

Limonene Control

A single control trial was performed in the test chamber to ensure the challenge gas concentrations were stable enough to assess the destruction rate of the CerroZone Mobile device. The test device was left in the chamber with all of the mixing fans and chamber configuration as the challenge trials. The control trial data can be found in **Appendix A.**

Limonene Medium Concentration Byproduct Degradation

The second challenge trial was performed to verify the byproducts were observed trending back to normal baseline levels verifying the Cerrozone Mobile device removes even the byproducts. This trial is found in **Figure 9 (left).**

Compounds Measured	Detection	Limits of Detection (ppb)
Acetaldehyde	Not Detected	120
Acetic Acid	Detected	25
Acetone	Detected	75
Butanone	Not Detected	50
Carbon dioxide	Detected	10
Carbon monoxide	Detected	75
Formaldehyde	Detected	30
Formic acid	Not Detected	50
Limonene	Detected	25
Methane	Not Detected	90
Methanol	Not Detected	40
o-Cresol	Not Detected	100
Toluene	Not Detected	120

Figure 8. *FTIR Acquisition Method Chemical List. Each of these compounds were monitored during each trial. The detection limits were provided by Thermo Fisher Analytics.*

The main byproducts measured during treatment with the CerroZone mobile device were carbon monoxide, carbon dioxide, acetone, acetic acid, and formaldehyde. These byproducts were observed increasing as the challenge chemicals were still present then subsequently decreased as the chemical was destroyed from the air.

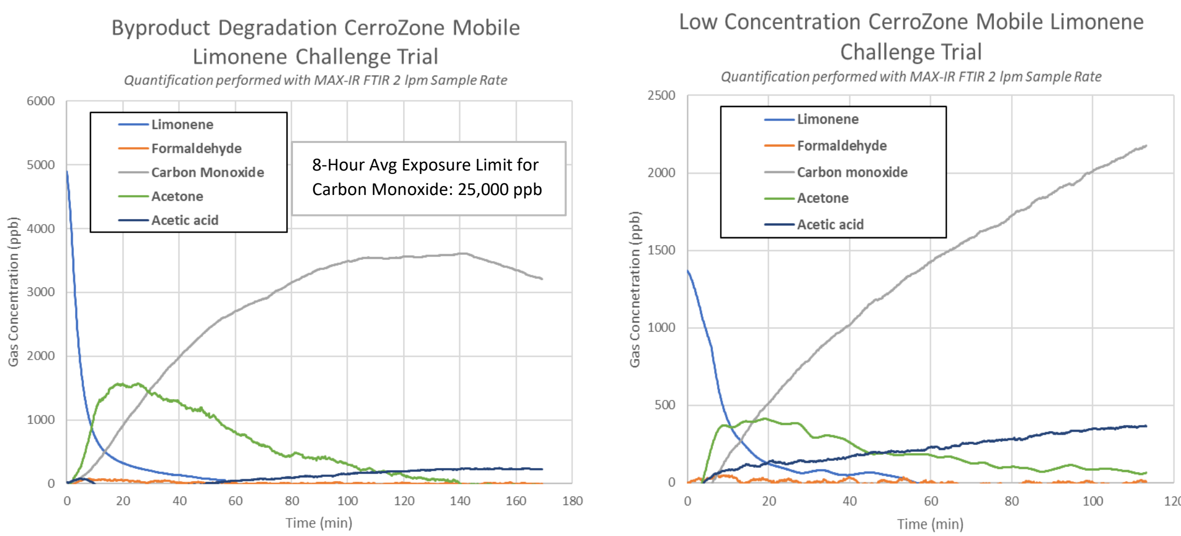

Figure 9. CerroZone Mobile VOC destruction challenges with byproduct quantification results. The byproduct degradation trial (left) shows the increase of byproducts then subsequent decrease when the limonene is no longer present. The low concentration trial (right) shows a similar increase, but only acetone was decreased after limonene was destroyed. Quantification was performed with the MAX-IR FTIR Spectrometer.

Limonene Low Concentration Challenge

For the low concentration challenge trial, there was a consistent destruction of the limonene and there was a noticeable increase in acetone when the device was powered on then acetone decreased to background levels. Carbon monoxide was also observed to increase after the device was powered on, which indicated these as byproducts of the limonene destruction as well. The list in **Figure 8** shows the compounds included in the acquisition method used for all tests including the manufacturer limits of detection for each.

Limonene Half-Life and CADR Results

The half-life and clean air delivery rate were calculated using trial data. The reduction rate or the natural log of gas concentrations over time was calculated for each trial using the initial point when the CerroZone Mobile was activated and a minimum 100 subsequent samples. A sample spectrum was taken every 6 seconds for all tests and used for quantification. The average half-life calculated for the four trials performed with the natural decay rate subtracted was 4.4 +/- 1.1 minutes and the average CADR was 92.4 +/- 22 CFM in the stainless-steel test chamber. **Figure 10** shows the trial data summary.

Limonene Testing Conclusion

The compounds observed to have the highest increase after treatment of the air during limonene exposures were carbon dioxide and carbon monoxide. Both were well below any hazardous levels and are both commonly found in the atmosphere at low levels. The 8-hour time weighted average OSHA limit is 25,000 ppb, and the highest observed level was below 4000 ppb in the trials performed.

In conclusion, the CerroZone Mobile device effectively reduced limonene in the high-level VOC challenge. The byproducts that were produced were subsequently observed to be reduced. Some low levels of acetic acid were detected from the limonene oxidation, in addition to carbon dioxide and carbon monoxide. None of the byproducts were detected at high levels. Given the destruction of such high levels of limonene and its byproducts, the test device proved both robust and effective at consistently destroying these commonly found VOCs.

Trial ID	Initial Gas Conc. (ppb)	Half Life (min)	CADR(m^3/h)	CADR(CFM)
Limonene Control	10,000	126	-	-
Limonene T1	60,000	4.1	164	96
Limonene T2	4,000	3.5	190	112
Limonene T3	2,000	5.7	117	69
Trial Average +/- St. Dev.		**4.4 +/- 1.1**	**157 +/- 37.3**	**92.4 +/- 22**

Figure 10. *Limonene Trial Summary. The natural log of the gas concentrations measured over time was used to calculate the clean air delivery rates for each trial.*

Toluene Results

Toluene Challenge Results

The toluene challenge was observed to be destroyed by the CerroZone Mobile at different concentrations in the test chamber. The custom toluene analysis method developed was used for all toluene challenge trials. The gases monitored were similar to those in the limonene trials. **Figure 13** shows the gases that were monitored based on byproduct identification testing, and the observance of the increase in spectral signal of the quantification regions for those compounds.

Toluene Control

A single control trial was performed in the test chamber to ensure the challenge gas concentrations were stable enough to assess the destruction rate of the CerroZone Mobile device. The test device was left in the chamber with all of the mixing fans and chamber configuration as the challenge trials. The control trial data can be found in **Appendix A.**

Toluene Medium Byproduct Degradation

The second challenge trial was performed to verify the byproducts were observed trending back to normal baseline levels verifying the Cerrozone Mobile device removes even the byproducts. This trial is found in **Figure 12 (left).**

Compounds Measured	Detection	Limits of Detection (ppb)
Acetaldehyde	Not Detected	120
Acetic Acid	Detected	25
Acetone	Detected	75
Butanone	Not Detected	50
Carbon dioxide	Detected	10
Carbon monoxide	Detected	75
Formaldehyde	Detected	30
Formic acid	Not Detected	50
Limonene	Not Detected	25
Methanol	Not Detected	40
o-Cresol	Detected	100
Toluene	Detected	120

Figure 11. *FTIR Acquisition Method Chemical List. Each of these compounds were monitored during each trial. The detection limits were provided by Thermo Fisher Analytics.*

The main byproducts measured during treatment with the CerroZone mobile device were carbon monoxide, carbon dioxide, acetone, acetic acid, a cresol species, and formaldehyde. These byproducts were observed increasing as the challenge chemicals were still present then subsequently decreased as the chemical was destroyed from the air.

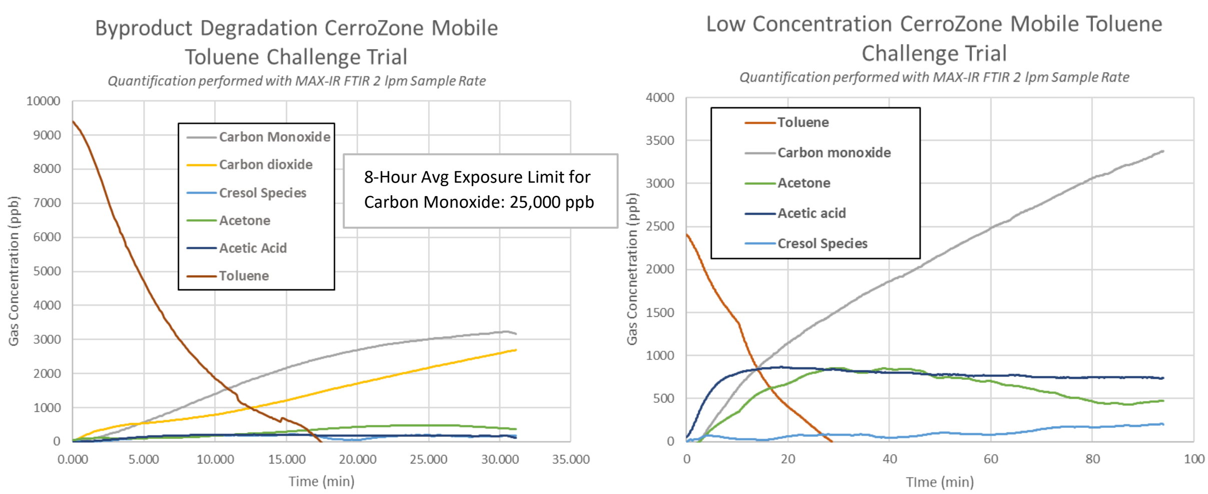

Figure 12. CerroZone Mobile VOC destruction challenges with byproduct quantification results. The byproduct degradation trial (left) shows the increase of byproducts then subsequent decrease when the challenge is no longer present. The low concentration trial (right) shows a similar increase with the low-level byproducts observed. Quantification was performed with the MAX-IR FTIR Spectrometer.

Toluene Low Concentration Challenge

For the low concentration challenge trial, there was consistent destruction of the toluene challenge, and there was an increase in acetone and acetic acid when the device was powered on. Then, acetone started to decrease to background levels. Carbon monoxide was also observed to increase after the device was powered on, indicating them as byproducts of the toluene destruction as well.

Toluene Half-Life and CADR Results

The half-life and clean air delivery rate were calculated using trial data. The reduction rate or the natural log of gas concentrations over time was calculated for each trial using the initial point when the CerroZone Mobile was activated and a minimum 100 subsequent samples. A sample spectrum was taken every 6 seconds for all tests and used for quantification. The average half-life calculated for the three trials performed with the natural decay rate subtracted was 5.6 +/- 1.4 minutes and the average CADR was 72.8 +/- 18.1 CFM in the stainless-steel test chamber. Figure 13 shows the trial data summary.

Toluene Testing Conclusion

The compounds observed to have the highest increase after treatment of the air during toluene exposures were carbon dioxide and carbon monoxide. Both were well below any hazardous levels and are both commonly found in everyday life at low levels. The 8-hour time weighted average OSHA limit is 25,000 ppb, and the highest observed level was below 4000 ppb in the trials performed.

In conclusion, the CerroZone Mobile device was effective at reducing the challenge VOC. The byproducts that were produced were subsequently observed to be reduced. Some low levels of acetic acid were detected from toluene oxidation in addition to carbon dioxide and carbon monoxide. None of the byproducts were detected at high levels. Given the destruction of such high levels of challenge VOCs, the test device proved both robust and consistently destroyed these commonly found compounds.

Trial ID	Initial Gas Conc. (ppb)	Half Life (min)	CADR(m^3/h)	CADR(CFM)
Toluene Control	8,000	141	-	-
Toluene T1	45,000	6.96	96	56
Toluene T3	10,000	4.25	157	92
Toluene T4	2,000	5.59	119	70
Trial Average +/- St. Dev.		**5.6 +/- 1.4**	**123.7 +/- 30.8**	**72.8 +/- 18.1**

Figure 13. *Toluene Trial Summary. The natural log of the gas concentrations measured over time was used to calculate the clean air delivery rates for each trial.*

Formaldehyde Results

Formaldehyde Challenge Results

The formaldehyde challenge was observed to be destroyed by the CerroZone Mobile at different concentrations in the test chamber. A custom formaldehyde analysis method was developed and used for all formaldehyde challenge trials. The gases monitored were like those in the previous trials. **Figure 14** shows the gases that were monitored and shows limits of detection and the compounds detected for the formaldehyde trials.

Formaldehyde Control

A single control trial was performed in the test chamber to ensure the challenge gas concentrations were stable enough to assess the destruction rate of the CerroZone Mobile device. The test device was left in the chamber with all of the mixing fans and chamber configuration as the challenge trials. The control trial data can be found in **Appendix A.**

Formaldehyde Medium Concentration Byproduct Degradation

The second challenge trial was performed to verify the byproducts were observed trending back to normal baseline levels verifying the Cerrozone Mobile device removes even the byproducts.

Compounds Measured	Detection	Limits of Detection (ppb)
Acetaldehyde	Not Detected	120
Acetic Acid	Detected	25
Acetone	Not Detected	75
Butanone	Not Detected	50
Carbon dioxide	Detected	10
Carbon monoxide	Detected	75
Formaldehyde	Detected	30
Formic acid	Not Detected	50
Limonene	Not Detected	25
Methanol	Not Detected	40
o-Cresol	Not Detected	100
Toluene	Not Detected	120

Figure 14. *FTIR Acquisition Method Chemical List. Each of these compounds were monitored during each trial. The detection limits were provided by Thermo Fisher Analytics.*

This trial is found in **Figure 15 (left).** The main byproducts measured during treatment with the CerroZone mobile device were carbon monoxide, carbon dioxide, and acetic acid. These byproducts were observed increasing as the challenge chemicals were still present then subsequently decreased as the challenge VOC was destroyed from the air.

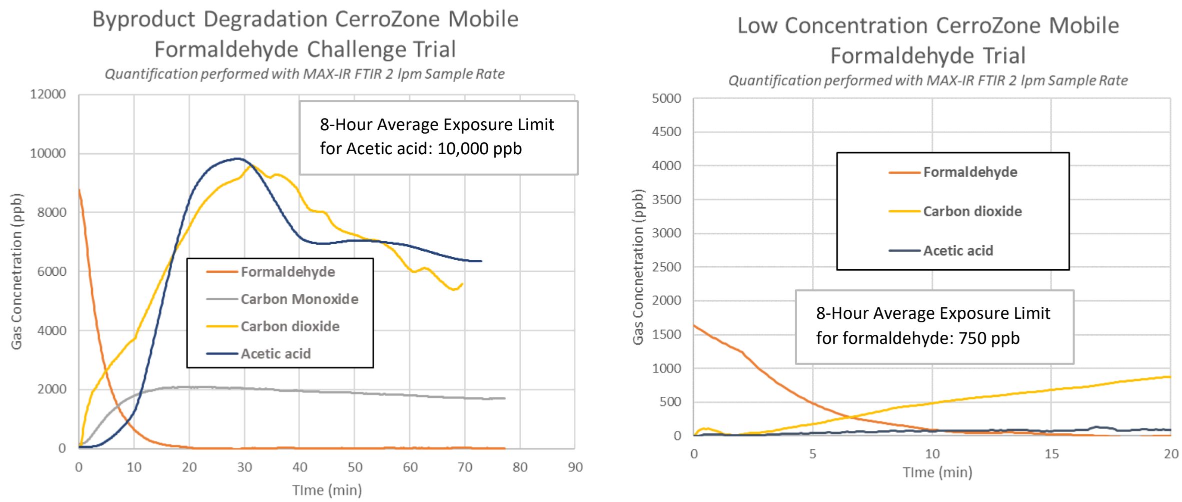

Figure 15. CerroZone Mobile VOC destruction challenges with byproduct quantification results. The byproduct degradation trial (left) shows the increase of byproducts then subsequent decrease when the challenge is no longer present. The low concentration trial (right) shows a similar increase with the byproducts observed. Quantification was performed with the MAX-IR FTIR Spectrometer.

Formaldehyde Low Concentration Challenge

For the low concentration challenge trial, there was a consistent destruction of the challenge VOC and there was an increase in carbon dioxide when the device was powered on. This trial showed very small amounts of acetic acid comparatively. Due to the common observance of acetic acid, acetic acid challenge trials were also performed, and can be found in the next results section of the report.

Formaldehyde Half-Life and CADR Results

The half-life and clean air delivery rate were calculated using trial data. The reduction rate or the natural log of gas concentrations over time was calculated for each trial using the initial point when the CerroZone Mobile was activated and a minimum 50 subsequent samples. A sample spectrum was taken every 6 seconds for all tests and used for quantification. The average half-life calculated for the three trials performed with the natural decay rate subtracted was 3.3 +/- 1.4 minutes and the average CADR was 133.7 +/- 51.7 22 CFM in the stainless-steel test chamber. **Figure 16** shows the trial data summary.

Formaldehyde Testing Conclusion

The compounds observed to have the highest increase in concentration after treatment of the air during formaldehyde exposures were carbon dioxide, carbon monoxide, and acetic acid. The highest carbon monoxide concentration was observed during the 70,000-ppb formaldehyde trial reaching 25,000 ppb. The high concentration of acetic acid observed in the 9,000-ppb trial could have been due to an unknown source since similar levels were not seen in the other trials, but the increase did correspond with activation of the device.

In conclusion, the CerroZone Mobile device was effective at reducing the challenge VOC. The byproducts that were produced were subsequently observed to be reduced. None of the byproducts were detected at hazardous levels. Given the destruction of challenge VOCs, the test device proved both robust and consistently destroyed these commonly found compounds.

Trial ID	Initial Gas Conc. (ppb)	Half Life (min)	CADR(m^3/h)	CADR(CFM)
Formaldehyde Control	10,000	397	-	
Formaldehyde T1	70,000	4.88	136	80
Formaldehyde T2	9,000	2.14	312	183
Formaldehyde T3	2,000	2.85	234	137
Trial Average +/- St. Dev.		**3.3 +/- 1.4**	**227.1 +/- 87.9**	**133.7 +/- 51.7**

Figure 16. *Formaldehyde Trial Summary. The natural log of the gas concentrations measured over time was used to calculate the clean air delivery rates for each trial.*

Acetic acid Results

Acetic acid Challenge Results

The acetic acid challenge was observed to be destroyed by the CerroZone Mobile at different concentrations in the test chamber. A custom acetic acid analysis method developed was used for all acetic acid trials. The gases monitored were similar to those in the previous trials. **Figure 17** shows the gases that were monitored and shows limits of detection and the compounds detected for the acetic acid trials. For this compound only a high and medium concentration were performed.

Acetic acid Control

A single control trial was performed in the test chamber to ensure the challenge gas concentrations were stable enough to assess the destruction rate of the CerroZone Mobile device. The test device was left in the chamber with all of the mixing fans and chamber configuration as the challenge trials. The control trial data can be found in **Appendix A.**

Acetic acid Medium Byproduct Degradation

The second challenge trial was performed to verify the byproducts were observed trending back to normal baseline levels verifying the Cerrozone Mobile device removes even the byproducts. This trial is found in **Figure 18.** The main byproducts measured during treatment with the CerroZone mobile device were carbon dioxide, carbon monoxide, acetone, and formaldehyde.

Compounds Measured	Detection	Limits of Detection (ppb)
Acetaldehyde	Not Detected	120
Acetic Acid	Detected	25
Acetone	Detected	75
Butanone	Not Detected	50
Carbon dioxide	Detected	10
Carbon monoxide	Detected	75
Formaldehyde	Detected	30
Formic acid	Not Detected	50
Limonene	Not Detected	25
Methanol	Not Detected	40
o-Cresol	Not Detected	100
Toluene	Not Detected	120

Figure 17. *FTIR Acquisition Method Chemical List. Each of these compounds were monitored during each trial. The detection limits were provided by Thermo Fisher Analytics.*

The byproducts were observed increasing as the challenge chemicals were still present then subsequently decreased as the challenge VOC was destroyed from the air except for carbon monoxide and carbon dioxide.

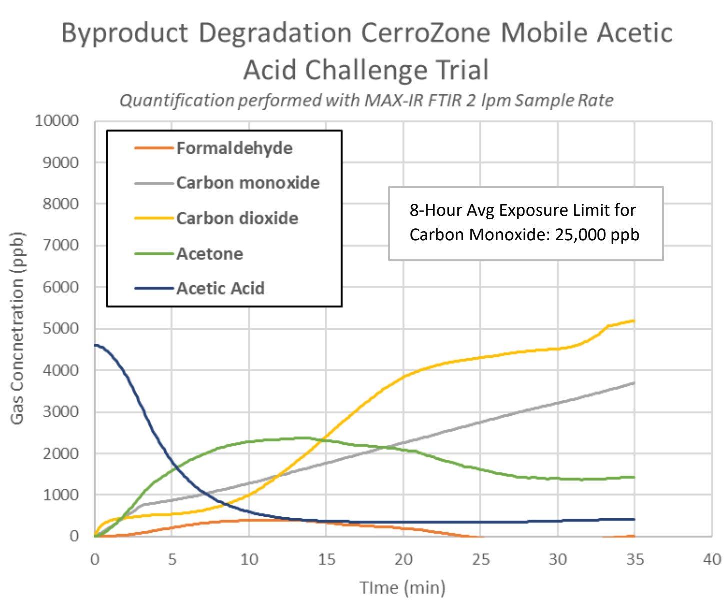

Figure 18. CerroZone Mobile VOC destruction challenges with byproduct quantification results. The byproduct degradation trial shows the increase of byproducts then subsequent decrease when the challenge is no longer present. Quantification was performed with the MAX-IR FTIR Spectrometer.

Acetic acid Half-Life and CADR Results

The half-life and clean air delivery rate were calculated using trial data. The reduction rate or the natural log of gas concentrations over time was calculated for each trial using the initial point when the CerroZone Mobile was activated and a minimum 100 subsequent samples. A sample spectrum was taken every 6 seconds for all tests and used for quantification. The average half-life calculated for the three trials performed with the natural decay rate subtracted was 2.9 +/- 0.3 minutes and the average CADR was 137.6 +/- 12.3 CFM in the stainless-steel test chamber. **Figure 19** shows the trial data summary.

Acetic acid Testing Conclusion

The compounds observed to have an increase in concentration after treatment of the air during acetic acid exposures were carbon dioxide, carbon monoxide, acetone, and formaldehyde. The carbon monoxide concentration was observed to be below 4,000 ppb for the two challenge trials. A higher concentration increase of acetone was observed during the 4,000-ppb acetic acid trial but then began to trend lower as the acetic acid was destroyed.

In conclusion, the CerroZone Mobile device was effective at reducing the challenge VOC. The byproducts that were produced were subsequently observed to be reduced. None of the byproducts were detected at hazardous levels. Given the destruction of challenge VOCs, the test device proved both robust and consistently destroyed these commonly found compounds.

Trial ID	Initial Gas Conc. (ppb)	Half Life (min)	CADR(m^3/h)	CADR(CFM)
Acetic Acid Control	13,000	128	-	
Acetic Acid T1	50,000	2.68	249	146
Acetic Acid T2	4,000	3.04	219	129
Trial Average +/- St. Dev.		**2.9 +/- 0.3**	**233.8 +/- 20.9**	**137.6 +/- 12.3**

Figure 19. *Acetic acid Trial Summary. The natural log of the gas concentrations measured over time was used to calculate the clean air delivery rates for each trial.*

Formic acid Results

Formic acid Challenge Results

The formic acid challenge gas was observed to be destroyed by the CerroZone Mobile at different concentrations in the test chamber. A custom formic acid analysis method developed was used for all formic acid trials. The gases monitored were similar to those in the previous trials. Figure 20 shows the gases that were monitored and shows limits of detection and the compounds detected for the formic acid trials.

Formic acid Control

A single control trial was performed in the test chamber to ensure the challenge gas concentrations were stable enough to assess the destruction rate of the CerroZone Mobile device. The test device was left in the chamber with all of the mixing fans and chamber configuration as the challenge trials. The control trial data can be found in **Appendix A.**

Formic acid 22,000 ppb Trial

The second challenge trial was performed to verify the byproducts were observed trending back to normal baseline levels verifying the Cerrozone Mobile device removes even the byproducts. This trial is found in Figure 21.

Compounds Measured	Detection	Limits of Detection (ppb)
Acetaldehyde	Not Detected	120
Acetic Acid	Detected	25
Acetone	Not Detected	75
Butanone	Not Detected	50
Carbon dioxide	Detected	10
Carbon monoxide	Detected	75
Formaldehyde	Not Detected	30
Formic acid	Detected	50
Limonene	Not Detected	25
Methanol	Not Detected	40
o-Cresol	Not Detected	100
Toluene	Not Detected	120

Figure 20. *FTIR Acquisition Method Chemical List. Each of these compounds were monitored during each trial. The detection limits were provided by Thermo Fisher Analytics.*

The main byproducts measured during treatment with the CerroZone mobile device were carbon dioxide, carbon monoxide, and acetic acid. These byproducts were observed increasing as the challenge chemicals were still present then subsequently decreased as the challenge VOC was destroyed from the air except for carbon monoxide.

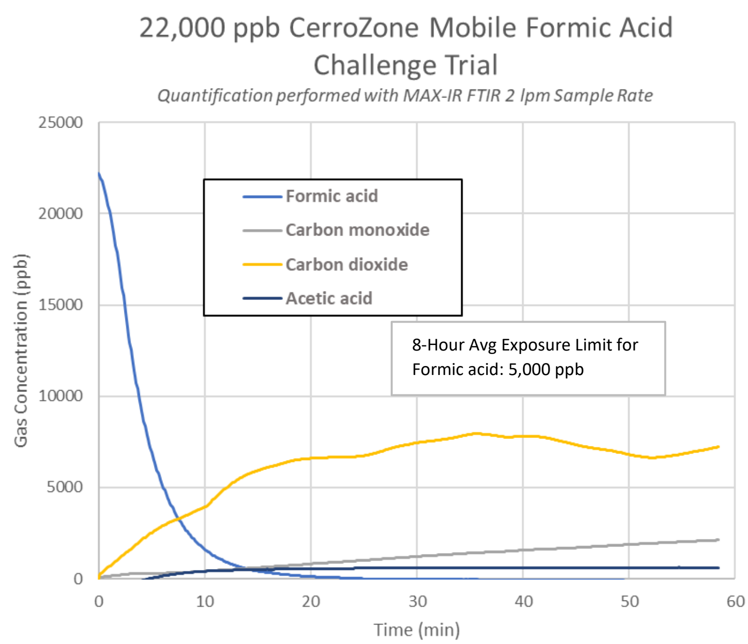

Figure 21. CerroZone Mobile VOC destruction challenges with byproduct quantification results. The byproduct degradation trial shows the increase of byproducts then subsequent decrease when the challenge is no longer present. Quantification was performed with the MAX-IR FTIR Spectrometer.

Formic acid Half-Life and CADR Results

The half-life and clean air delivery rate were calculated using trial data. The reduction rate or the natural log of gas concentrations over time was calculated for each trial using the initial point when the CerroZone Mobile was activated and a minimum 90 subsequent samples. A sample spectrum was taken every 6 seconds for all tests and used for quantification. The half-life calculated for the two trials performed with the natural decay rate subtracted was 2.7 +/- 0.2 minutes and the average CADR was 147.8 +/- 11.5 CFM in the stainless-steel test chamber. **Figure 22** shows the trial data summary.

Formic acid Testing Conclusion

The compounds observed to have an increase in concentration after treatment of the air during formic acid exposures were carbon dioxide, carbon monoxide, and acetic acid. The carbon monoxide concentration was observed to be below 3,000 ppb for the two challenge trials. A higher concentration increase of carbon monoxide was observed during the 22,000-ppb formic acid trial at a slow rate.

In conclusion, the CerroZone Mobile device was effective at reducing the challenge VOC. The byproducts that were produced were all below hazardous levels. The formic acid was reduced by the highest rate of all the challenge VOCs tested. Given the destruction of challenge VOCs, the test device proved both robust and consistently destroyed these commonly found compounds.

Trial ID	Initial Gas Conc. (ppb)	Half Life (min)	CADR(m^3/h)	CADR(CFM)
Formic Acid Control	24,000	113	-	
Formic Acid T1	100,000	2.80	237	140
Formic Acid T2	20,000	2.51	265	156
Trial Average +/- St. Dev.		**2.7 +/- 0.2**	**251.1 +/- 19.6**	**147.8 +/- 11.5**

Figure 22. *Formic acid Trial Summary. The natural log of the gas concentrations measured over time was used to calculate the clean air delivery rates for each trial.*

Results

Half-lives and CADRs of the challenge species in the control and test trials were calculated and formaldehyde was found to have a nearly three-fold longer control trial half-life than the other species, **Figure 23**. The other four challenge chemical species have half-lives that are affected by atmospheric conditions such as the presence of hydroxyl atoms. Formaldehyde is more affected by the presence of sunlight. This explains why formaldehyde could be more persistent in an indoor environment, and consequently the test chamber control trials. Despite its long half-life, it was quickly reduced by the mobile device.

During the limonene trials, the CerroZone Mobile device had an average CADR of 92.4 +/- 22 CFM. For the toluene and formaldehyde trials, they were observed to have CADRs of 72.8 +/- 18.1 and 133.7 +/- 51.7 CFM respectively. The acetic acid and formic acid trials had similar results. The average CADR was observed to be 137.6 +/-12.3 and 147.8 +/- 11.5 CFM respectively.

Discussion

One dissimilarity was noticed in regard to the byproduct production rates when the different challenge concentrations were introduced and sampled with the FTIR. The higher concentrations appeared to produce significantly less when comparing the stoichiometric ratios of the reactants and products. This could have been due to differences in environmental conditions or catalyst changes. More testing would be needed to determine the potential for variation from these differences.

Conclusion

The CerroZone Mobile device was effective at removing all of the challenge and byproduct VOCs at different rates in the stainless-steel test chamber. A summary of the half-life values and CADRs can be found in **Figure 23.**

Each rate of destruction was calculated using the natural log of the gas concentrations over time for each of the trials that were performed. The rate of destruction from control trials was subtracted for net destruction by the CerroZone Mobile device captured in the CADR and half-life values.

Trial ID	Initial Gas Conc. (ppb)	Half Life (min)	CADR(m^3/h)	CADR(CFM)
Limonene Control	10,000	126	-	-
Limonene T1	60,000	4.1	164	96
Limonene T2	4,000	3.5	190	112
Limonene T3	2,000	5.7	117	69
Trial Average +/- St. Dev.		**4.4 +/- 1.1**	**157 +/- 37.3**	**92.4 +/- 22**
Toluene Control	8,000	141	-	-
Toluene T1	45,000	6.96	96	56
Toluene T3	10,000	4.25	157	92
Toluene T4	2,000	5.59	119	70
Trial Average +/- St. Dev.		**5.6 +/- 1.4**	**123.7 +/- 30.8**	**72.8 +/- 18.1**
Formaldehyde Control	10,000	397	-	
Formaldehyde T1	70,000	4.88	136	80
Formaldehyde T2	9,000	2.14	312	183
Formaldehyde T3	2,000	2.85	234	137
Trial Average +/- St. Dev.		**3.3 +/- 1.4**	**227.1 +/- 87.9**	**133.7 +/- 51.7**
Acetic Acid Control	13,000	128	-	
Acetic Acid T1	50,000	2.68	249	146
Acetic Acid T2	4,000	3.04	219	129
Trial Average +/- St. Dev.		**2.9 +/- 0.3**	**233.8 +/- 20.9**	**137.6 +/- 12.3**
Formic Acid Control	24,000	113	-	
Formic Acid T1	100,000	2.80	237	140
Formic Acid T2	20,000	2.51	265	156
Trial Average +/- St. Dev.		**2.7 +/- 0.2**	**251.1 +/- 19.6**	**147.8 +/- 11.5**

Figure 23. *Executive Trial Summary. The natural log of the gas concentrations measured over time was used to calculate the clean air delivery rates for each trial.*

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GLP Certificate

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Client: CerroZone
ARE Project#: 10880.130.1

Study Director

Richard Ludwick
Aerosol Research and Engineering Laboratories

GLP Statement

We, the undersigned, hereby 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.

Study Director:

Richard Ludwick Study Director ARE Labs, Inc.	2/23/2024 Date

Principal Investigator:

Sean McLeod Principle Investigator ARE Labs Inc.	2/23/2024 Date

Appendix A: VOC Control Trials

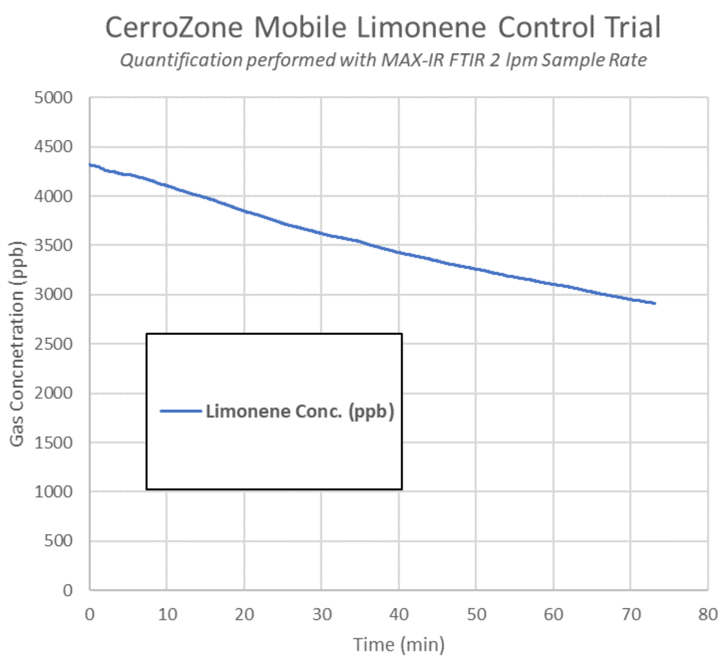

Figure 1A: Limonene Control Trial

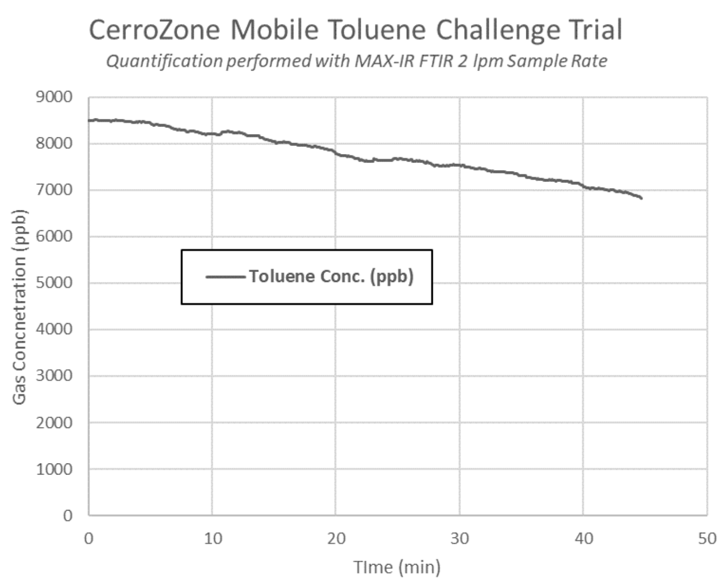

Figure 2A: Toluene Control Trial

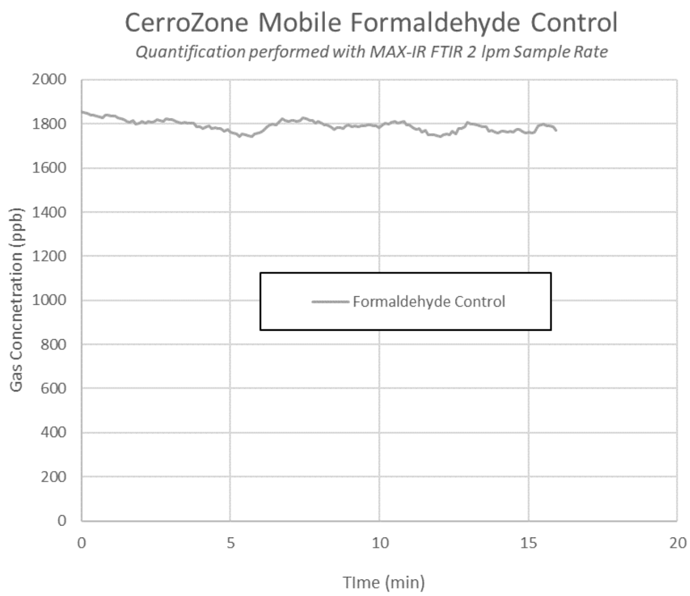

Figure 3A: Formaldehyde Control

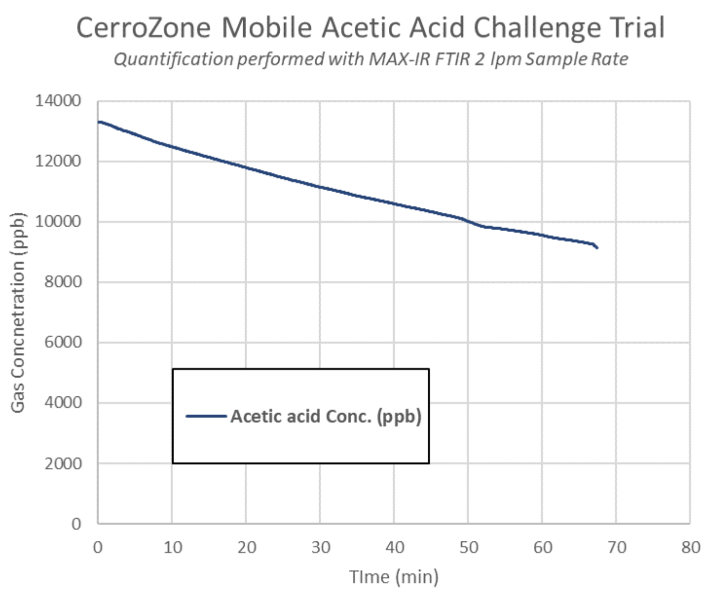

Figure 4A: Acetic acid Control

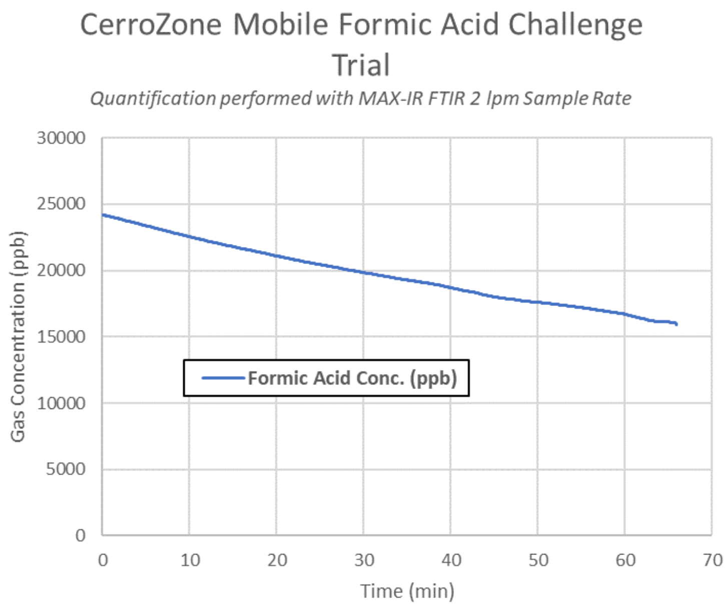

Figure 5A: Formic acid Control