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To: Mr. Tony Turiello, Rescue Air Systems, Inc.
Mr. Prabodh Panindre, New York University

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Reference: Summary of Compressed Air Samples from Firefighter Air Replenishment Systems (FARS)

Background & Methodology

Mr. Anthony Turiello, CEO of Rescue Air Systems, Inc. (RAS) requested and granted permission to Trace Analytics, LLC (TA) to provide a summary of their confidential compressed air sample results for the purpose of an NYU research project on FARS. The goal of the summary was to provide a comparison between compressed air sample results from FARS and the general population of air sample results in terms of their success/failure to meet NFPA 1989 air quality standards.

RAS personnel took samples from firefighter air replenishment systems (FARS) throughout the United States. RAS uses mobile air compressors to supply air to test FARS installed in high-rise buildings. Purification filters are replaced on a quarterly basis for the 18 & 27 horsepower compressors. Filters are replaced every 8 hours of runtime on the 5 horsepower compressors.

The FARS compressed air sample results span the time period of January 2013 through December 31, 2019. A total of 6,859 samples from FARS were processed during this time period. Also included in results are percentages of similar results from the general population of samples submitted to Trace Analytics, LLC for the same time period. All NFPA samples include FARS samples.

Executive Summary

An independent analysis by Trace Analytics LLC compared FARS and non-FARS compressed breathing air samples using NFPA 1989 air quality metrics. Samples for the analysis covered the time period from January 2013 through December 31, 2019. Based on these samples, Trace Analytics concludes:

- **FARS air samples met NFPA 1989 compliance standards more often than non-FARS compressed breathing air samples.**
    - FARS samples complied with NFPA 1989 standards 97% of the time (6,675/6,859 samples), versus 96% for non-FARS compressed breathing air samples.
- **Conversely, FARS samples were non-compliant only 2.7% of the time, versus 3.95% for non-FARS compressed breathing air samples.**
    - For almost all analytes tested, FARS failure rates were less than failure rates of non-FARS compressed breathing air samples.
    - The most common failures in compressed breathing air -- water vapor and carbon dioxide -- were less likely to be detected in the FARS samples.
    - The most common failure detected in FARS samples -- oxygen/nitrogen imbalances -- occurred most likely as a result of new filter cartridge installations combined with an inadequate running of the compressor to normalize air in the system.
- **Overall, FARS air samples were at least as safe and more compliant with NFPA 1989 air quality standards than non-FARS compressed breathing air samples.**

FARS Air Samples vs All NFPA Samples*					
			FARS Compliant	FARS vs All NFPA	
Compliant NFPA 1989 Air Samples (2013-2019)			**6,675**	**97.32%**	**96.05%**
			FARS Non-Compliant	FARS vs All NFPA	
Total Non-Compliant Samples			**184**	**2.68%**	**3.95%**
Sampling Errors or Equipment Malfunction			FARS Non-Compliant	FARS vs All NFPA	
	Glass Sample Bottle - Gases		17	0.25%	0.29%
	Filter Membrane - Oil and Particulate		10	0.15%	0.52%
		Total Errors/Malfunctions	**27**	**0.39%**	**0.81%**
NFPA 1989	Analyte	Allowable Limit	FARS Non-Compliant	FARS vs All NFPA	
5.6.1	Oxygen, %	19.5-23.5	64	0.93%	0.42%
5.6.2	Carbon Monoxide, ppm	5	7	0.10%	0.15%
5.6.3	Carbon Dioxide, ppm	1000	25	0.36%	0.75%
5.6.4	Oil & Particulate, mg/m^3	2	1	0.01%	0.08%
5.6.5	Water, ppmv	24	28	0.41%	1.40%
5.6.6	Non-Methane VOCs	25	0	0.00%	0.11%
5.6.7	Odor	Not pronounced	3	0.04%	0.05%
5.6.8	Nitrogen, %	75.0-81.0	29	0.42%	0.19%
		Total Analyte Non-Compliant Samples	**157**	**2.29%**	**3.14%**
*Samples from 1/1/2013-12/31/2019		Total FARS Samples	**6,859**		

Non-Compliant Results and Possible Sources for Contamination

5.6.1 Oxygen (O_2)

Frequently, when oxygen/nitrogen is out of compliance; we also see a lower than normal carbon dioxide (CO_2) reading. This is a common effect after a filter cartridge replacement.

The reason CO_2 is lower than the atmospheric level of 407 ppm[(1)] is that the molecular sieve used to remove water has a weak affinity for CO_2. This weak affinity means that CO_2 is retained by the molecular sieve initially.

This effect is true of N_2 and O_2 also. Nitrogen is held just slightly more strongly than O_2 so that on a new filter, the N_2 value is lower and the O_2 value is higher than normal atmospheric air.

When the molecular sieve releases the N_2, it then makes for a higher than usual N_2 value and lower than usual O_2 value. The molecular sieve retains the components in this order:

Water>>Carbon Dioxide>>Nitrogen>>Oxygen and Methane

This is all a function of new filter cartridge installation. It is unknown exactly how long the O_2 / N_2 balance takes to normalize. We advise running the compressor for 15–20 minutes after a filter cartridge replacement to avoid this, in a few rare cases, it may require more time.

5.6.2 Carbon Monoxide (CO)

Fumes from motor exhaust at the compressor intake are the most common source for elevated CO in compressed air. Other sources from within the compressor can be caused from combustion product of hydrocarbon fuels and lubricants due to overheated oils, and/or oxidation of charcoal filters due to overheating.

Purification filters are designed to remove CO by converting it to carbon dioxide. When purification filters are saturated with water, they will no longer remove CO but allow it to pass through.

5.6.3 Carbon Dioxide (CO_2)

The current level of CO_2 in atmospheric air is approximately 407 ppm [1]. Catalytic converters in vehicles convert CO and hydrocarbons to CO_2. The position of the compressor intake is very important to avoid excess contamination from entering into compressor. The intake can become overloaded with gaseous contaminants from an idling vehicle near the intake of the compressor.

Purification filters are designed to remove CO by converting it to CO_2. The filter will then hold the CO_2 along with other removed impurities. If a sudden pressure drop occurs, like when the bleed valve to the purification chamber is opened too quickly or a sudden failure of the pressure maintaining valve occurs, CO_2 and other contaminants can be released into the air stream.

Another scenario that can cause high CO_2 levels is when a purification filter is not replaced but is moved up the chain of cartridges to a front position (rotating filters instead of replacement).

Some filter cartridges have a viewable moisture indicator strip, the problem occurs when it is assumed that the filter is “good as new.” A filter is like a sponge, it can hold on to unknown quantities of CO_2 or gaseous hydrocarbons. When it becomes saturated, it will not continue to remove contaminants but allow them to simply pass through the filter. If a pressure drop occurs at this point, large amounts of CO_2 and/or gaseous hydrocarbons can be released.

5.6.4 Oil and Particulates

Compressor or filter malfunction, contaminated piping, fittings, or hoses can lead to oil and particulate contamination. Contamination can also be a result of lack of maintenance and/or timely filter changes.

Atmospheric air typically contains between 0.05 mg/m^3 and 0.5 mg/m^3 of oil vapor (gaseous not aerosol) from sources such as vehicle exhaust and industrial processes. Once again, the compressor intake location is critical. Oil vapor can cool and condense in the compressed air system. [2] Millions of particles in the form of dust, pollen, and microorganisms occur naturally and are also present in atmospheric air.

Particulate contamination (dust from charcoal or desiccant) can occur when a filter ruptures or is damaged. Wear particles from normal compressor operation are also a possible source of contamination.

5.6.5 Water (H_2O)

Water results over the limit are typically resolved with a filter change. High temperatures at the inlet of the compressor will affect the life of the filter. We historically have a higher rate of failure during the summer months.

Other sources for this problem can be the malfunction of the manual or automatic water drain or priority valve on the compressor. Sometimes, the filter itself may be damaged or not seated properly in the filter housing. Other potential sources include recent hydrostat of storage bottles, the use of fill hoses greater than 5 feet in length, fill hoses left unpressurized and/or valves left open, recent depressurization of filters, or relocation of a stationary compressor without replacing filter cartridges. Additionally, cascade systems that have been contaminated with water will require significant purging to remove collected water.

5.6.6 Non-Methane Volatile Organic Compounds (VOCs)
Non-methane volatile organic compounds can come from within the compressor or from the intake air, resulting in elevated levels. Overheated compressor lubricants can cause the generation of lubricant vapors which can slip by piston rings. VOCs in intake air can come from motor exhaust fumes, stored cleaning solvents, chemical plants, industrial/manufacturing facilities, or retail shops such as dry cleaners or beauty salons.

5.6.7 Odor
The sampling technician determines if there is evidence of a pronounced odor. A pronounced or foul odor can be due to overheated oil, excess water, cleaning agents, microbial activity, and poor intake air quality. Pronounced odors have been described as stale, musty, rubber-like, exhaust, oily, and moldy.

5.6.8 Nitrogen (N_2)
See 5.6.1

Non-Compliant Due to Sampling Errors or Sampling Hardware Malfunction

Glass Sample Bottle – All Gases

A 20 mL glass sample bottle filled with an indicator gas is used to capture the gaseous portion of the sample. The glass vial is inserted into a bottle holder that has two stainless steel needles that puncture the self-sealing stopper. If the needles are bent, damaged, or plugged, an inadequate air exchange of the indicator gas with the compressed air can occur. If the indicator gas level exceeds 6%, the sample is considered invalid due to inadequate air exchange during sampling.

In a few cases, an unused glass vial is submitted in error resulting in the same determination of inadequate air exchange.

Filter Membrane – Oil and Particulate

Samples are taken with a pre-weighed filter membrane inside a filter cassette. When the filter membrane is torn or damaged, the laboratory is unable to perform the necessary analysis. Damage to the filter membrane can occur when the flow rate is too high, not measured properly, or unregulated. Sudden pressure drops can also affect the integrity of the membrane. Sometimes if a large quantity of particulate matter is present, it can rip, tear or shred the filter membrane rendering it unsuitable for analysis.

In this same group of sampling errors, we sometimes have customers that fail to return the filter cassette to the laboratory for analysis.

Conclusion

The most common causes of failures in compressed breathing air samples are water vapor (1.4%) and carbon dioxide (0.75%) levels. Typically, when water vapor failures occur, it is because the purification cartridge needs to be replaced. Carbon dioxide failures can be due to intake air quality or a sudden pressure change releasing the retained carbon dioxide from the filter.

In the case of more than 6,800 FARS samples, the most common cause of failure (in 93 instances) was oxygen/nitrogen imbalances due to the frequency of filter changes required for the mobile compressors. The percentage of FARS sample failures after a filter change may be higher than the average semi-annual or annual replacements by fire departments. All other type of failures from FARS samples (64) were less than the general population of all NFPA samples.

Each failed FARS sample was accompanied or immediately followed by compliant samples. Not a single failed FARS sample necessitated corrective work to on an actual FARS system, since failures were likely due to sampling errors, equipment malfunctions, or technician error.

Overall, FARS air quality tests results demonstrate that FARS breathing air samples outperform non-FARS breathing air samples.

If you have further questions, please feel free to contact Ruby Ochoa, President/Co-Owner of Trace Analytics, LLC, Austin TX.

References

[1] NOAA, Climate.gov, https://www.climate.gov/news-features/understanding-climate/climate-change-atmospheric-carbon-dioxide

[2] CAGI, cagi.org, https://www.cagi.org/working-with-compressed-air/mythbusters/air-treatment-myths.aspx#!prettyPhoto

For further information on sources of contamination, visit https://www.airchecklab.com/aircheck-academy/breathing-air/sources-of-contamination/