ASHRAE 110 Tracer Gas Containment Report - UCSF

Berkeley hood; Labconco Prototype, Alpha version

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ASHRAE 110 Tracer Gas Containment Test

Conducted at University of California, Medical Center, Department of Pathology, San Francisco, California

Overview

The ASHRAE Standard, ANSI/ASHRAE 110- 1995, *Method of Testing Performance of Laboratory Fume Hoods*, is the foremost protocol used when testing laboratory-type fume hood performance. The ASHRAE-110 "Method" is an elaborate, three-part test that involves face velocity testing, flow visualization, and a tracer gas test. Refer to ANSI/ASHRAE 110-1995 for specific information regarding its Purpose (Section 1), Scope (Section 2), Definitions (Section 3), Instrumentation and Equipment (Section 4), and Test Conditions (Section 5). The tests, referenced below, used the ASHRAE 110 method's Section 6.1, Flow Visualization and Section 7 (7.1 through 7.10), Tracer Gas Testing Procedure to evaluate containment performance.

An Innovative Laboratory-type hood

Researchers at Lawrence Berkeley National Laboratory (LBNL) are developing an innovative containment technology that reduces required airflow through laboratory fume hoods. This technology provides containment at 50 to 70 percent lower airflow than a typical fume hood, based on total exhaust volume. It does not rely on face velocity, in the traditional sense, to maintain fume containment within a hood. Therefore, ASHRAE 110 face velocity tests were not performed (Section 6.2, Face Velocity Measurements).

The LBNL containment technology uses a "push-pull" displacement airflow approach to contain fumes and move air through a hood. Displacement air "push" is introduced with supply vents near the hood's sash opening. Displacement air "pull" is provided by simultaneously exhausting air from the hood. Thus, an "air divider" is created, between an operator and a hood's contents, that separates and distributes airflow at the sash opening. This air divider technology is simple, protects an operator, and delivers dramatic cost reductions in a facility's construction and operation.

Evolution of the Berkeley hood

Dr. Helmut Feustel, a LBNL staff researcher, developed basic concepts for a High-Performance Laboratory Fume Hood during 1995–1998. This High-Performance Laboratory Fume Hood is referred to, in this document, as the "Berkeley hood." In January 1999, LBNL's Environmental Energy Technologies Division (EETD) transferred the project to its Applications Team. At this time, the research project team developed a "prototype" Berkeley hood.

Prototype Berkeley hood

The prototype hood was built with a superstructure provided by Labconco in early 1999. The standard superstructure was modified significantly to include the air divider technique.

By August 2000, the hood had been evaluated extensively with a series of containment tests. This incarnation represented the "final" Berkeley hood configuration both dimensionally and functionally. The resulting design information was transferred to Labconco. They proceeded to build an "alpha" version of the Berkeley hood for the UCSF demonstration project.

Labconco Alpha Berkeley hood

The “alpha” Berkeley hood was delivered to LBNL by Labconco in September 2000. It was based on a standard Labconco fume hood superstructure. However, it was highly customized by Labconco to accommodate supply air system installation and baffle modifications that are fundamental to the air divider technique. However, this early alpha version of the Berkeley hood required modification and adjustments prior to the demonstration installation at University of California, San Francisco Medical Center.

Labconco Alpha Berkeley hood at UCSF

The four-foot-wide version of the Berkeley hood by Labconco is slightly deeper than a ‘standard’ hood (28 inches versus 25 inches for the standard hood, from the sash to the rear baffle). The fully open sash dimensions are 38-1/4 inches wide by 29-1/4 inches high, for a total open area of 7.76 square feet.

Alpha Test Configuration

Initial tests conducted used a Siemens Mechanical Equipment Controller (MEC) to control exhaust flow to 388 CFM via a Siemens Fume Hood Exhaust Terminal (FHET). This corresponds to a face velocity of 50 FPM in a standard hood. However, the Berkeley hood uses three fans to push room air into the hood's cabinet. This makes face velocity measurements irrelevant. The "top" fan pushes air from behind the top of the sash towards the rear baffle. The "lower" fan pushes air from behind the lower airfoil towards the rear of the cabinet. The "front" fan blows air from the top of the face area down (across the front of the sash when it is closed). All three fans have individual rheostats to manually control their speed. These three fans produce a vectored airflow that allows containment at lower than normal exhaust airflow.

Installation Photos

Figures 1 and 2, of the Berkeley hood, are at the UCSF Department of Pathology, Scanning Electron Microscopy and Cardiovascular facility.

Fig. 1 – Berkeley hood installation at UCSF Medical Center

Fig 2 – Lab Manager using the Berkeley hood.

Containment Tests and Setup

Description of Test Procedure

As noted above, LBNL researchers successfully applied two of ASHRAE's 110-1995 test methods, flow visualization and tracer gas tests, Section 6.1 and Section 7, respectively. A general overview of these two tests is provided:

1) Flow visualization tests can be performed with various smoke-generating substances. Theatrical smoke, superheated glycol, smoke "sticks", titanium tetrachloride, and dry ice, solid-phase CO_2, are examples of smoke sources. A qualitative understanding of containment is gained from conducting smoke tests. A rating system has been devised for "poor- to-good" patterns of smoke containment by Tom Smith[1]. However, these tests are only used as indicators of containment. When satisfactory results are observed, they should be followed by tracer gas testing.

[1] Tom Smith, President of Exposure Control Technologies, Inc.; 231-C East Johnson St., Cary, NC 27513; ph: 919.319.4290

2) Tracer gas testing is the most reliable test for determining a fume hood's containment performance. A highly generalized overview of the test is provided. The gas most typically used is sulfur hexafluoride, or SF_6. This gas flows into a fume hood being tested through a specially constructed "ejector." The ASHRAE 110 guideline includes engineering drawings to fabricate this ejector. The "pure" SF_6 flow rate is set at four liters per minute. The ejector is placed in different positions (center, left, and right) in the hood. A mannequin is placed in front of the hood being tested to simulate an operator. An inlet port to a detector device is placed at the "breathing zone" (the nose) of the mannequin. Tracer gas is allowed to flow for five minutes and spillage levels are recorded by the detector. Ratings can be provided for a hood at three levels of installation:

- "As manufactured" (AM) — initial test of performance in a highly controlled/idealized setting at the manufacturer's facility.
- "As installed" (AI) — testing is completed in the actual, fully operating facility, potentially more difficult conditions than the manufacturers' facility.
- "As used" (AU) — testing is performed by adding a hood operator's experimental equipment, a.k.a., "clutter", to the "as installed" hood, making the test conditions even more difficult.

Test Instrumentation

Test instrument used to detect SF6 was a ITI-Qualitek Leakmeter 120. Inlet tube was located at nose of mannequin. Calibration was with known sources of SF_6 in "cal bags." (A conversion factor of 0.31 PPM was equal to 1.0 volts; therefore, the concentration was equal to 0.31 times voltage indicate by a VOM.)

Mannequin Setup

In the following, Figures 3 & 4 show the mannequin positioned in front of the Berkeley hood prior to mounting the ITI tracer gas detector. Figure 5 is a photo of the recording data logger and laptop computer. In Figures 6 & 7, the "as used" condition is simulated with laboratory "clutter' of beakers and test hardware with the mannequin in the "center" position. In Figure 8 the same clutter is used, but the mannequin is positioned to the right side of the hood.

Fig. 3 – Mannequin position for standard ASHRAE 110 SF6 test; 26 inches above, Center.

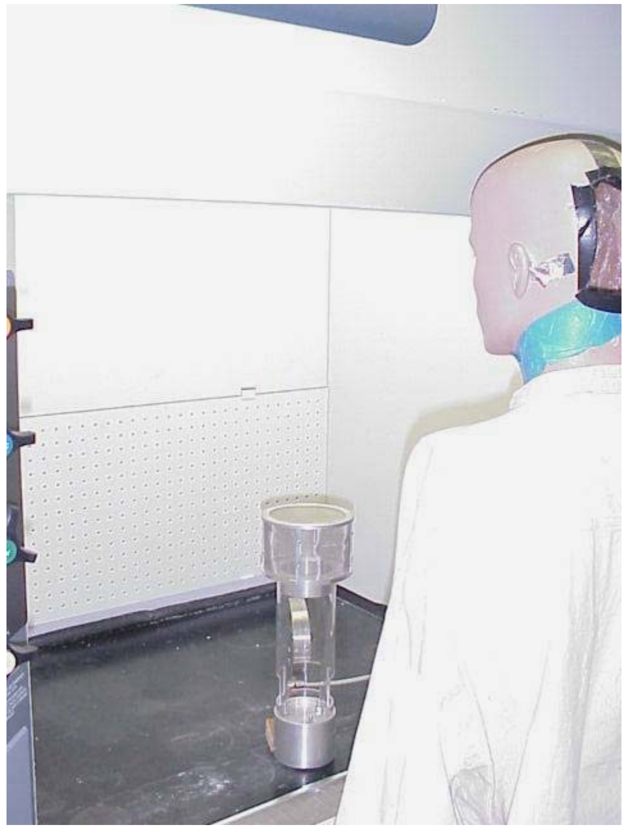


Fig. 4 – Ejector center position for standard ASHRAE 110 SF6 test.

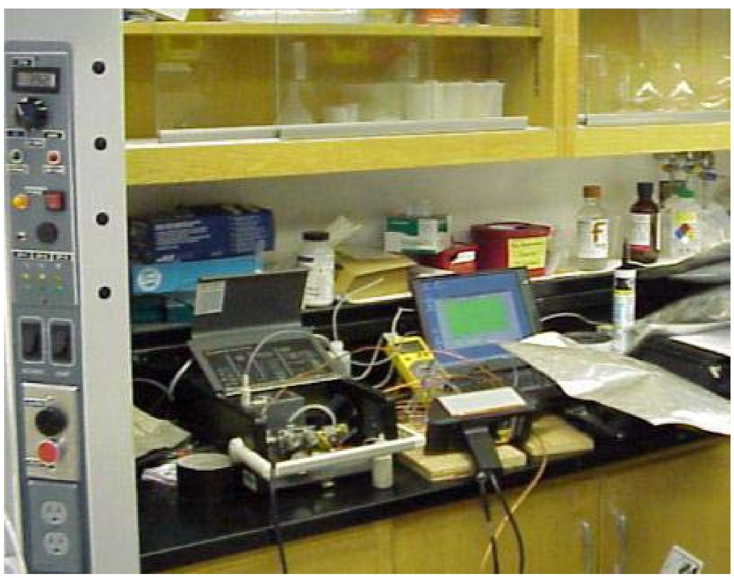


Fig. 5 – Instrumentation and data recording equipment.

Fig. 6 – Tracer gas test setup for as used (AU) challenge with clutter, center position.

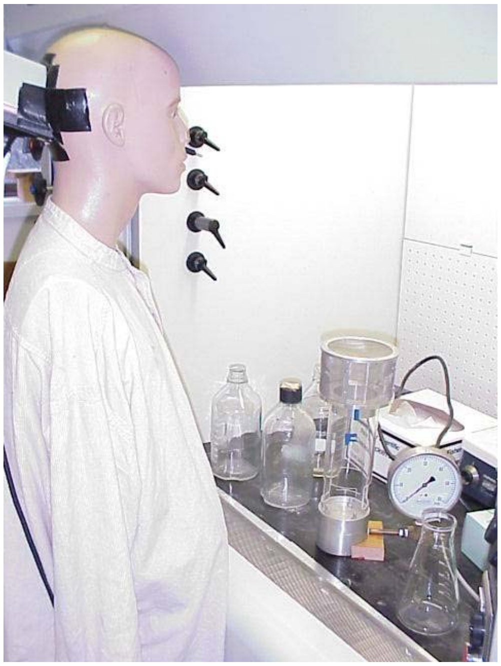


Fig. 7 – Same as Fig. 6, long view.

Fig. 8 – Tracer gas test setup for as used (AU) challenge with clutter, right position.

Acceptability Level

Testing criterion used is from ANSI/AIHA Standard Z9.5 (1992) for the "as installed" (AI) and "as used" (AU) designations for the situation in the test/fabrication laboratory. The acceptability level required for AI, or AU, designation is 0.1 PPM or less for five minute average at three mannequin positions; left, center, and right. Note that the more stringent "as manufactured" (AM) designation was also noted in test results. In this case, AM designation is 0.05 PPM or less for five minute average at three mannequin positions.

Deviations from ASHRAE 110 Test Procedure

Face velocity tests (Section 6.2) and Variable Volume Tests (Sections 6.3 and 6.4) were not performed.

Exception Report

Many non-standard tracer gas tests were performed that are more challenging than outlined in the main sections of the ASHRAE 110 method (refer to ASHRAE 110-1995, Appendix A). Fifteen tracer gas test runs were performed. See Tracer Gas Run Summary, below.

Containment Test Airflows

Exhaust Airflow Rate

In a “conventional” hood, exhaust airflow rate is attained by flowing air at an average value of 100 FPM through the open sash area (a.k.a. face velocity). The open sash area of the Berkeley hood is equal to 7.76 square feet. Therefore, at a “conventional” face velocity of 100 FPM, this would require an exhaust airflow of 776 CFM through the hood. However, the Berkeley hood was operated and tested at an exhaust rate from 388 CFM, which is 50 percent of conventional hood down to a lower volume of 260 CFM, which is 34 percent of a conventional hood. The hood’s exhaust airflow was determined with a via a calibrated Siemens Fume Hood Exhaust Terminal (FHET). Volume was varied by manually adjusting this FHET.

Supply Airflow Rate

Supply flows were set at the values listed below. Airflow rates were determined by using a hot wire anemometer.

1) Top Plenum: average 50 FPM velocity at outlet.

2) Front Plenum: average 60 FPM velocity at outlet.

3) Lower (bottom) Plenum: average 35 FPM velocity at outlet.

Containment Test Results

Summary of Results

As noted in Table 1, the Labconco "alpha" prototype hood passed in all tests completed except when operated to a "failure" condition deliberately (See notations on charts, below). Comparison to a standard ("existing") hood that the Berkeley hood replaced are also presented.

Table 1: ASHRAE 110 Test results for Labconco unit at UC San Francisco.

Test Type	*Test Conditions*	*Air Flow % of "normal" (100 fpm)*	*Berkeley Hood Containment AM (as mf'd)*	*Berkeley Hood Containment AI (as installed)*	*Berkeley Hood Containment AU (as used)*	*Standard (Existing) Hood Containment @ 100 FPM*
Smoke	Small volume Smoke tube	50%	Good	Good	Good	Fair
Face Velocity [a]	Sash Full Open	50%	N/A	N/A	N/A	Fail
Tracer gas [b]	Sash Full Open; Three Positions	50%	Pass	Pass	Pass	Fail [c]
Tracer gas [b]	Sash movement; three positions	50%	Pass	Pass	Pass	N/A
Tracer gas [b]	Safety margin check	50%	Pass	Pass	Pass	N/A
Tracer gas [b]	Sash full open; Three positions; breathing zone @ 18 inches	50%	Pass	Pass	Pass	N/A
Tracer gas [b]	Sash movement; three positions; breathing zone @ 18 inches	50%	Pass	Pass	N/A	N/A
Tracer gas [b]	Sash full open; breathing zone @ 18 inches	40%	Pass	Pass	Pass	N/A
Tracer gas [b]	Sash full open; breathing zone @ 26 inches	33%	Fail	Fail	Fail	N/A

a. Face velocity Pass/Fail criterion per CAL/OSHA 5154.1.
b. Tracer gas Pass/Fail criterion per ANSI Z9.5 1992.
c. Fail criterion per NIH (1996); marginal pass per ANSI Z9.5 1992.
N/A = not applicable or not done

Test Run Narrative

Standard – Runs #1 through #3

ASHRAE's 110 method, Section 7 – Tracer Gas Test Procedures was completed from approximately 1:00 p.m. to 1:25 p.m. Specifically, Sections 7.1 through 7.10 were performed with passing ratings for both "as manufactured" and "as installed." As noted above, the gas detector used was an Ion Tracker Instruments (ITI) Leakmeter 120. Its operation was checked with calibrated bags of SF_6 tracer gas just prior to the tests to ensure readings during the subsequent tests would be accurate.

As Used with clutter – Runs #4 through #15

A set of tracer gas containment tests began at approximately 1:30 p.m. with the hood "loaded" with various beakers at front of the work surface and small boxes near the rear baffle to challenge the hood to create an "as used" (AU) condition. A containment guideline of less than 0.1 PPM was used. The hood contained to less than 0.02 PPM (minimum detectable) when the AIHA recommends that a hood should contain to less than 0.05 PPM "as manufactured" (AM). There were some slight changes, consistent with the lab door being opened, but the readings always returned to "background." By any standard, the hood contained quite well with 50 percent of the flow required at a 100 FPM face velocity. Abbreviated AU tracer gas tests on the left and right sides were conducted; they were slightly less in duration than the required five minutes. There was no detectable leakage on either side.

Sash Movement Effect – Runs #7 through #12

At approximately 1:40 p.m., a Sash Movement Effect (SME) test per ASHRAE 110 Section 7.12 was performed center, left, and right; however, stabilizing times were shortened. This challenge involves opening the sash from 25 percent to fully open three times. The hood contained to less than 0.02 PPM *with clutter*. Following the SME tests at a 26 inch breathing zone height, the mannequin was lowered so the detector was located 18 inches above the work surface (to simulate a short or disabled operator) and conducted the SME test again. The hood contained to less than 0.02 PPM *with clutter*.

Safety margin – Runs #13 & #14

At about 2:00 p.m., it was felt that the team needed to investigate the Berkeley hood's operational safety margin. Therefore, the total exhaust airflow rate was slowly reduced (via a rheostat on the hood) to see when containment would be lost. With the mannequin in the center position at the normal 26 inch height above the work surface (per ASHRAE 110), the starting point was 388 CFM, as described above. The flow rate was reduced in five steps. Each step lasted approximately 20 seconds. Tracer gas spillage (indicating loss of containment) was noted at approximately 260 CFM. This corresponds to a face velocity of approximately 34 FPM on a standard hood. With the detector lowered to 18 inches to simulate a breathing zone of a seated hood user or a person of short stature, containment was lost at approximately 300 CFM. This corresponds to a face velocity of approximately 39 FPM.

Periphery test – Run #15

At about 2:25 p.m., a peripheral test commenced by moving the detector around the outer edge of the sash opening per ASHRAE 110, Section 7.11. The hood contained well at a flow corresponding to 50 FPM; there was no detectable leakage. However, the tracer gas detector reading slowly increased during the approximate five minute test. Within a couple of minutes of the end of the test, the background SF_6 concentration in the room was 0.08 PPM. This indicates re-entrainment from the fume hood exhaust to the building supply intake. This was confirmed later by going up on the laboratory's roof and examining the proximity of the hood's exhaust duct outlet and the room's air handling unit intake; they are only separated by fifteen feet with the intake downwind of the exhaust outlet.

Tracer Gas Run Summary

The following table, Table 2, summarizes the test runs performed on the Labconco Alpha prototype hood at UCSF on 05 December 2000. Column 1 is the run number which corresponds to the data plot presented in the following section of this report. Column 2 is the height of the mannequin's breathing zone above the hood's work surface in inches. Clutter in column 3 refers to research equipment and hardware, such as beakers, that were inserted into the hood to simulate an "as used" condition. Position in column 4 is the horizontal location of the mannequin in front of the hood per the ASHRAE 110 protocol. Column 5 notes whether the hood's sash was in its standard (Std) full open position or being moved from 25 percent open to full open and back to 25 percent open per the ASHRAE 110 protocol for Sash Movement Effect (SME) three times. The last column, number 6, notes whether the hood was tested to a "fail" per ANSI Z9.5 1992 for "as installed" hoods.

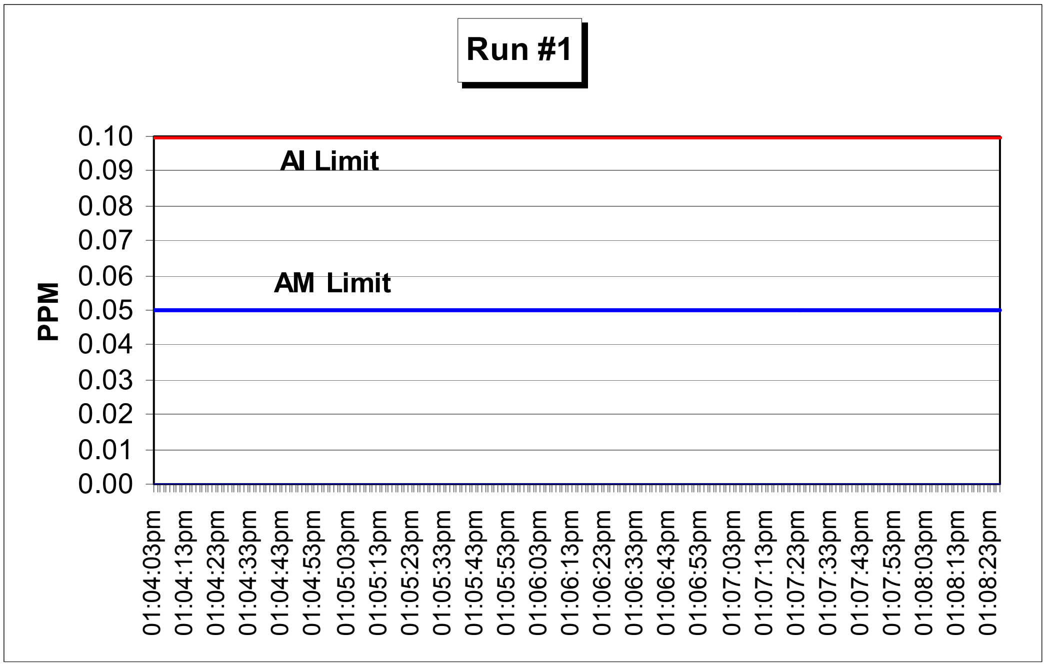
Table 2: Tracer Gas Runs

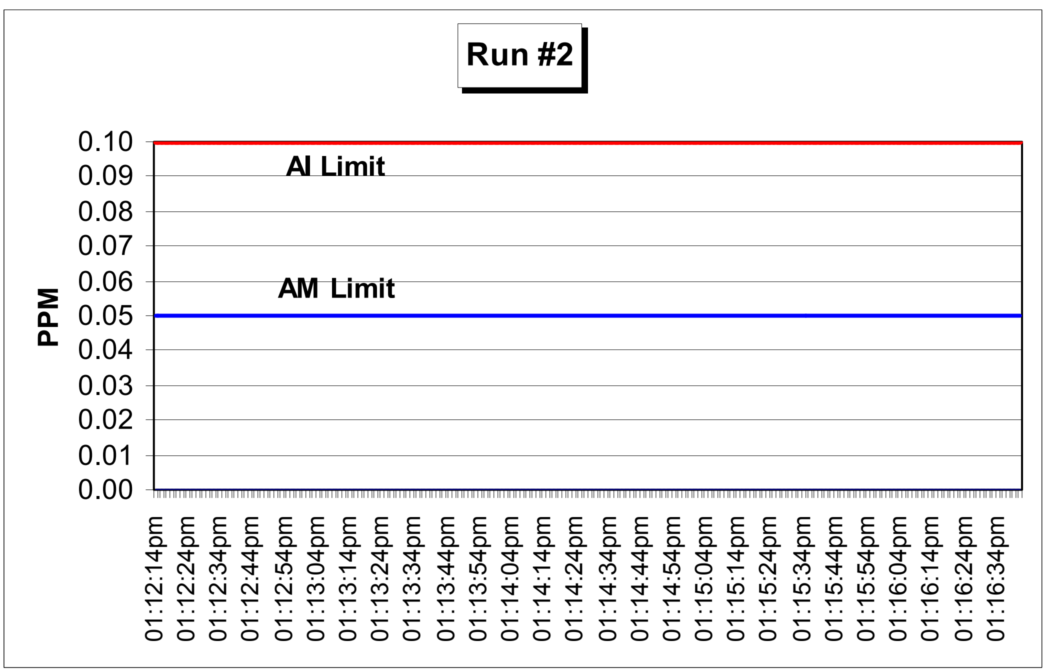
Run#	Height Inches		Clutter		Position			Sash		Test to Fail	
	26	18	Yes	No	Center	Left	Right	Std	SME	Yes	No
1	X			X	X			X			X
2	X			X		X		X			X
3	X			X			X	X			X
4	X		X		X			X			X
5	X		X			X		X			X
6	X		X				X	X			X
7	X		X		X				X		X
8	X		X			X			X		X
9	X		X				X		X		X
10		X	X		X				X		X
11		X	X			X			X		X
12		X	X				X		X		X
13	X		X				X	X		X	
14		X					X	X		X	
15	N.A.		X		Perimeter Test			X			X

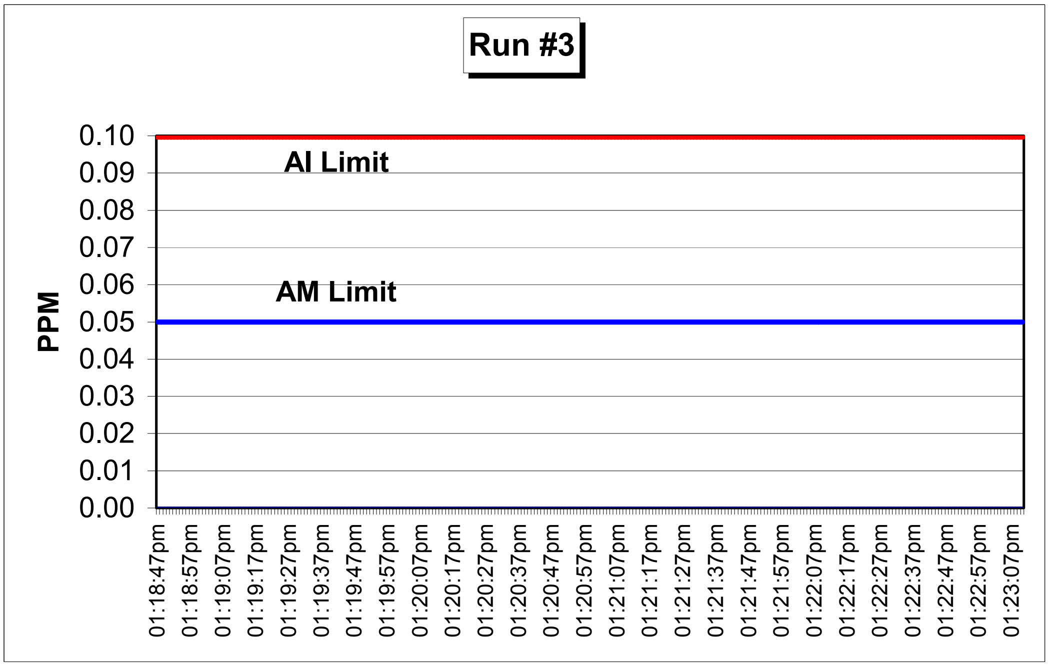
Use Run #, above, as a key for referencing charts in following Containment Test Plots.

Containment Test Run Plots

See Tracer Gas Run Summary table, Table 2, above, for description of each run.






Run #3
AI Limit
AM Limit
PPM
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
01:18:47pm
01:18:57pm
01:19:07pm
01:19:17pm
01:19:27pm
01:19:37pm
01:19:47pm
01:19:57pm
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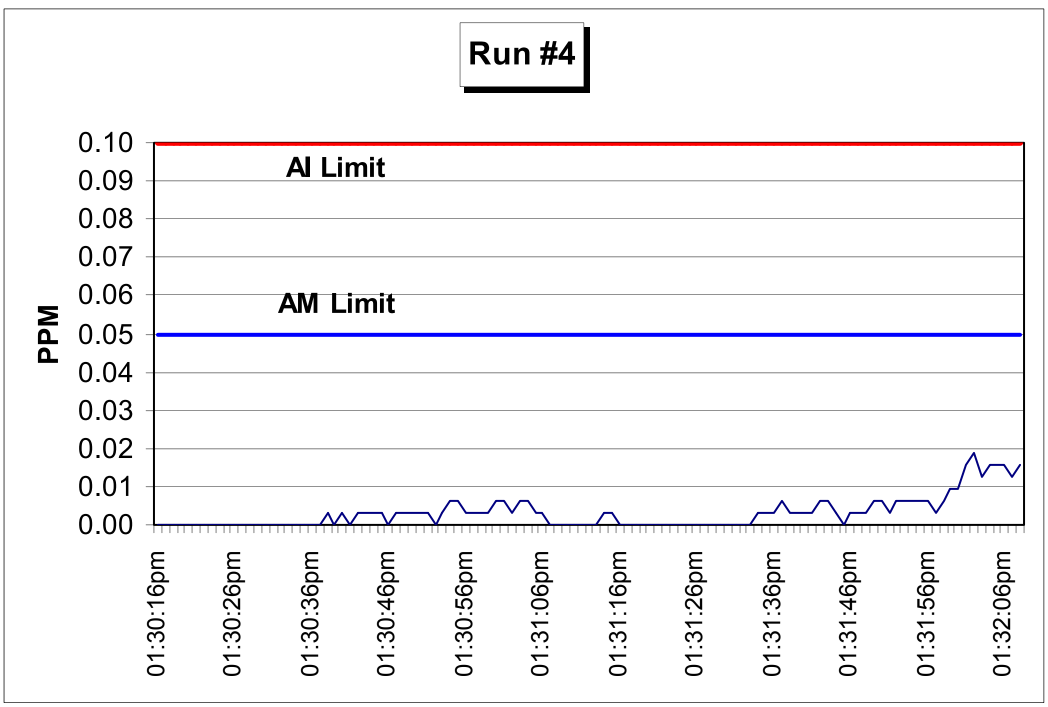
Run #4
AI Limit
AM Limit
PPM
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
01:30:16pm
01:30:26pm
01:30:36pm
01:30:46pm
01:30:56pm
01:31:06pm
01:31:16pm
01:31:26pm
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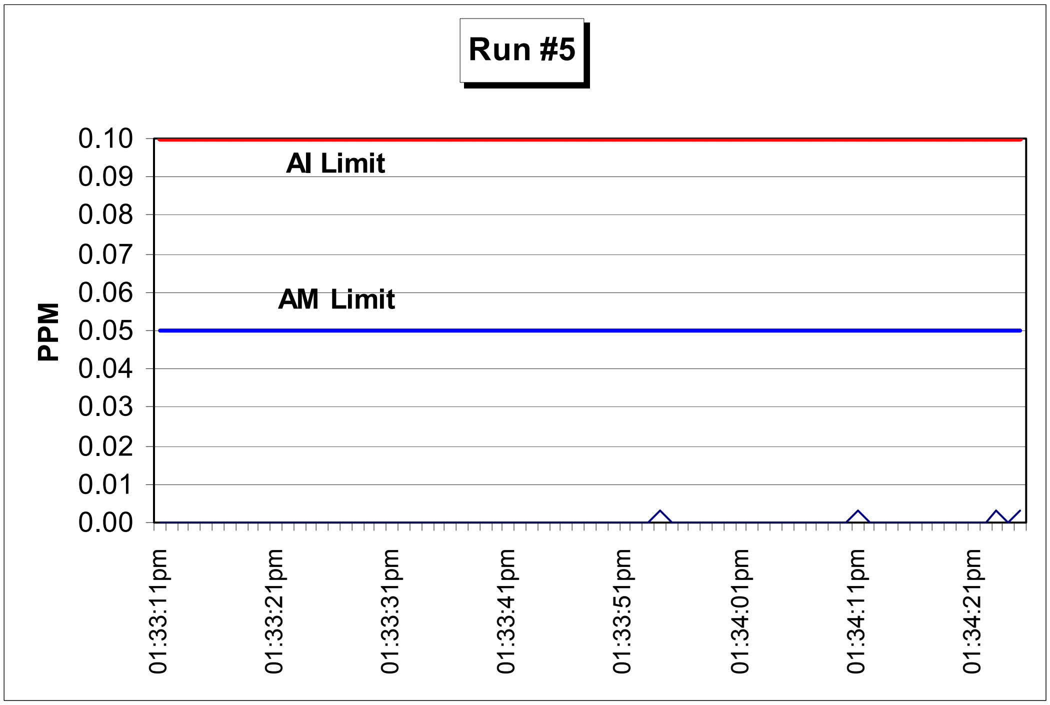
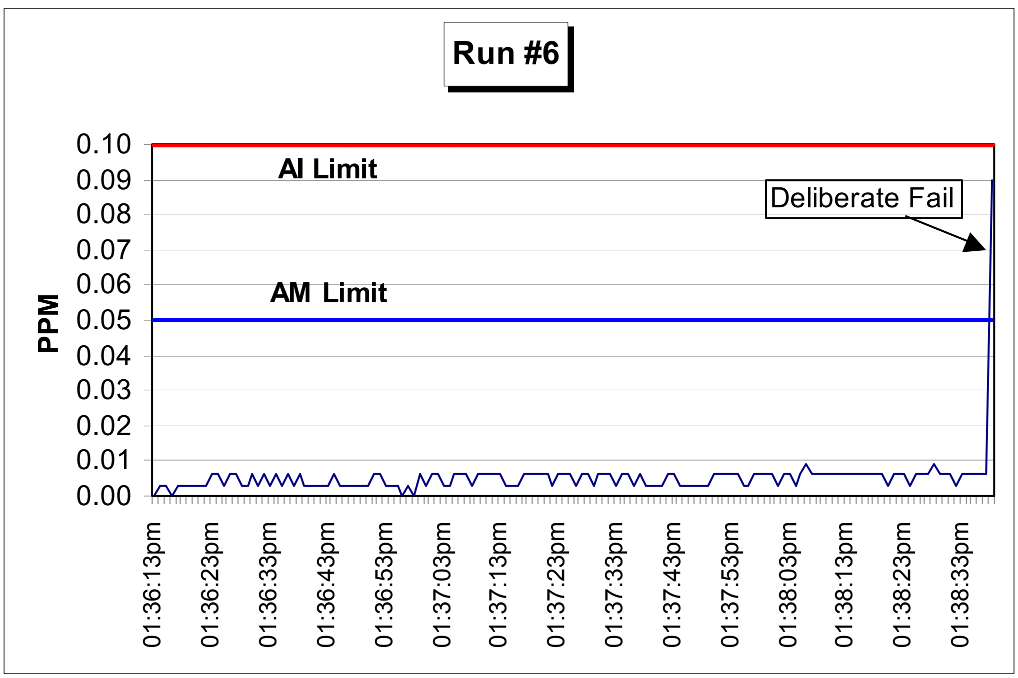
01:31:56pm
01:32:06pm


Run #5
AI Limit
AM Limit
PPM
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
01:33:11pm
01:33:21pm
01:33:31pm
01:33:41pm
01:33:51pm
01:34:01pm
01:34:11pm
01:34:21pm


Run #6
AI Limit
Deliberate Fail
AM Limit
PPM
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
01:36:13pm
01:36:23pm
01:36:33pm
01:36:43pm
01:36:53pm
01:37:03pm
01:37:13pm
01:37:23pm
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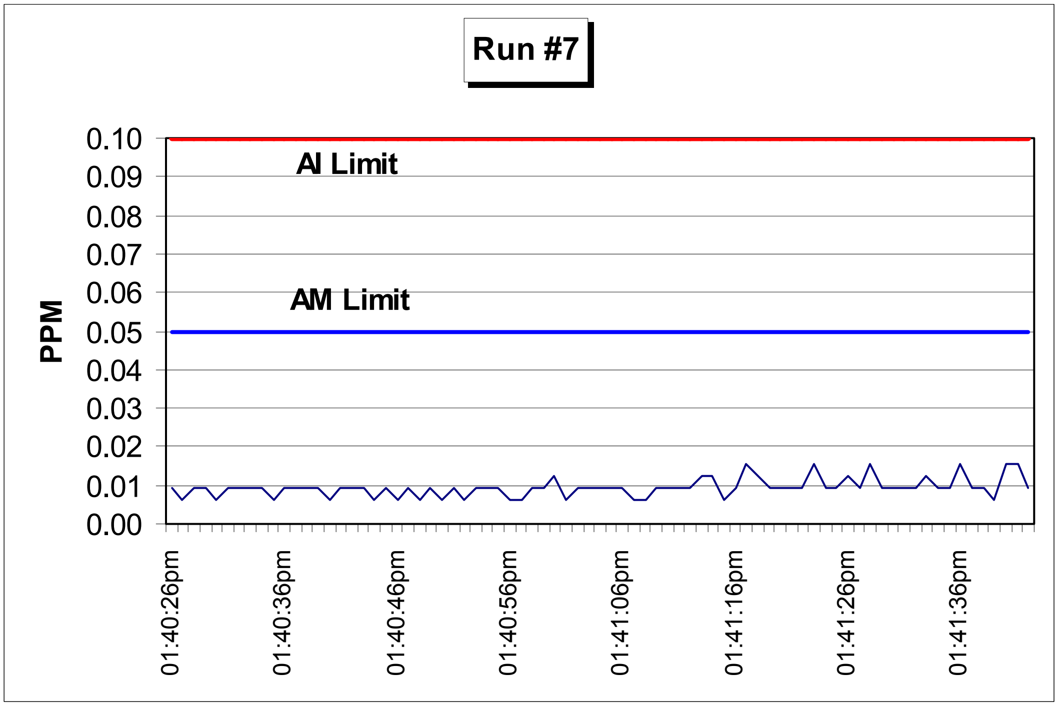
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Al Limit
AM Limit
PPM
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
01:40:26pm
01:40:36pm
01:40:46pm
01:40:56pm
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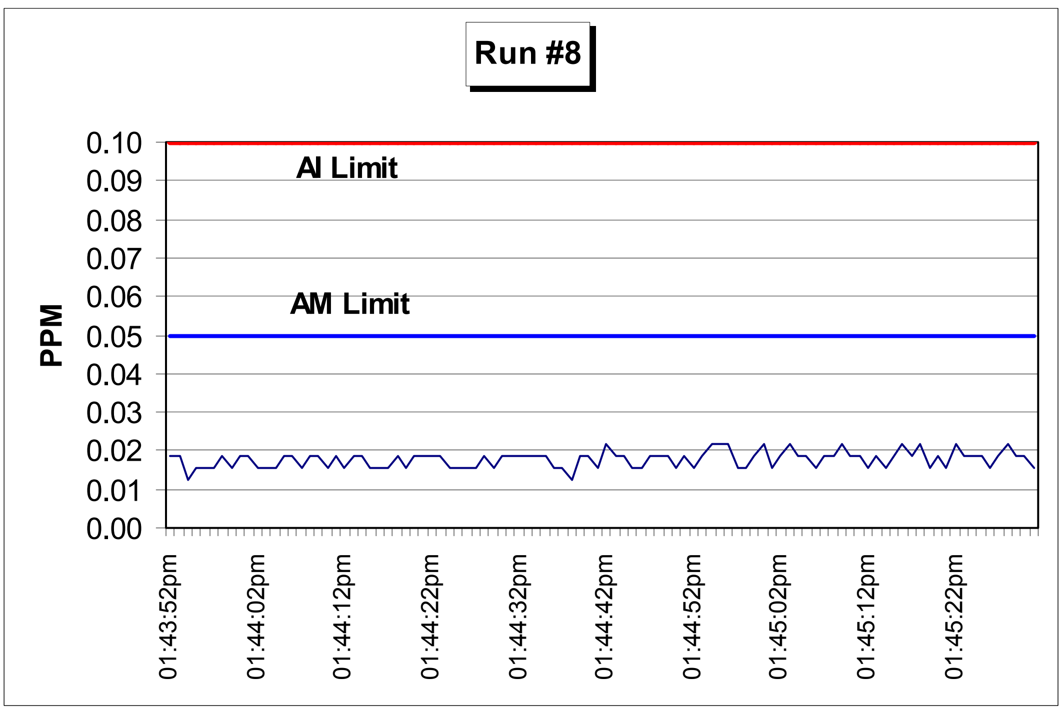
01:41:16pm
01:41:26pm
01:41:36pm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Al Limit
AM Limit
PPM
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
01:43:52pm
01:44:02pm
01:44:12pm
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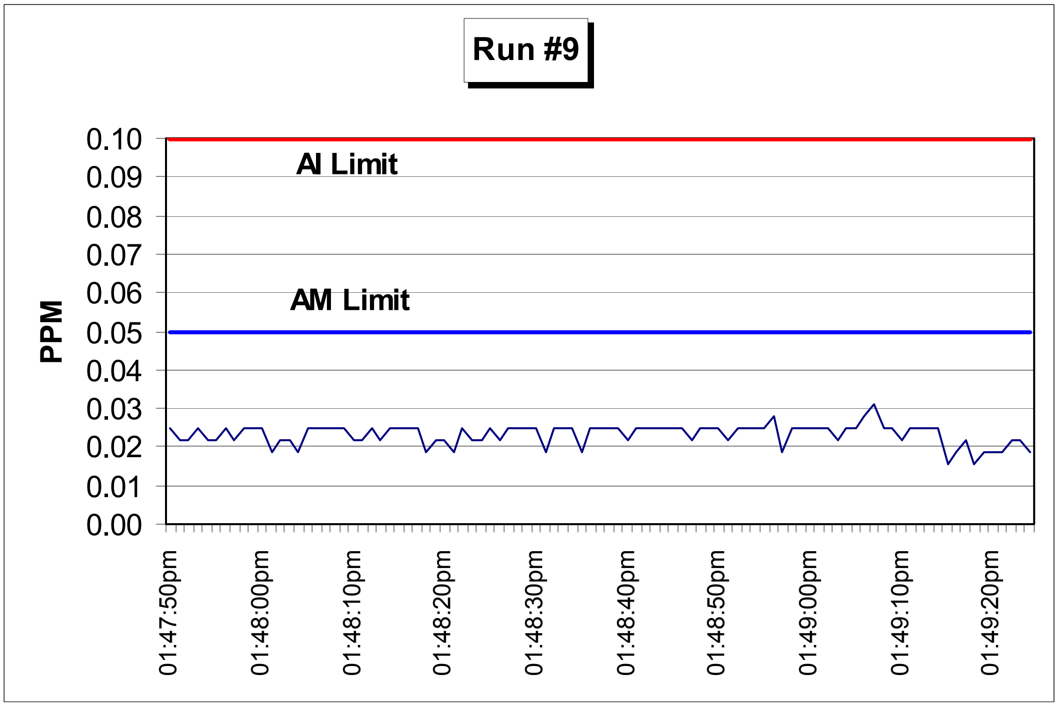
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0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
PPM
AI Limit
AM Limit
01:47:50pm
01:48:00pm
01:48:10pm
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01:48:30pm
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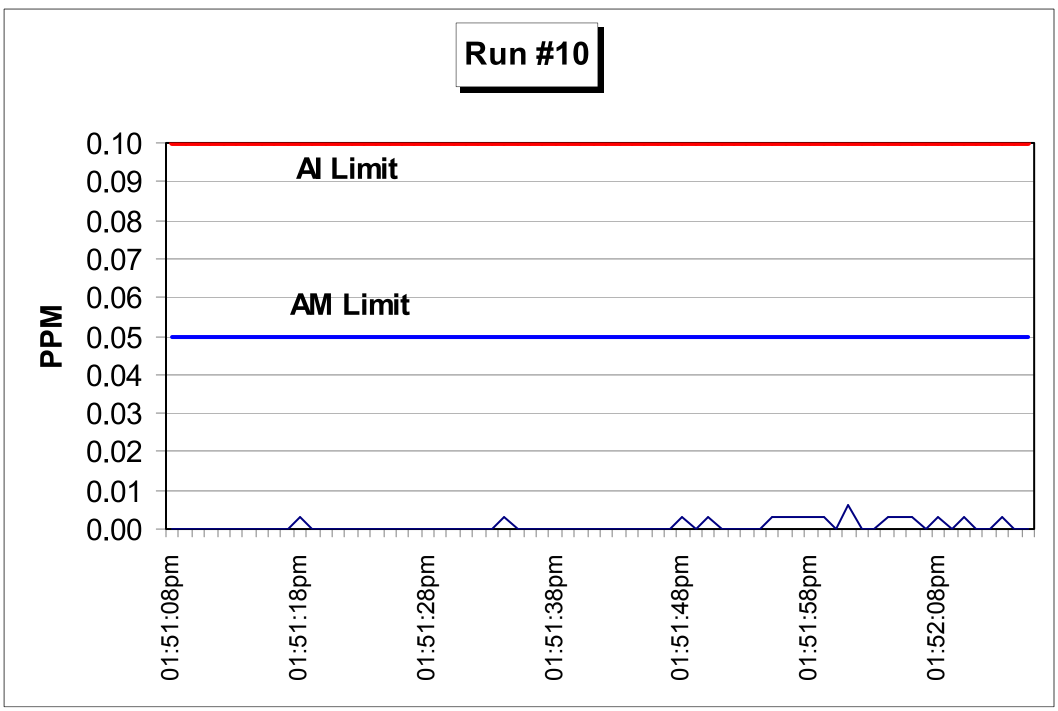
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0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
PPM
AI Limit
AM Limit
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01:51:28pm
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01:51:48pm
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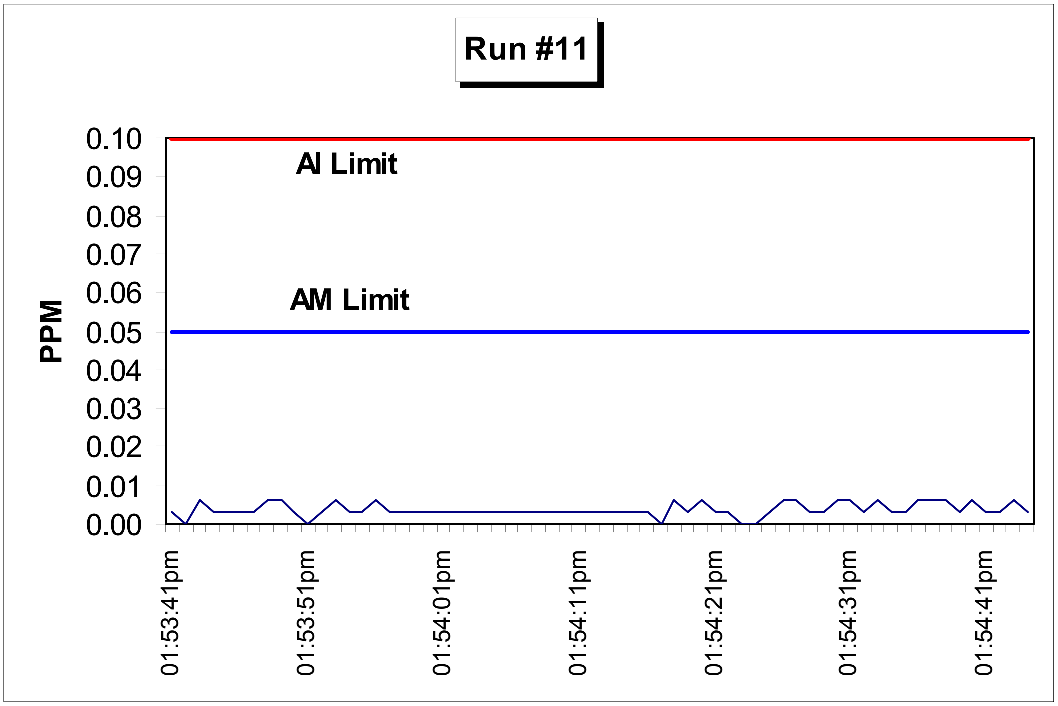
01:52:08pm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AM Limit
PPM
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0.08
0.07
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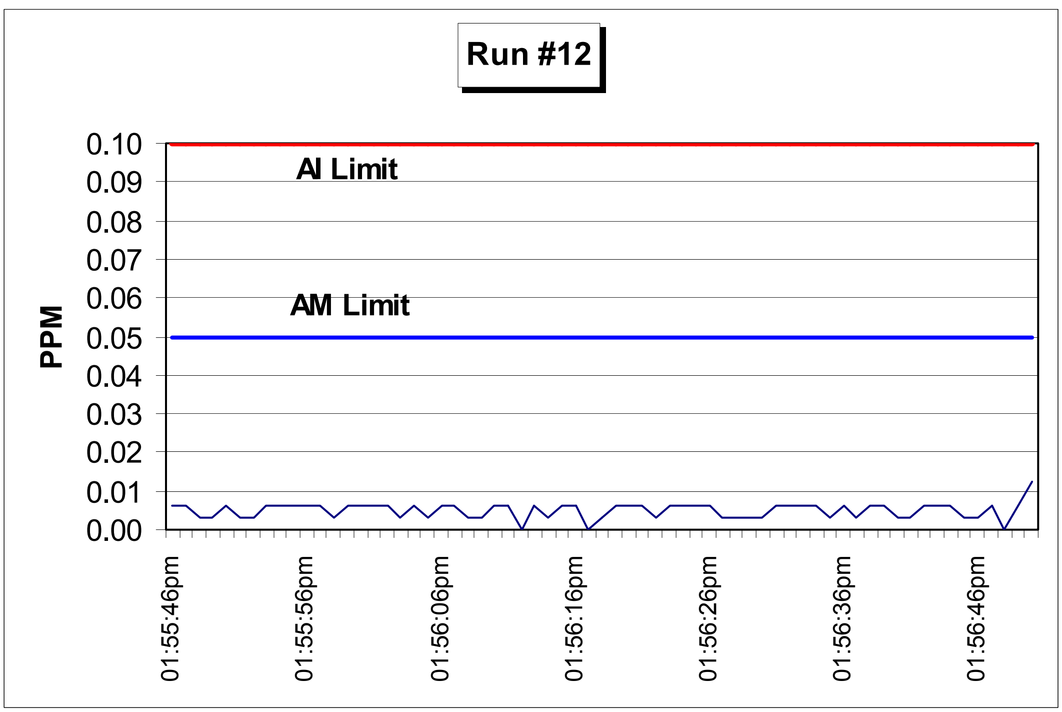
01:54:11pm
01:54:21pm
01:54:31pm
01:54:41pm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Al Limit
AM Limit
PPM
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
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01:56:36pm
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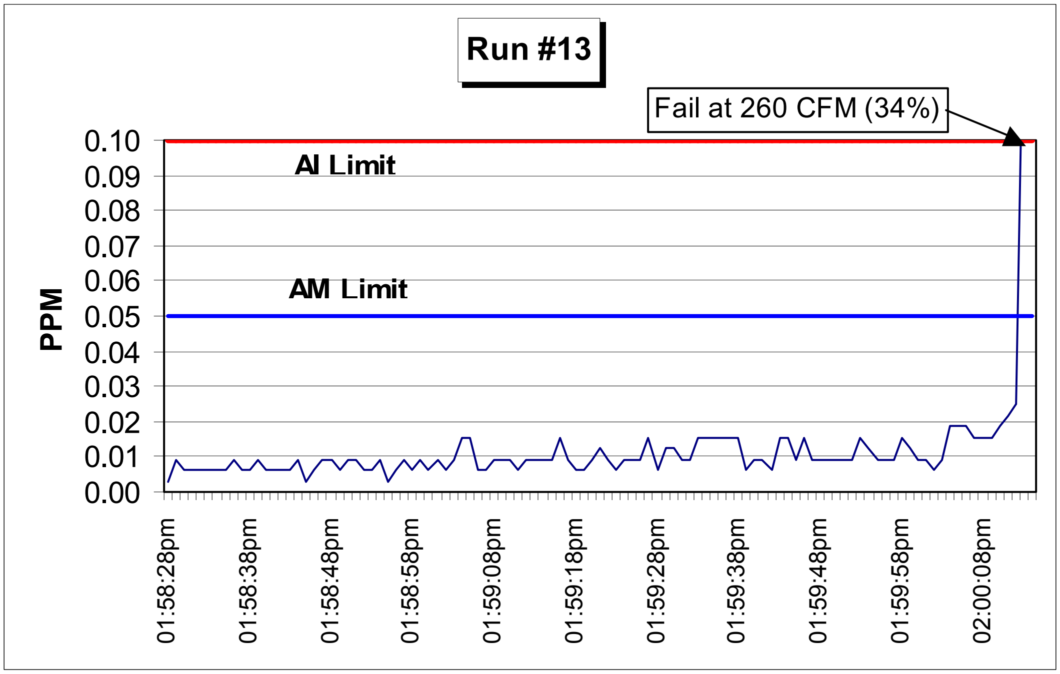
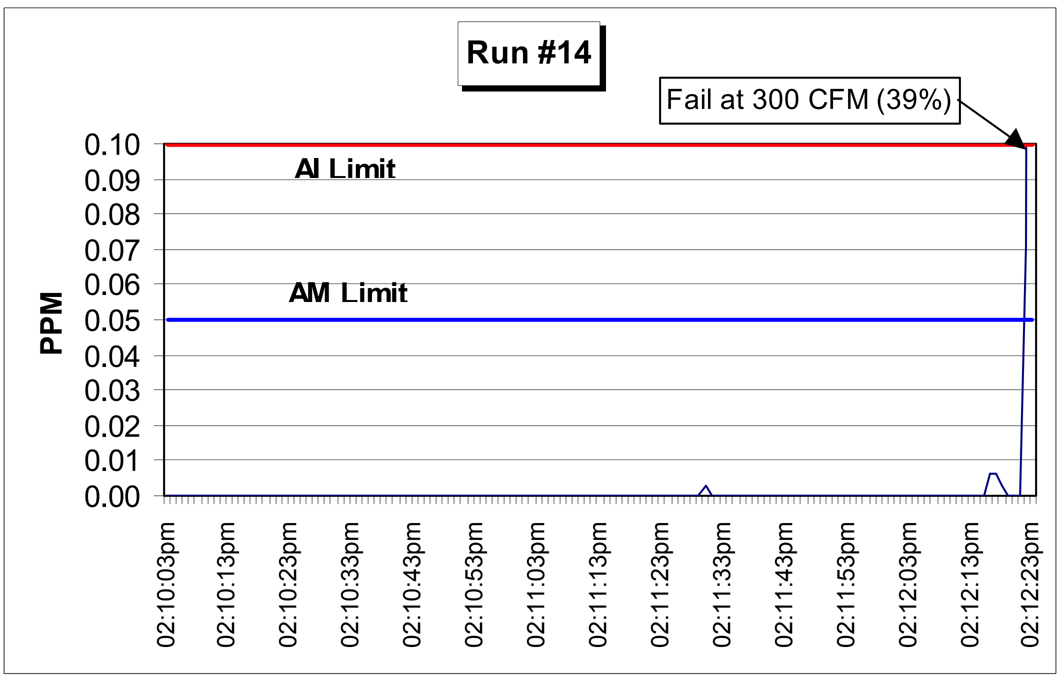
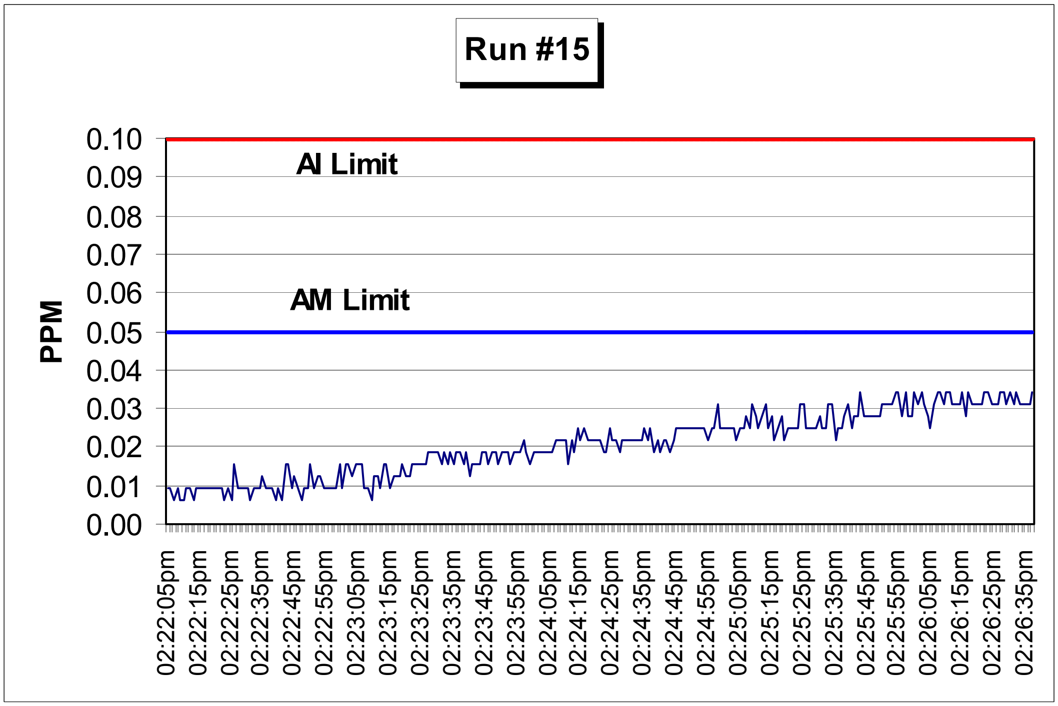

Run #13
Fail at 260 CFM (34%)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
PPM
AI Limit
AM Limit
01:58:28pm
01:58:38pm
01:58:48pm
01:58:58pm
01:59:08pm
01:59:18pm
01:59:28pm
01:59:38pm
01:59:48pm
01:59:58pm
02:00:08pm


Run #14
Fail at 300 CFM (39%)
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
PPM
AI Limit
AM Limit
02:10:03pm
02:10:13pm
02:10:23pm
02:10:33pm
02:10:43pm
02:10:53pm
02:11:03pm
02:11:13pm
02:11:23pm
02:11:33pm
02:11:43pm
02:11:53pm
02:12:03pm
02:12:13pm
02:12:23pm


Run #15
AI Limit
AM Limit
PPM
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
02:22:05pm
02:22:15pm
02:22:25pm
02:22:35pm
02:22:45pm
02:22:55pm
02:23:05pm
02:23:15pm
02:23:25pm
02:23:35pm
02:23:45pm
02:23:55pm
02:24:05pm
02:24:15pm
02:24:25pm
02:24:35pm
02:24:45pm
02:24:55pm
02:25:05pm
02:25:15pm
02:25:25pm
02:25:35pm
02:25:45pm
02:25:55pm
02:26:05pm
02:26:15pm
02:26:25pm
02:26:35pm