Evolution of Combustion Byproducts from Gaseous Fire Suppression Agents

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Task 3.3.2 Provide subject matter expertise in the area of fire prevention, detection, and suppression and for other damage prevention and damage reduction systems. (**Deliverable 4.8:** Ground Vehicle Survivability Technologies and Demonstrators Reports).

The US Army plans to modernize legacy vehicle platforms, including Automatic Fire Extinguishing Systems (AFES), and is considering replacing legacy agents with more environmentally friendly suppression agents. TARDEC's exploratory tests are intended to compare various suppression agents, including new, more environmentally friendly ones, with those currently deployed.

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U.S. ARMY RESEARCH, DEVELOPMENT AND ENGINEERING COMMAND

EVOLUTION OF COMBUSTION BYPRODUCTS FROM GASEOUS FIRE SUPPRESSION AGENTS

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11 OCT 2018

INTRODUCTION

- An interesting observation made during a study of potential fire suppression agents with lower GWP than those currently used, was that the byproducts from FK-5-1-12 evolved quite differently than those from Halon 1301 or HFC227-BC.[1]

  "Note that although the peak acid levels for 'HFC-227BC' and 'FK-5-1-12+' … are similar, the integrated levels used in casualty assessments were very different: none of the FK-5-1-12-based tests 'passed,'…. The difference is related to the relative evolution in time of COF_2 and HF. Halon and HFC-227BC tests with good fire suppression show COF_2 quickly peaking and then slowly decaying as the HF level slowly rises; in FK-5-1-12 tests both COF_2 and HF peak quickly and then slowly decay. The result is that the total integrated acid level used in casualty assessments … is higher in FK-5-1-12-based tests."

1. Hodges, S. E. and McCormick, S. J., "Fire Extinguishing Agents for Protection of Occupied Spaces in Military Ground Vehicles," Suppression & Detection Symposium (SUPDET), National Fire Protection Association (NFPA), 2010. http://www.dtic.mil/dtic/tr/fulltext/u2/a517470.pdf

BACKGROUND – 2008

The US Army plans to modernize legacy vehicle platforms, including Automatic Fire Extinguishing Systems (AFES).

Legacy vehicles use Halon 1301 or HFC-227BC to protect the crew. 1301 has high Ozone Depletion Potential (ODP) and Global Warming Potential (GWP). HFC-227 has high GWP.

The Army is considering replacing legacy agents with more environmentally friendly suppression agents.

TARDEC was tasked to test alternate agents, including FK-5-1-12.

- FK-5-1-12 suppression agent has zero ODP and low GWP. The manufacturer has claimed that it is essentially a drop-in replacement for 1301 or HFC-227ea.

Excerpt from www.dtic.mil/docs/citations/ADA517470

EXPLORATORY TESTS 2008-2009

Purpose

TARDEC's Exploratory tests are intended to compare various suppression agents, including new, more environmentally friendly ones, with those currently deployed.

Approach

Three extinguisher suppliers supported the tests (12/08-9/09) – they were asked to provide suppression systems that would yield marginal suppression 'passes' and 'failures' based on current vehicle performance criteria.

The tests were conducted in a 260 ft^3 (7.36 m^3) box with relatively little clutter, no stowage, and no active air flow.

Excerpt from www.dtic.mil/docs/citations/ADA517470

EXPLORATORY TESTS (CONTINUED)

Seven test series conducted between Dec08 and Sep09

157 live-fire tests

9 suppression agents

- Halon 1301 - 'halon' (*used in legacy vehicles)*
- Halon 1301 with Dry Chemicals (DC) – 'halon+' & 'halonK'
- HFC-227ea with DC – 'HFC227BC' (*used in vehicles since 2001)*
- FK-5-1-12
- FK-5-1-12 with DC – 'FK-5-1-12+'
- Water with Potassium Acetate – 'water+'
- Two Dry Chemicals – Sodium (+) and Potassium (K) Bicarbonates

4 Extinguisher configurations from 3 suppliers

- N_2 charged with solenoid valve
  (Abrams, BFV, FAASV, STRYKER, UAH, & some MRAP)
- N_2 charged with linear actuated valve (NLOS-C Crew & Mission)
- N_2 charged with SQUIB actuated valve (some MRAP)
- Hybrid Fire Extinguisher actuated by Gas Generator (experimental)

Excerpt from www.dtic.mil/docs/citations/ADA517470

EXPLORATORY TESTS
UNSUPPRESSED FIRE (BL1)

EXPLORATORY TESTS SUPPRESSED FIRE (KHBC1)

OVERVIEW OF 2009 RESULTS

				**Best Performance			
Agent	Total	*Pass	**Least Agent Weight (lb)	Lowest Acid Dose (ppm-min)	Lowest Pressure Peak (psi)	Fastest Fire Out Time (ms)	Note
Halon	21	12	~5	~500	<1	<200	Legacy fielded product
Halon+	19	16	~2.5	<20	<1	<200	New mix compatible with fielded extinguishers
HalonK	7	4	~2.5	<20	<1	<200	New mix compatible with fielded extinguishers
HFC227BC	36	17	~5	<20	<1	<200	Fielded product
FK-5-1-12	21	0	>25	~2,000	1.2	<200	Available
FK-5-1-12+	15	0	>15	~1,300	1.6	<200	Invention required
Water+	23	12	~4	0	1.5	~400	Development required; operational issues?
NaBC	13	7	~3	0	<1	<200	Available; safety & operational issues?
KBC	2	2	~2	0	<1	<200	Available; safety & operational issues?
Total	**157**	**70**					

* The goal was to 'pass' half the tests

** Best Performance and Least Agent Weight are not obtained simultaneously

Excerpt from www.dtic.mil/docs/citations/ADA517470

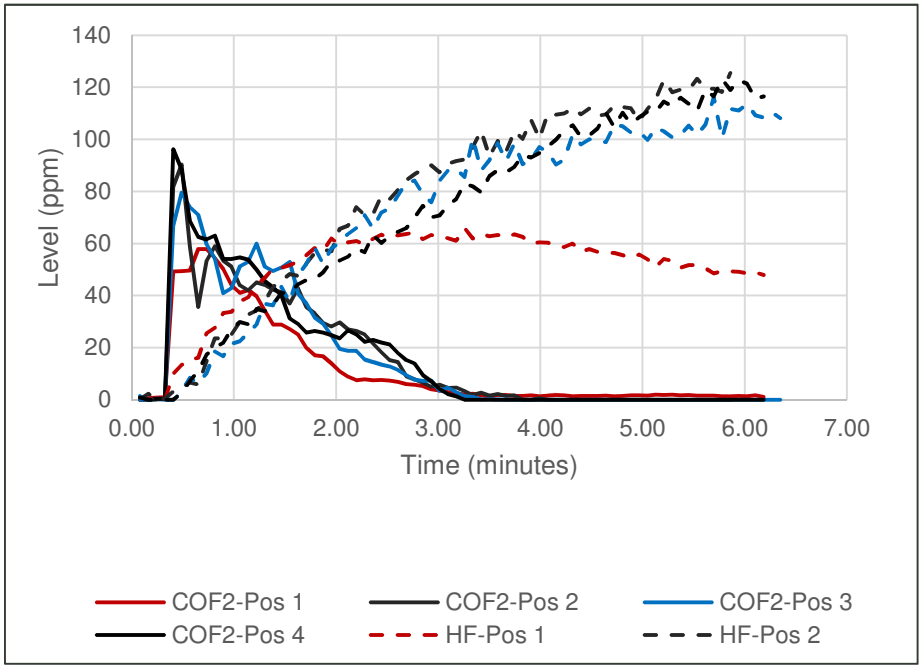
COMBUSTION BYPRODUCTS[1]

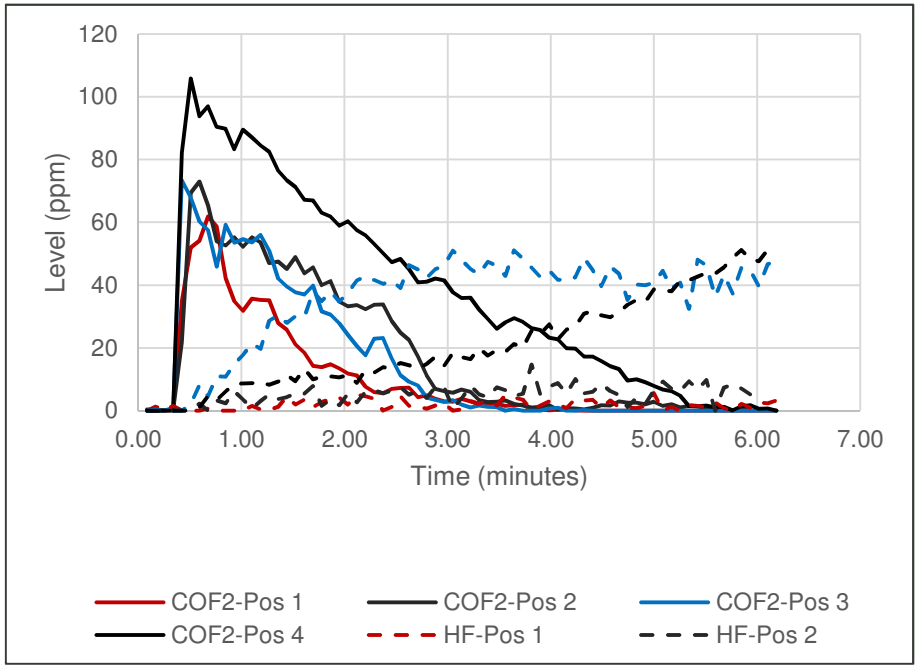
- Continuous sampling gas phase Fourier Transform Infrared (FTIR) spectrometers were used to analyze the combustion byproducts from each trial in near real time. Using this technique allows for the accurate measurement of multiple analytes, including COF_2 and HF.
- Since the relative toxicity of these compounds are quite different, the ability to quantify each of these compounds is necessary for an adequate determination of injury or incapacitation due to inhalation of these toxic gases.

1. ATC Chemistry test report no. 2009-CC-359.

DEPLOYED AGENT - HALON 1301

Minimum Design Concentration: 5.0%





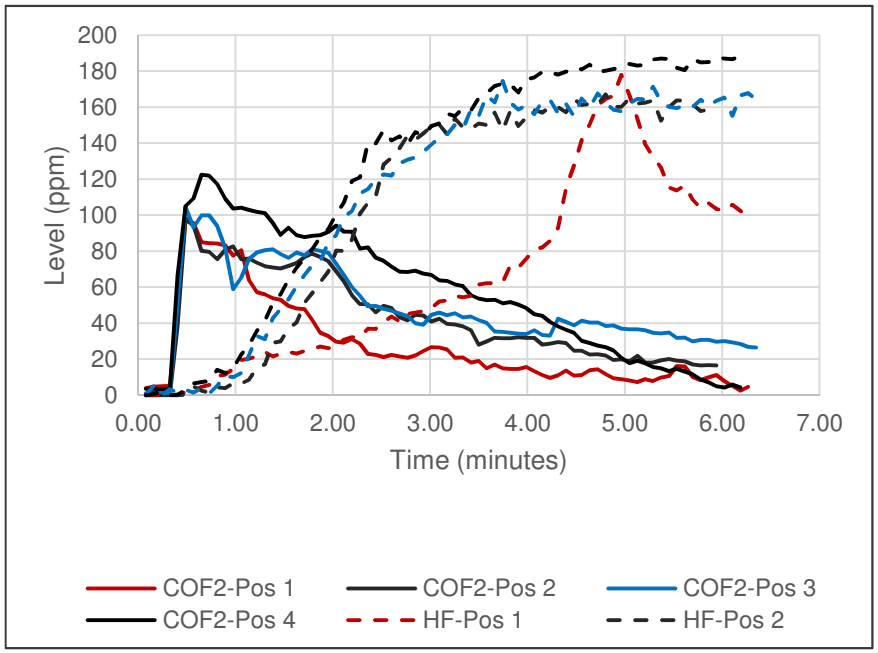
Halon 1301 @ 3.25%
5-min Dose 439 ppm-min

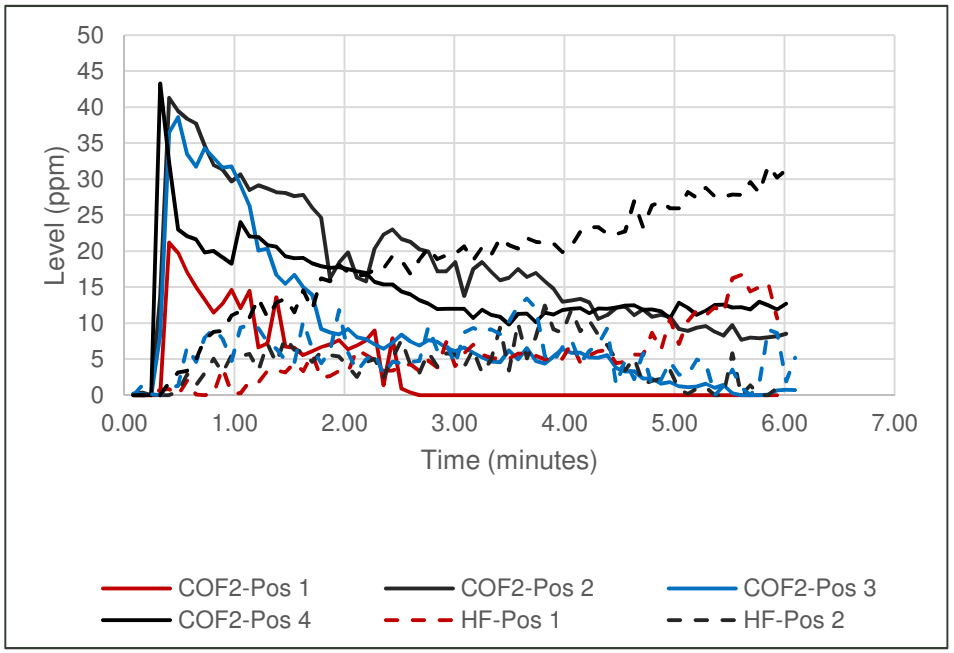
Halon 1301 @ 4.77%
5-min Dose <233 ppm-min

$$Dose = \int_0^{5\ min} (HF + HBr + 2COF_2)dt \leq 746 \text{ ppm-min}$$

DEPLOYED AGENT – HFC227-BC

Minimum HFC-227ea Design Concentration: 8.7%





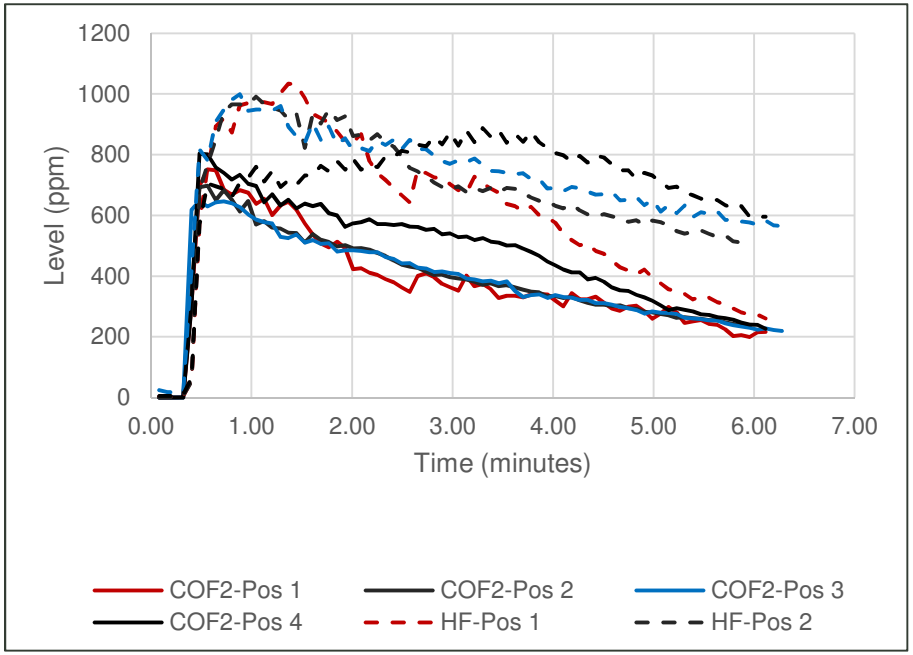
HFC-227ea @ 2.50%, 5%w/w BC
5-min Dose 1,070 ppm-min

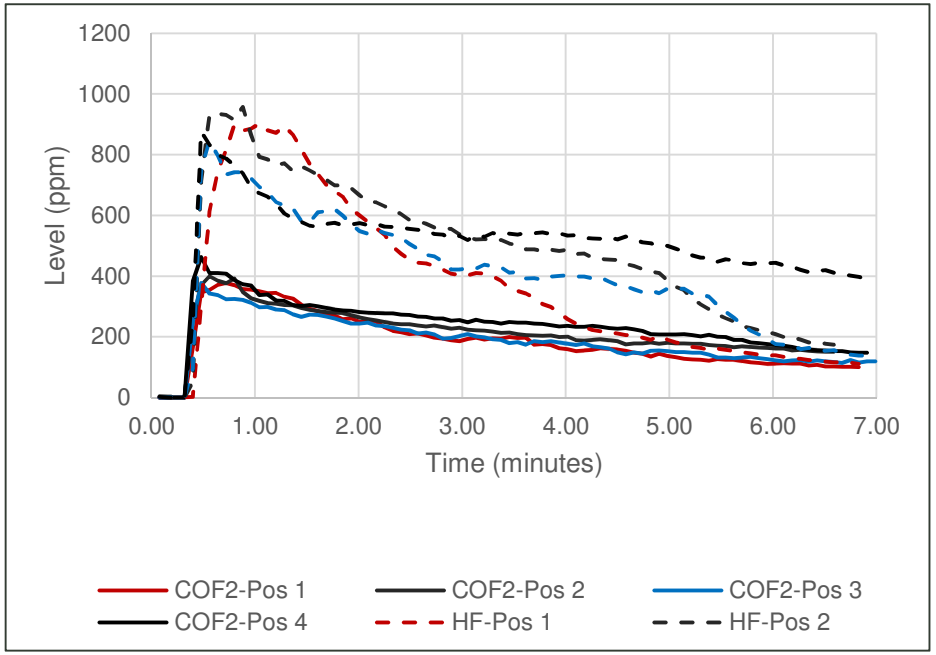
HFC-227ea @ 4.88%, 5%w/w BC
5-min Dose <125 ppm-min

$$Dose = \int_0^{5\ min} (HF + 2COF_2)dt \leq 746 \text{ ppm-min}$$

TESTED LOW-GWP AGENT – FK-5-1-12

Minimum Design Concentration: 5.9%





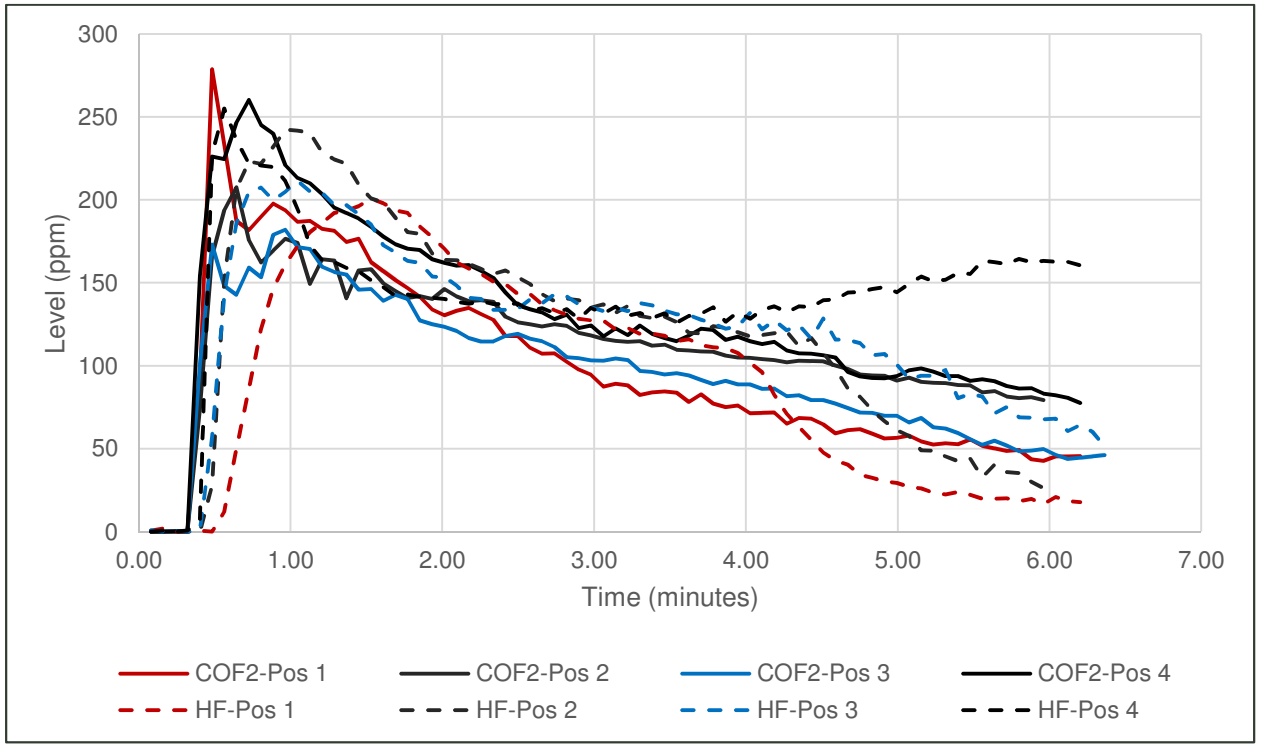
FK-5-1-12 @ 5.90%
5-min Dose 8,100 ppm-min

FK-5-1-12 @ 9.31%
5-min Dose 4,959 ppm-min

$$Dose = \int_0^{5\ min} (HF + 2COF_2)dt \leq 746 \text{ ppm-min}$$

TESTED LOW-GWP AGENT – FK-5-1-12-BC

Minimum FK-5-1-12 Design Concentration: 5.9%



FK-5-1-12 @ 9.32%, 5% w/w BC*
5-min Dose 1,900 ppm-min

$$Dose = \int_0^{5\ min} (HF + 2COF_2)dt \leq 746 \text{ ppm-min}$$

*FK-5-1-12 and BC powder can not be stored together; they react chemically

SUMMARY

- Halon 1301 and HFC227-BC generally produced significant levels of carbonyl fluoride (COF_2) initially which then decayed into hydrogen fluoride (HF), generally the levels of byproduct remained below acceptable limits
- FK-5-1-12 produced very high levels of HF and COF_2 simultaneously, and the levels of byproduct remained above acceptable limits
- Adding BC dry chemical to the FK-5-1-12 discharge nozzle improved performance, but did not change the temporal trend, and the levels of byproduct remained above acceptable limits
- Even when HFC227-BC was applied at less than 1/3 of the HFC-227ea class B minimum design concentration of 8.7%, the byproduct levels were much lower than the criteria dose limit

CONCLUSION

- Correlated with the distinct differences in the temporal evolution of byproducts, the dose of acid and carbonyl byproducts from FK-5-1-12, neat or with dry chemical, were consistently well above the US Army casualty criteria limit of 746 ppm-min (5-minute dose), while byproducts from HFC227-BC and Halon 1301, used with normal design concentrations, were well below the limit.
- Overall, this result suggests that chemicals, such as FK-5-1-12, that are designed to be more reactive, thus yielding shorter atmospheric lifetimes and therefore lower GWPs, generate much higher byproduct levels during the fire suppression process than more stable, and thus likely higher GWP, compounds.

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