US Army Handheld Fire Extinguisher Hardware Development for Use with Blended HFC-227ea/Sodium Bicarbonate Agent

Leonard Lombardo – Aberdeen Test Center
Dr. J. Douglas Mather – CGI Federal (Stanley Associates, Inc.)
Timothy Helton – U.S. Army Aviation and Missile Command (AMCOM) G-4
Kevin Dowell – Aberdeen Test Center
Alivio Mangieri – AGSE PM Technical Branch - Redstone Arsenal

Synopsis

United States (U.S.) Army Program Executive Office (PEO) Aviation sought a replacement for the 2.75 pound Halon Handheld Fire Extinguisher (HHFE) (National Stock Number-NSN: 6830-00-555-8837) currently mounted in/on rotary wing weapon systems. The U.S. Army Aviation Ground Support Equipment (AGSE) Product Manager Office (PMO) was tasked with finding a non-ozone depleting substance (ODS) and environmentally friendly fire suppression agent to replace the 2.75lb. Halon 1301 HHFE for Army rotary wing aircraft. The existing Halon 1301 extinguisher specification (MIL-E-52031D) did not indicate the "B" firefighting performance required and the extinguisher was unrated necessitating baseline performance characterization as an initial project goal. Baseline testing employed Underwriters Laboratories (UL) 711 as did all project related agent fire suppression performance testing. Overall, the HHFE agent development program ran from the summer of 2008 through the fall of 2012. Initially, agent development resulted in optimized agent/hardware configurations for three of the four fluorocarbon candidate agents under test. Subsequent development work provided two blended agents based on nano and ultra-fine sodium bicarbonate (SBC) powders blended with HFC-227ea and the development of a new nozzle design for use with the SBC based blended agents.

The initial agent development work focused on testing of four commercially available clean fluorocarbon agents. Development testing included the following phases: an initial round of fire suppression optimization (testing involving varied extinguisher configurations and nozzles to establish a baseline performance on each commercial candidate), a second round of optimization sought to further improve fire suppression performance through additional changes to nozzles, pressurization, pressurization gas, discharge horn, and extinguisher fill as well as perform initial testing of operational temperature range fire suppression performance. A final characterization check of each optimized agent was performed, this included the following: spray pattern and agent discharge distance characterization, operational temperature range performance verification, storage temperature pressure and leakage checks and final fire suppression performance characterization. A down-selection based on these performance objectives and the maximum safe allowable fire suppressant agent air concentrations for the crew occupied space in the smallest aviation weapons platform resulted in the recommendation of only one of the four fluorocarbon agents for consideration as a replacement for Halon 1301.

As fire suppression performance of the optimized agent selected lagged performance of the current Halon 1301 configuration, a limited series of fire suppression tests utilizing SBC blends was performed with promising results. Subsequent acquisition and development testing of nano- and ultra-fine powders of SBC demonstrated dramatic fire suppression performance enhancement using this strategy. It should be noted that an addition of a small amount SBC to a clean agent requires minimal clean-up after discharge, and poses very minimal visual obscuration to aviation crew members if discharged during flight operations.

Extensive testing of available SBC powders from commercial processes occurred but proved unsatisfactory for the HHFE application. The potential to generate nano and ultra-fine SBC powders were investigated and SBC powders were sourced from a commercial vendor and a supplier of research quantities of nano-powders. Both of these powders dramatically improved fire suppression performance of the selected fluorocarbon agent and demonstrated promise of performing as needed in the HHFE application.

New proprietary and non-proprietary processing methods for generation of nano-particle powders of SBC were identified. Strategies for prevention/reduction of SBC caking, the characterization of the SBC particle sizes, optimizing SBC suspendability in HFC-227ea and maximizing agent fire suppression performance were pursued. The project developed SBC characterization methods (field emission scanning electron microscopy, SBC surface area characterization, particle size distribution characterization, and SBC powder water content). A procurement specification for the process specific types of SBC used in the agent blends along with the overall hardware configuration was also developed.

The final phase of the blended SBC/fluorocarbon agent development work included extensive testing of alternate sodium bicarbonate processing methods to provide alternative sourcing and potentially identify superior powder processing methods. Processes were sought that yielded the smallest SBC particle sizes, high suspendability SBC powders (in fluorocarbons), minimal required SBC loading in the fluorocarbon, and minimal SBC water content). Testing of long term aging and temperature effects on the SBC/fluorocarbon blend as well as materials compatibility testing were performed with satisfactory results on SBC's from two different sources. The characterization information for these two SBC's was assembled into a now published procurement specification covering both nano and the ultra-fine SBC powders and the blended agents based on these two powders.

The published agent specification is MIL-DTL- 32412 DETAIL SPECIFICATION, "HFC-227ea FIRE EXTINGUISHING AGENT ENHANCED WITH SPECIAL SODIUM BICARBONATE POWDER (HFC-227ea/$\mathrm{SBC_S}$). MIL-DTL-32412 is available for use by all Departments and Agencies of the Department of Defense. This specification established the requirements and verification methods for two HFC-227ea/$\mathrm{SBC_S}$ Fire Extinguishing agents based on different SBC powders requiring different weight percent's when mixed with the HFC-227ea. These two agents when used in the new HHFE hardware, also developed at the direction AGSE PMO, performed equivalently in JP-8 fire suppression applications compared to the Halon 1301 configuration.

The two Agents are free-flowing slurries of specialized sodium bicarbonate powder (SBC_S) suspended in HFC-227ea that will be used in the non-ODS HHFE. The specialized sodium bicarbonate (SBC_S) powders are designated as SBC-1 and SBC-2. While the agent development presented many hurdles, the successful development of HHFE hardware that met strict requirements was also difficult.

HHFE Development Unique Challenges

The development of this replacement HHFE presented several unique challenges. One of the requirements of this development is to utilize the same cylinder size and height to avoid any type of modification to aircraft and/or cylinder mounting location. In order to match the Halon 1301 HHFE capability and effectiveness with a clean agent HHFE during the initial phases, an increase in agent volume was required. Since the total volume of the cylinder (80 cubic inches) was fixed, the ullage volume was reduced.

The reduction in ullage space presented issues, early on, with extreme temperature testing. At the low operational temperature, UL 711 requires successful extinguishment at 40% of the test pan fire size at ambient temperature. At the low operational temperature, discharge rates were significantly slower due to a reduction in vapor pressure of the agent and the overpressure gas. The effect of the reduced pressure is especially pronounced with the reduced ullage volume. In general, the reduced temperature of the agent aided fire extinguishment as long as agent flow was sustained. For the high operational temperature, the thermal expansion of the agent and increases in vapor pressure of the agent and pressure of the overpressure gas produce high pressures within the cylinder. The effect of the thermal expansion of the agent is especially pronounced with the reduced ullage volume. Maximum design pressures of the available cylinder hardware were taken into consideration early on during the non-Halon replacement extinguisher development.

Another issue caused by the reduced ullage was the difficulty of maintaining a sustained flow rate over the course of the discharge. As the agent is discharged from the cylinder, the pressure dropped reducing the flow rate over time. Testing was completed to measure the pressure as a function of time to better understand how flow rate changed during the discharge. Initial testing was completed using water instead of a candidate agent since water would a give a predictable result. This was to verify the test setup. Figure 1 illustrates the pressure profile for the discharge of 1000 ml of water when the cylinder was pressurized with 600 psig of nitrogen. As shown in Figure 1, the pressure drops quickly over the first few seconds of discharge because of a large initial change in ullage volume. Hence, the flow rate rapidly decreases over the first few seconds of discharge.

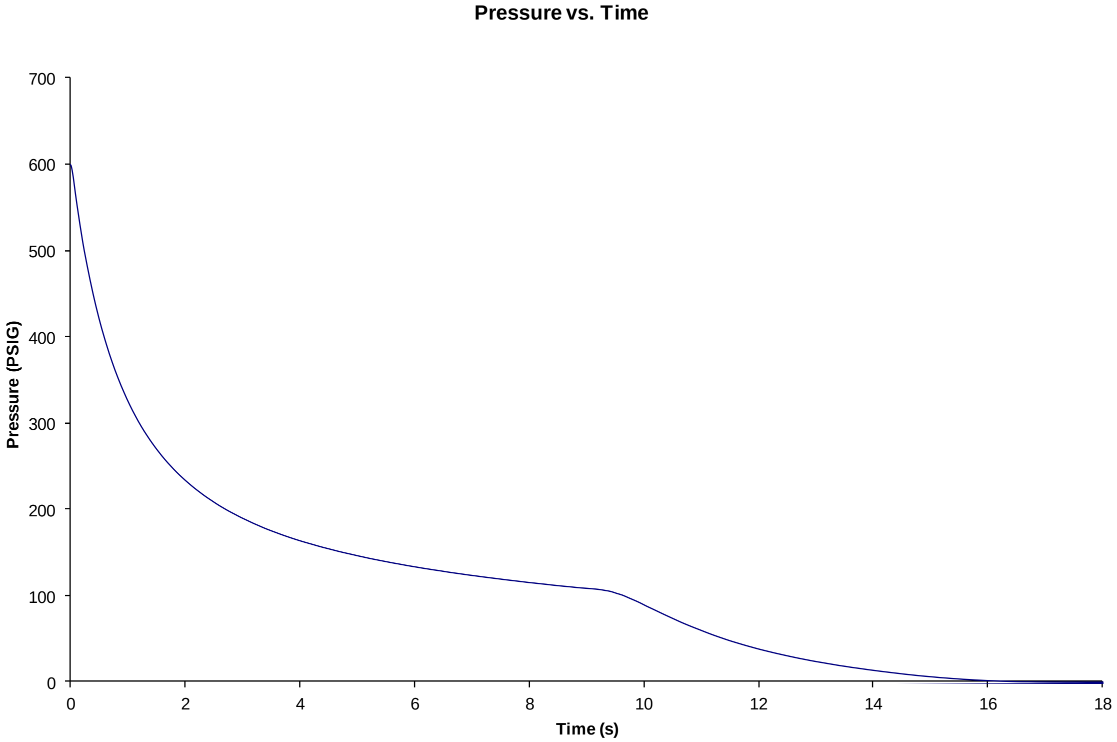


Figure 1. Pressure versus time for the discharge of 1000 ml of water.

Testing was also completed for the four candidate agents under various conditions. Figure 2 shows the pressure as a function of time for a discharge of 1080 ml of HFC-227ea (~200 ml ullage) with 525 psig nitrogen overpressure. As shown, after a large drop in pressure at the beginning of the discharge, the pressure increased before it steadily decreased again. This increase occurs despite the extinguisher continually discharging agent and is caused by a combination of bubbling of the HFC-227ea and degassing of the dissolved nitrogen. While there will always be some degassing and evaporation of agent during a discharge, these effects are more pronounced due to the relatively small ullage and large initial overpressure of nitrogen.

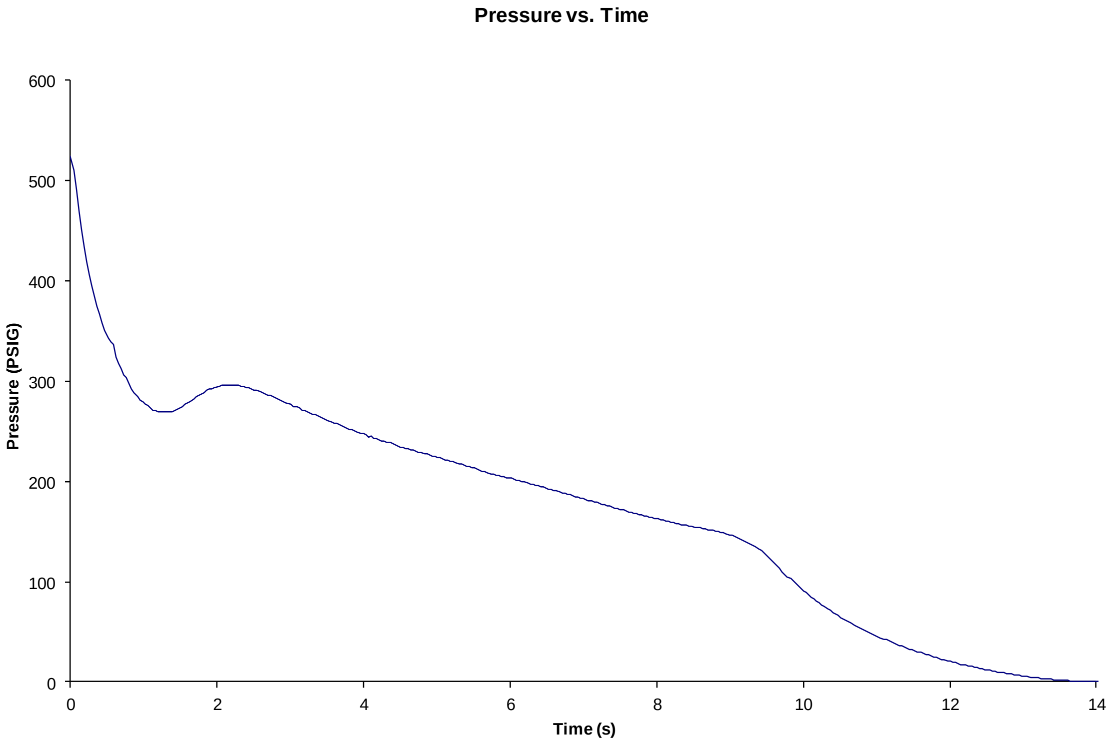


Figure 2. Pressure versus time for the discharge of 1080 ml of HFC-227ea.

The clean agent candidates for this project were required to have an internal pressure not to exceed 1000 psig when exposed to a temperature 185°F (High storage temperature). The above configuration (as shown in Figure 2) would not pass this requirement due to thermal expansion of the agent and the relatively high pressure. To comply with this requirement, testing was conducted on multiple configurations with lower fill ratios and lower pressures. Figure 3 shows the pressure as a function of time for a discharge of 1000 ml of HFC-227ea with 230 psig nitrogen overpressure at ambient conditions. As shown, the effect of the bubbling of the agent and the degassing of the nitrogen is less pronounced. After the initial drop in pressure, the pressure decreased slowly throughout the remainder of the discharge.

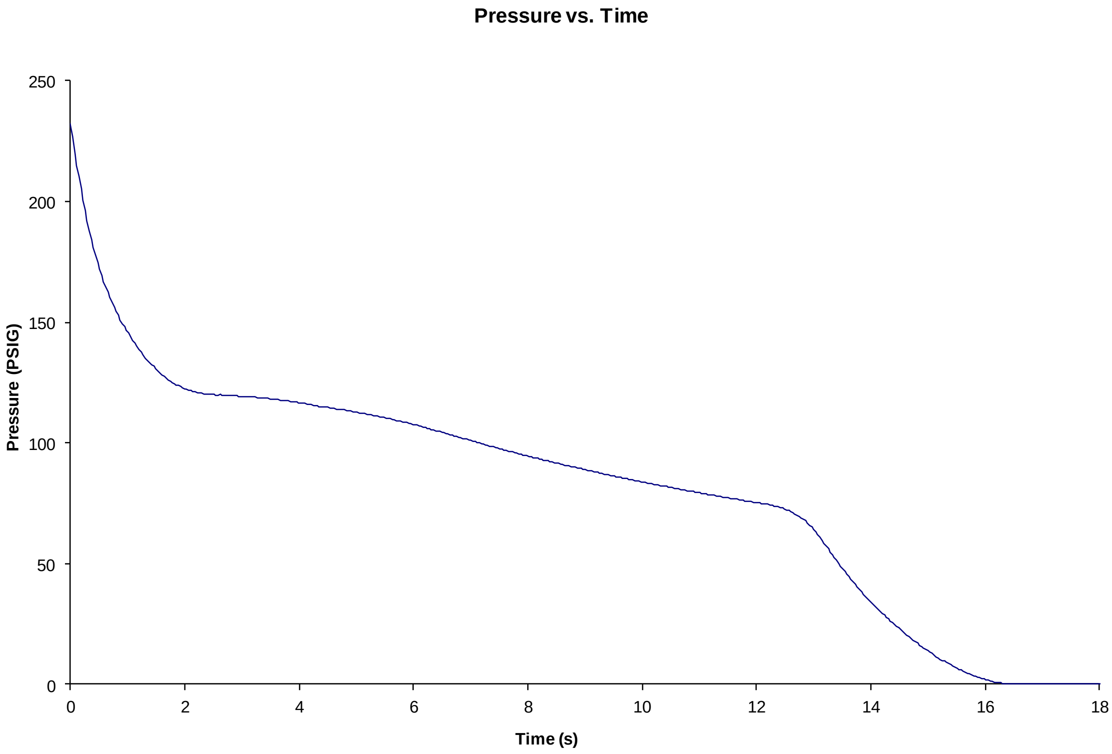


Figure 3. Pressure versus time for the discharge of 1000 ml of HFC-227ea.

Early Nozzle Development

In addition to the flow rate discussed above, agent spray characteristics were a critical factor to fire extinguishing performance. Spray characteristics of interest were agent droplet size, discharge distance, agent spray throw and angle characteristics. Each of the four agents under test was optimized to take advantage of the heat of vaporization of the agent and to generate an inert blanket over the burning fuel. While several factors (e.g., overpressure and introduction of two phase flow) affected agent spray characteristics, a critical factor was the cylinder spray nozzle design.

Dozens of commercially available and custom nozzle designs were evaluated during the optimization process. For the lower boiling agents (HFC-227ea and HFC-236fa), nozzle designs aimed to generate large droplet sprays. Conversely, for the higher boiling agents (HCFC Blend B and C6-Fluroketone), nozzle designs aimed to generate small droplet sprays.

To aid in the evaluation of the spray patterns, multiple co-planar lasers were utilized to allow visualization of the discharge. These assessments were used to make design adjustments to nozzles and pressures before conducting fire performance testing. Figures 4 and 5 show photographs of two different spray patterns while using the co-planar lasers. The spray pattern shown in Figure 4 had small droplets and a good agent throw. Conversely, the spray pattern shown in Figure 5 had larger droplets with a relatively poor agent throw.

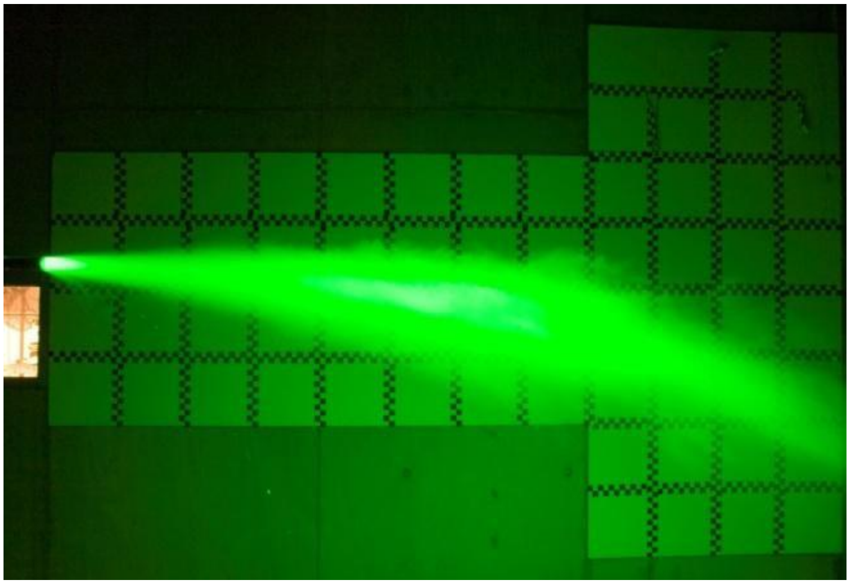


Figure 4. Photograph of a spray pattern with small droplets using multiple co-planar lasers

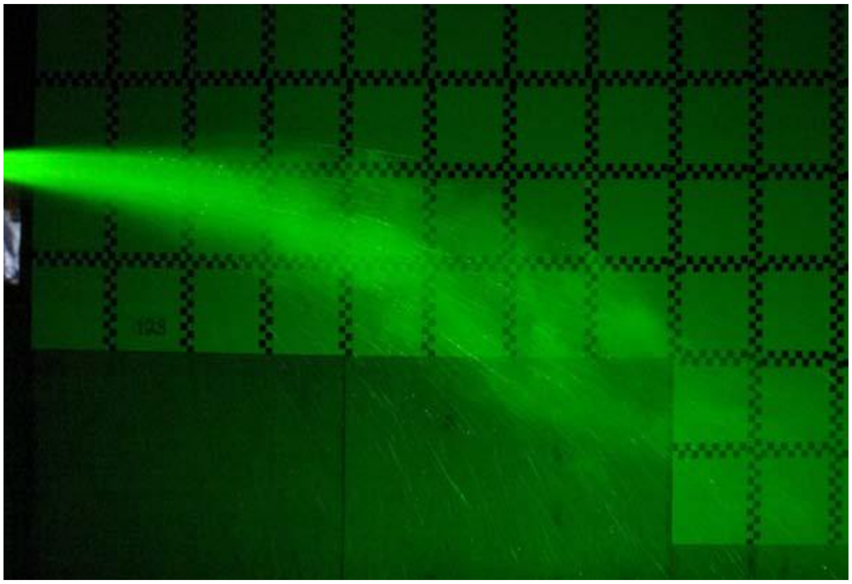


Figure 5. Photograph of a spray pattern with larger droplets using multiple co-planar lasers

Table 1 contains descriptions of the selected nozzles for testing HFC-227ea, HFC-236fa, and HCFC Blend B. Figures 6 through 8 show prototypes of the selected nozzles that were tested. While several nozzle designs were utilized to optimize C6-Fluoroketone, no nozzle selection was made since development of a replacement extinguisher for this agent was discontinued after the first phase of optimization since it did not perform as well as the other agents in the configurations tested.

TABLE 1. DESCRIPTION OF SELECED NOZZLES

Agent	Nozzle Description
HFC-227ea	Modified nozzle blank (1-7/64” center hole, 6-5/64” side holes, center bored to 5/16")
HFC-236fa	Modified nozzle blank (9-1.8 mm center holes, 6 – 1.6 mm holes in sides)
HCFC Blend B	Customized multi-hole nozzle blank with 16 1.2 mm holes in the center

Figure 6. Final spray nozzle for HFC-227ea

Figure 7. Final spray nozzle for HFC-236fa

Figure 8. Final spray nozzle for HCFC Blend B.

Overview of Performance of Candidate Replacement Extinguishers

Table 2 presents a summary of the fire suppression performance of each candidate replacement extinguisher against JP-8 fires compared to the performance of the current Halon 1301 HHFE. The candidate replacement extinguisher containing HCFC Blend B was the only extinguisher that exceeded the Halon 1301 HHFE performance. Both candidates using HFC-227ea and HFC-236fa were limited to extinguishing 10 ft^2 pan fires with the HFC-236fa extinguisher performing slightly better than the HFC-227ea extinguisher.

TABLE 2. OVERVIEW OF PERFORMANCE FOR EACH CANDIDATE REPLACEMENT EXTINGUISHER AGAINST JP-8 FIRES.

Agent	Pan Size (ft^2)	Tests Completed	Number of Fire Outs	Consecutive Fire Outs	Average Fire Out Time (s)	Average Agent Remaining (g)
Halon 1301	12.5	3	3	3	7.5	Not Recorded
HFC-227ea	10	6	4	2	4.5	245
HFC-236fa	10	7	7	7	3.0	350
HCFC Blend B	12.5	6	6	6	3.0	480

Table 3 presents a summary of the fire suppression performance of each candidate replacement extinguisher against n-heptane fires compared to the performance of the current Halon 1301 HHFE. None of the candidate extinguishers matched the performance of Halon 1301. Only HFC-227ea in its final configuration was able to extinguish 5 ft^2 n-heptane fires. The "Average

Fire Out Time" and the "Average Agent Remaining" for agent HFC-236fa and HCFC Blend B were not applicable because there were no successful fire extinguishments.

TABLE 3. OVERVIEW OF PERFORMANCE FOR EACH CANDIDATE REPLACEMENT EXTINGUISHER AGAINST N-HEPTANE FIRES.

Agent	Pan Size (ft^2)	Tests Completed	Number of Fire Outs	Consecutive Fire Outs	Average Fire Out Time (s)	Average Agent Remaining (g)
Halon 1301	7.5	6	4	3	7.0	Not Recorded
HFC-227ea	5	2	2	2	3.4	350
HFC-236fa	5	2	0	0	Not Applicable	Not Applicable
HCFC Blend B	5	3	0	0	Not Applicable	Not Applicable

Table 4 presents the results of the high temperature storage testing. High temperature storage testing was completed for each of the selected clean agent candidate in its final configuration. For this testing, a 2.5-lb. CO2 extinguisher cylinder (DOT 3AL 2216) was used because it was rated for higher pressures than the candidate extinguisher cylinders (DOT 4B 500). The approximate volume of the higher pressure cylinder was 1750 ml. To account for the volume increase, the volume of the agent was increased to maintain the same fill ratio. As shown in Table 4, each of the selected clean agent candidates met the criteria of not exceeding the 1000 psig at the high storage temperature.

TABLE 4. TEST RESULTS FOR HIGH TEMPERATURE STORAGE TESTING

Extinguisher Configuration			
Agent	FM-200	FE-36	Halotron I
Target Agent Volume (ml)	1346	1346	1346
Equivalent Target Agent Volume for Current Cylinder (ml)	1000	1000	1000
Target Fill Ratio	0.77	0.77	0.77
Pressurization Gas	Nitrogen	Nitrogen	Argon
Target Starting Pressure (PSIG)	185	210	250
Target Temperature (°F)	185	185	185
High Temperature Storage Test Results			
Actual Agent Volume (ml)	1346	1346	1344
Actual Fill Ratio	0.77	0.77	0.77
Actual Starting Pressure (PSIG)	185	210	250
Maximum Pressure (PSIG)	782	518	473

Despite performing well against JP-8 fires and passing the high temperature storage testing, the clean agent candidate containing Halotron I was not selected due to toxicological concerns on smaller aircraft. Since the selected clean agent candidate containing HFC-227ea had some success against both JP-8 and n-heptane fires along with acceptable environmental properties, it was selected for further development. Ultimately the blending of HFC-227ea with sodium bicarbonate (SBC) was investigated as an attempt to meet the fire extinguishing performance of the Halon 1301 HHFE against JP-8 and n-heptane fuels.

Addition of Sodium Bicarbonate to HFC-227ea

SBC had been used previously by other Army programs to increase agent extinguishing performance in ground vehicles. However, this application was for total flooding. The goal for the ground vehicle total flooding application was to have a fast discharge with the SBC portion of the blend being discharged first.

Very crude, yet effective, exploratory testing of a readily available SBC powder mixed with HFC-227ea provided promising pan fire test results. Additional development was necessary to refine a blended agent configuration that was effective for this application.

The goal for this streaming agent application was to maintain a continuous discharge of the blended agent. To maintain a discharge of blended agent, the SBC would have to be suspended well into the HFC-227ea. To achieve the suspension, smaller, dryer particles of sodium bicarbonate were developed. In addition to greater suspension characteristics, smaller particles are more effective in fire suppression applications.

Before adding SBC, larger droplets of HFC-227ea were desirable to take advantage of the heat of vaporization of the agent. However, after adding the SBC the focus shifted towards better dispersion of the agent. The nozzle from the candidate replacement extinguisher containing HCFC Blend B was selected for the blended agent. This nozzle has sixteen holes that act to break up the spray and disperse the agent. These holes are angled to cover more area and provide better droplet separation. Figure 9 shows a drawing of a production representative nozzle.

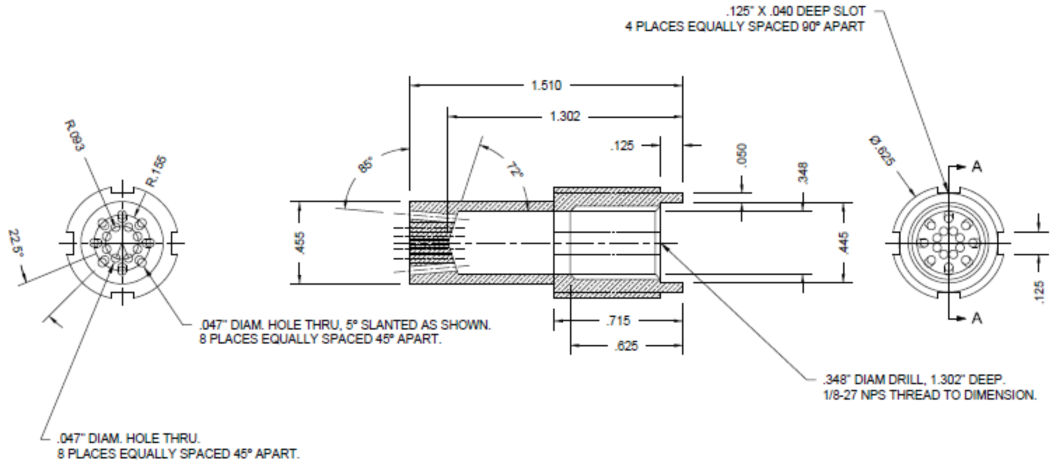


Figure 9. Drawing of production representative nozzle for HFC-227ea/SBC slurry.

Two types of SBC were developed for blending with the HFC-227ea. SBC-1 was developed using a jet-milling method with particles in the micron range. For this type of SBC, a 5% to 5.5% by mass concentration was used for blending with HFC-227ea. SBC-2 was developed using proprietary cryogenic technique particles in the 100 nm range. For SBC-2, mass concentrations of less than 3% were used for blending with HFC-227ea.

Table 5, shows a summary of the results of extinguishment attempts (during the later stages of development testing) against a 12.5 ft^2 JP-8 fire using both SBCs blended with HFC-227ea forming slurries. As shown in Table 5, the addition of SBC improved the fire suppression performance over HFC-227ea alone and allowed the non-Halon agent candidate to meet the JP-8 pan fire test performance of the Halon 1301 extinguisher. While the SBC-1 slurry performed slightly better than the SBC-2 slurry with respect to average fire out time and average agent remaining, the SBC-1 slurry had one failed extinguishment attempt. The SBC-2 slurry successfully extinguished the 12.5 ft^2 JP-8 fire in all six attempts.

TABLE 5. OVERVIEW OF PERFORMANCE FOR EACH SBC-1 AND SBC-2 SLURRIES AGAINST JP-8 FIRES.

Agent	Pan Size (ft^2)	Tests Completed	Number of Fire Outs	Consecutive Fire Outs	Average Fire Out Time (s)	Average Agent Remaining (g)
Halon 1301	12.5	3	3	3	7.5	N/A
HFC-227ea	10	6	4	2	4.5	245
SBC-1 Slurry	12.5	6	5	4	4.3	390
SBC-2 Slurry	12.5	6	6	6	4.5	340

Filling Extinguishers

During the developmental stages of blending the HFC-227ea and SBCs to form slurries, extinguishers were filled successfully in a glove box using hand filling methods. However, this process would be too costly and impractical for large scale production. Therefore, attempts were made to utilize a pre-blended slurry of HFC-227ea and SBC from a large storage vessel to fill extinguishers. Early attempts to fill extinguishers with the slurry at a constant weight percent loading of SBC failed. In fact, some attempts resulted in extinguishers only having trace amounts of SBC within the filled cylinder.

To successfully fill extinguishers with the desired loading of slurry (correct amount of SBC and HFC-227ea), a process was developed that kept the slurry well mixed during the filling process which also allowed for slurry sampling to verify SBC concentration. Figure 10, shows the integrated equipment that was developed to implement the slurry process filling technique. The reactor was able to withstand the high pressure from the vapor pressure for HFC-227ea. The mixer gently keeps the agent slurry well mixed. Lastly, a port allowed for in-stream sampling of the slurry to verify a consistent SBC concentration during the filling process.

Figure 10. HFC-227ea/SBC HHFE filling station.

A pictorial of the process for filling the extinguishers with the HFC-227ea/SBC slurry is shown in Figure 11. The major steps for filling extinguishers are as follows: transferring agent to reactor, initial resuspension of sodium bicarbonate at the bottom of the reactor, sampling of the slurry, sonication (if necessary), adjusting mass percent of SBC (if necessary), filling extinguishers, and transferring remaining agent to storage tank.

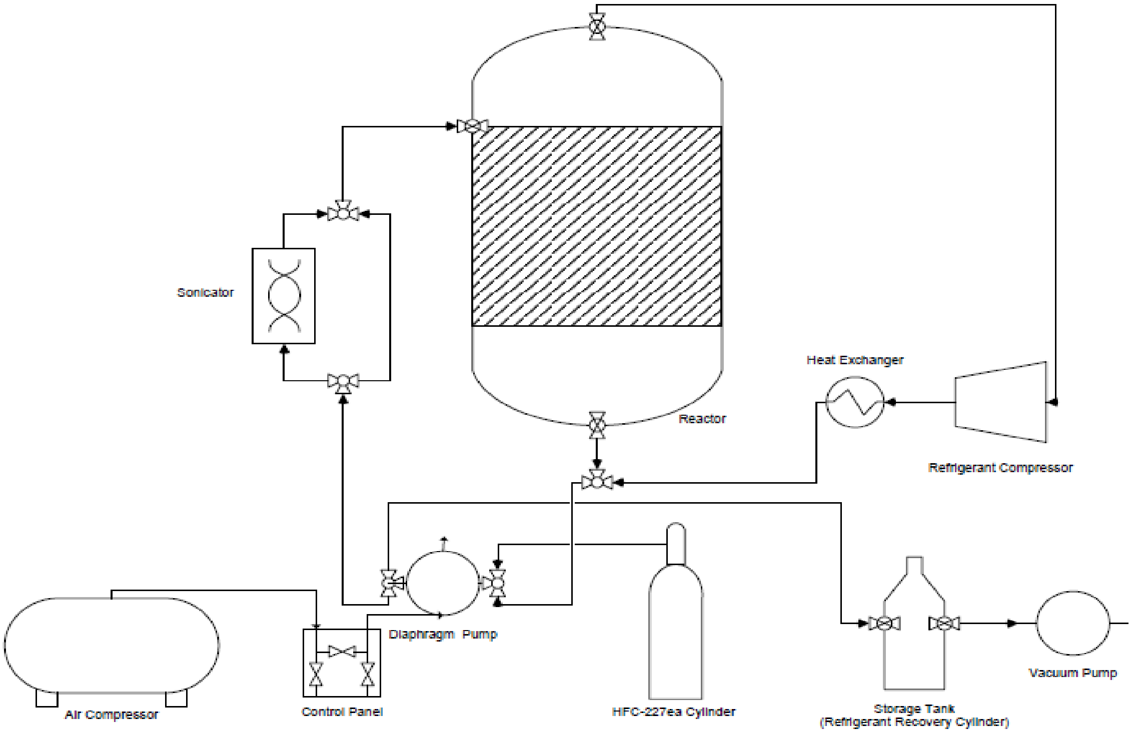


Figure 11. Drawing of the process to fill extinguishers.

Transfer agent (slurry of HFC-227ea and SBC) from storage vessel to reactor. The storage tank containing the agent must be mixed prior and during the transfer process. The agent is pumped from the storage tank to the reactor using the diaphragm pump. The valves should be set to bypass the sonicator. In addition, the other valves for the reactor should be closed.

Initial resuspension of sodium bicarbonate at the bottom of the reactor. Before pumping the agent from the bottom of the reactor, it may be necessary to resuspend any SBC that has settled. This is especially true if the SBC has been sitting in the reactor over several days. The valve between the reactor and the diaphragm pump should be closed. The valves between the reactor and the refrigerant compressor to include the three-way valve should be open. Once these valves are open, the compressor can be turned on to allow bubbling of the vapor HFC-227ea through the bottom of the reactor. The compressor may be run for several minutes to ensure that any SBC that had settled at the bottom of the reactor is resuspended.

Sampling of the slurry. An Andrews glass pressure jar (Part number 1101080006) or equivalent is required for the sampling process. The first step is to pull a vacuum on the pressure jar and weigh it (W_{empty}). The empty pressure jar is then filled with slurry from the sampling port and weighed again (W_{Total}). The jar is then slowly vented to allow the HFC-227ea vapor to escape. Once the HFC-227ea has been vented, a vacuum is pulled on the sampling jar to remove the last of the HFC-227ea. Then the jar containing only SBC is weighed ($W_{Total-1}$). The following equation is used to determine the mass percent of SBC (m_{SBC}).

$$m_{SBC} = 100 \times \frac{W_{SBC}}{W_{Slurry}}$$

W_{SBC} is given by W_{Total} minus W_{empty} and W_{Slurry} is given by $W_{Total-1}$ minus W_{empty}.

Sonication. If the sampled slurry appears to have formed very small clumps or if the slurry is otherwise showing poor suspension properties, then the slurry can be sonicated to enhance resuspension of SBC. Using the diaphragm pump, the slurry is pumped through the flow cell and then back into the reactor. The sonicator should be cycled on and off to prevent overheating. The slurry may be sampled until the slurry displays adequate suspension properties.

Adjusting mass percent of SBC. If the mass percent of SBC is different than the target mass percent (m_{target}) then the amount of HFC-227ea will have to be adjusted. This problem may occur due to vaporization of the HFC-227ea during the transfer of the agent to the empty reactor. The equation to calculate how much HFC-227ea to add ($W_{HFC-227ea}$) is given below.

$$W_{HFC-227ea} = m_{SBC} \times W_{slurry}\left(\frac{1}{m_{target}} - \frac{1}{m_{SBC}}\right)$$

In this case, W_{slurry} is the weight of the slurry that was transferred to the reactor. After the additional HFC-227ea is added, the slurry is recirculated to allow thorough mixing. The contents are then resampled to verify that the proper mass percent has been achieved.

Conversely, if the mass percent is too low, then HFC-227ea must be removed from the slurry. The total amount of HFC-227ea to remove is calculated using the same equation as before. A refrigerant recovery unit is then used to remove HFC-227ea vapor and transfer it to a recovery tank. The amount removed is monitored using a scale. After the proper amount of HFC-227ea is recovered from the reactor, the slurry is allowed to recirculate before resampling to verify concentration.

Filling extinguishers. Once the correct mass percent of SBC is achieved, extinguisher filling may begin. An empty extinguisher is weighed. The extinguisher is then attached to the filling adaptor and the scale is tared. Using the diaphragm pump, the extinguisher is filled while monitoring the extinguisher weight. Once the extinguisher has reached the desired weight, the valve is closed and the filling adaptor is removed and the weight is verified one last time.

Transferring remaining agent to storage tank. Before transferring the agent, a vacuum is pulled on the storage tank using a vacuum pump. The weight of the empty tank is weighed. Then the agent is transferred from the reactor to the storage tank using the diaphragm pump. The filled tank is then weighed again and the weight of agent is recorded. This may be necessary to clean the reactor, store the remaining agent or to fill the reactor for a different purpose.

Hardware Testing

The non-Halon replacement HHFE was thoroughly tested to ensure that it met the requirements for use on Army aviation rotary wing weapon systems. The test requirements for the non-Halon replacement HHFE were quite extensive and very detailed. Testing was accomplished through inspections, verification of a safe design, fire suppression performance testing, operational testing, and environmental qualification testing. A list of the conducted tests is shown in Table 6.

TABLE 6. LIST OF TESTS

Item	Criteria
Initial Inspection (1-18)	
1	Cylinder Shell
2	Cylinder Volume
3	Cylinder Contents/Charge
4	Dimensions
5	Mounting Bracket Latch
6	Unlatching Process
7	Removal Interference
8	Pressure indicator Gauge
9	Weight. No more than 3.6 kg (7lbs, 14 oz)
10	Interface with Aircraft
11	Interfacing Materials
12	Agent Release Mechanism
13	Operating Mechanism Locking Device/Safety
14	Valve/Nozzle Assembly
15	Siphon Tube
16	Handle
17	Exterior Surfaces
18	Cylinder Shell
Safe Design (19-27)	
19	Stress Corrosion
20	Safe to Handle
21	Bracket Test Shock/Vibe
22	Legacy Bracket Test
23	Cylinder Retention on new bracket design
24	Cylinder Fragmentation Resistance (non-shatterability)
25	Hydrogen Embrittlement
26	Immersion Corrosion Properties of Agent
27	Aircraft Personnel Emergency Egress
Performance (28-31)	
28	Discharge Angle and Range
29	Discharge Time and Amount

30	Class B Fire Extinguishment
31	Discharge Pattern
Operation (32-36)	
32	Method of Operation
33	Bracket Unlatching Effort
34	Discharge Effort
35	Heavy Gloves/Arctic Mitten Operation
36	Operating Mechanism Locking Device/Safety
Environmental Qualifications (37-49)	
37	Temperature Extremes
	High Temperature
	Low Temperature
	Temperature Shock
38	Altitude
39	Humidity Exposure
40	Fungus
41	Salt Fog
42	Sand and Dust Environment
43	Acidic Atmosphere
44	Functional Shock
45	Bench Handling Shock
46	Crash Hazard Shock
47	Vibration Testing
48	Drop Test
49	Accelerated aging for rubber materials

While all test requirements were met, some issues were discovered during testing that required special attention to resolve. During the temperature shock testing, several extinguishers failed due to leakage of agent. Upon further investigation, it was discovered that there was some metal-to-metal contact preventing a proper seal at the valve seat. Figure 12 presents a photograph of the valve seat with a section removed to show internal surfaces. This problem was identified as overlapping tolerances. To resolve the problem, the valve seat retainer was trimmed. Also, a valve seat material with an increased durometer value was introduced to prevent deformation.

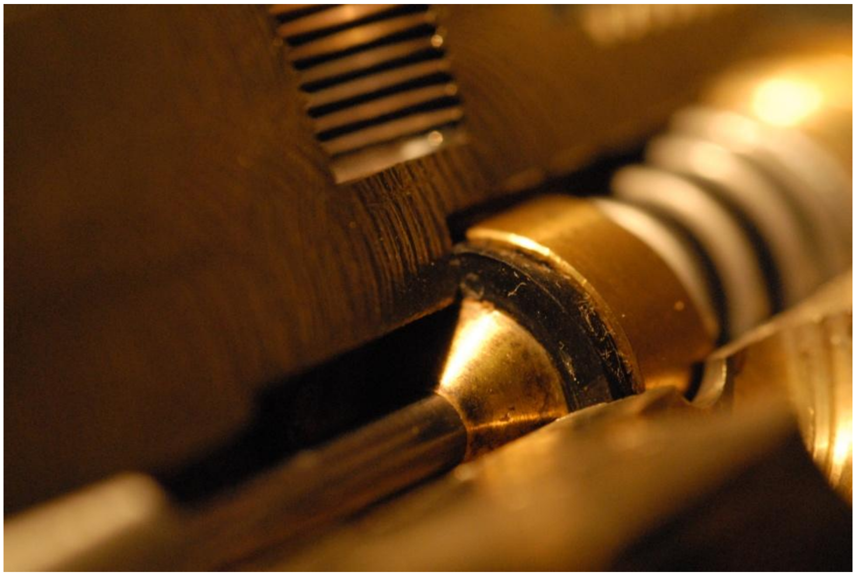


Figure 12. Photograph of the valve seat cut to show internal surfaces.

Also during temperature shock testing, several extinguishers failed due to the burst discs failing prematurely. Upon further investigation it was found that the problem was caused by deformation of the burst disc seat. Figure 13, presents a photograph of the burst disc with a section of the valve removed to show the seat deformation caused by improper thread depth. The problem was resolved by reducing the thread depth.

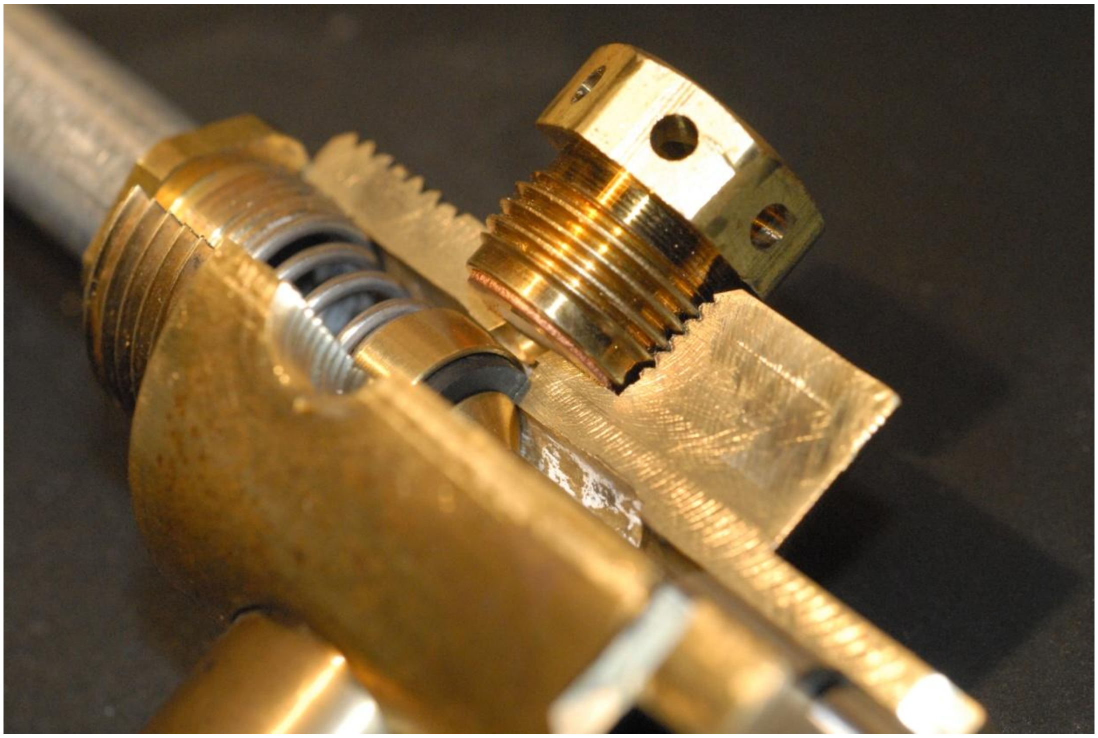


Figure 13. Photograph of the burst disc with the valve cut to show the seat deformation.

Drop testing is used to verify that the non-Halon replacement HHFE will remain operational after a series of drops and rough handling. This test required the HHFE to be dropped six times in various orientations from a height of four feet onto a 2-inch thickness plywood backed by a concrete floor. When a preliminary design of the extinguisher was dropped on the valve head, the handle, rivet and pull pin bent causing the HHFE to fail the test. Figure 14, shows a photograph of a damaged handle and pull pin. The pull pin, rivet, and handle materials were modified. Modifications including increasing the pull pin diameter to provide a more robust design.

Figure 14. Photograph of damaged handle and pull pin after a drop test.

Initially, both a steel cylinder and an aluminum cylinder were tested and evaluated. An aluminum cylinder is desired to allow for approximately one (1) pound of weight reduction. A prototype of the aluminum cylinder failed the ballistic test. Figure 15, presents a photograph of a large portion of the aluminum cylinder breaking away after the projectile made contact with its surfaces. After this test failure, an aluminum cylinder that met the ballistic requirement (RR-C-901) was tested but failed to meet the internal volume requirement of 80 cubic inches. The aluminum cylinder's reduced volume of three (3) cubic inches negatively affected the ullage which resulted in unsatisfactory flow rates for fire suppression. When the agent volume was reduced to match the fill ratio, the flow rate was still affected and there was not enough agent to extinguish the fire. The steel cylinder configuration passed all test requirements.

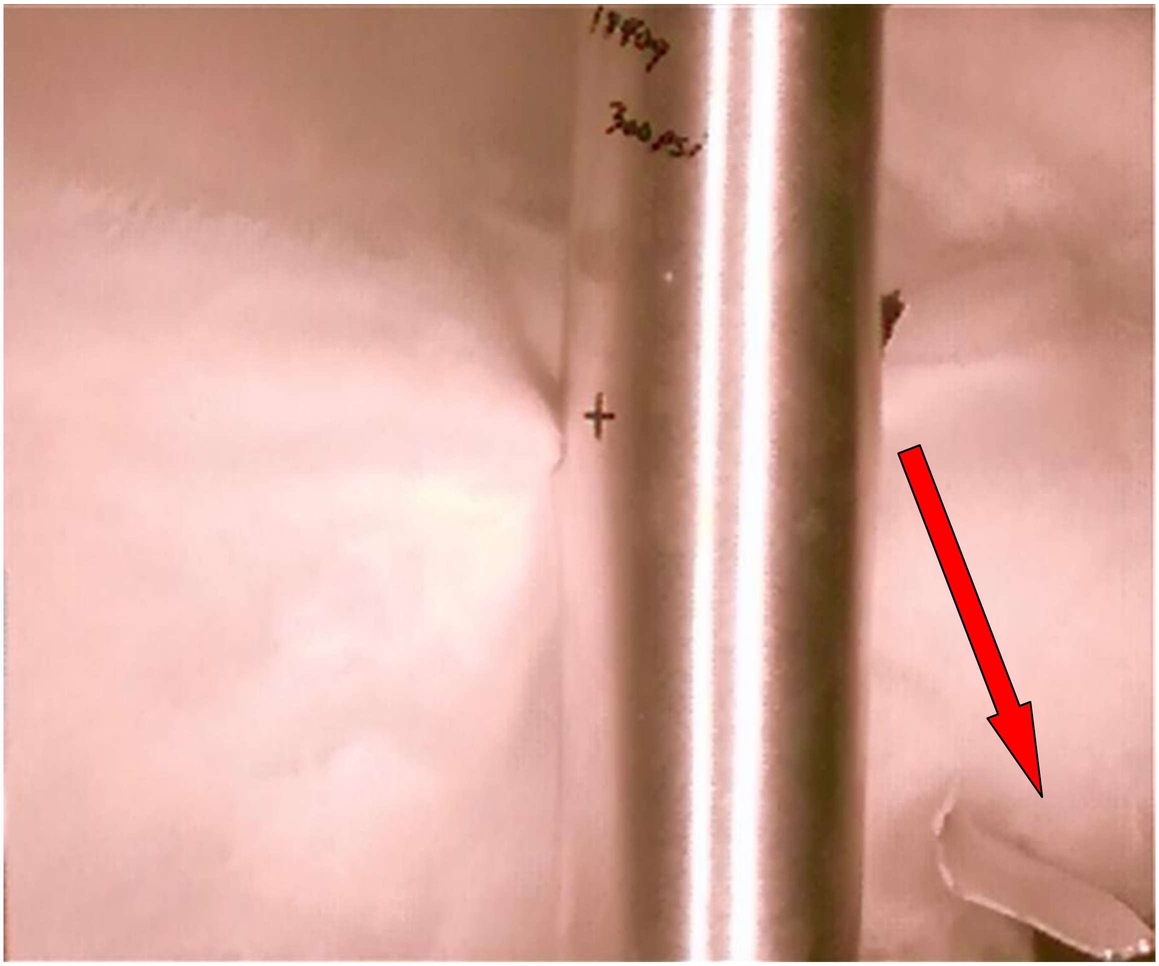
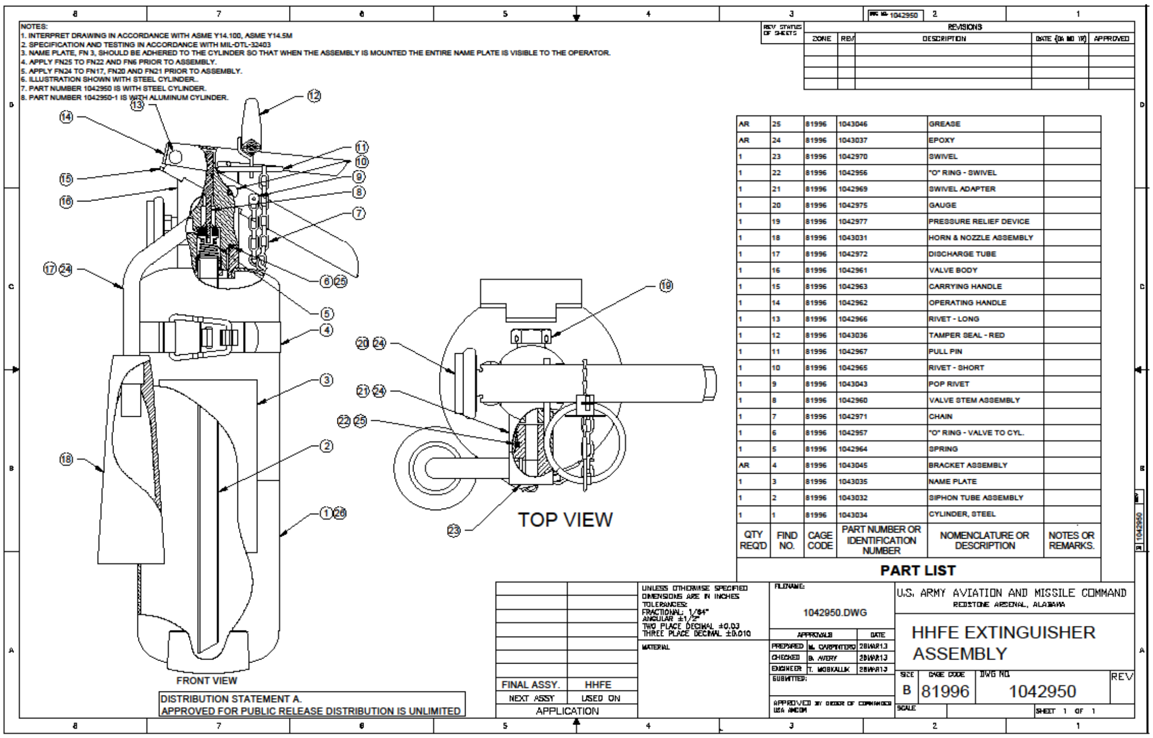


Figure 15. Photograph of the failed ballistic test.

Documentation to Support Fielding

Despite not having a commercially available aluminum cylinder to complete all testing, requirements for an aluminum cylinder are included in the extinguisher specification in the event a suitable aluminum cylinder is made available in the future. The extensive hardware specification was published in December 2012, and is designated as MIL-DTL-32403, Titled: “FIRE EXTINGUISHER, EMPLOYING HFC-227ea AGENT ENHANCED WITH SPECIAL SODIUM BICARBONATE POWDER (HFC-227ea/SBCS), PORTABLE, WITH BRACKET”. All hardware testing was completed in March 2013. The technical data package (TDP) including over 40 drawings for the new HHFE configuration was finalized in July 2013. The top level drawing for the non-Halon replacement extinguisher is shown in Figure 16. A safety confirmation for the non-Halon replacement extinguisher was released in July 2013 from the US Army Evaluation Center. Lastly, an Airworthiness Assessment was completed in September 2013.



NOTES:
1. INTERPRET DRAWING IN ACCORDANCE WITH ASME Y14.100, ASME Y14.5M
2. SPECIFICATION AND TESTING IN ACCORDANCE WITH MIL-DTL-32403
3. NAME PLATE, FN 3, SHOULD BE ADHERED TO THE CYLINDER SO THAT WHEN THE ASSEMBLY IS MOUNTED THE ENTIRE NAME PLATE IS VISIBLE TO THE OPERATOR.
4. APPLY FN25 TO FN22 AND FN6 PRIOR TO ASSEMBLY.
5. APPLY FN24 TO FN17, FN20 AND FN21 PRIOR TO ASSEMBLY.
6. ILLUSTRATION SHOWN WITH STEEL CYLINDER..
7. PART NUMBER 1042950 IS WITH STEEL CYLINDER.
8. PART NUMBER 1042950-1 IS WITH ALUMINUM CYLINDER.

REV STATUS OF SHEETS	ZONE	REV	DESCRIPTION	DATE (DA MO YR)	APPROVED

PART LIST

QTY REQ'D	FIND NO.	CAGE CODE	PART NUMBER OR IDENTIFICATION NUMBER	NOMENCLATURE OR DESCRIPTION	NOTES OR REMARKS.
AR	25	81996	1043046	GREASE	
AR	24	81996	1043037	EPOXY	
1	23	81996	1042970	SWIVEL	
1	22	81996	1042956	"O" RING - SWIVEL	
1	21	81996	1042969	SWIVEL ADAPTER	
1	20	81996	1042975	GAUGE	
1	19	81996	1042977	PRESSURE RELIEF DEVICE	
1	18	81996	1043031	HORN & NOZZLE ASSEMBLY	
1	17	81996	1042972	DISCHARGE TUBE	
1	16	81996	1042961	VALVE BODY	
1	15	81996	1042963	CARRYING HANDLE	
1	14	81996	1042962	OPERATING HANDLE	
1	13	81996	1042966	RIVET - LONG	
1	12	81996	1043036	TAMPER SEAL - RED	
1	11	81996	1042967	PULL PIN	
1	10	81996	1042965	RIVET - SHORT	
1	9	81996	1043043	POP RIVET	
1	8	81996	1042960	VALVE STEM ASSEMBLY	
1	7	81996	1042971	CHAIN	
1	6	81996	1042957	"O" RING - VALVE TO CYL.	
1	5	81996	1042964	SPRING	
AR	4	81996	1043045	BRACKET ASSEMBLY	
1	3	81996	1043035	NAME PLATE	
1	2	81996	1043032	SIPHON TUBE ASSEMBLY	
1	1	81996	1043034	CYLINDER, STEEL	

FINAL ASSY.	HHFE
NEXT ASSY	USED ON
APPLICATION	

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES
TOLERANCES:
FRACTIONAL: 1/64"
ANGULAR ±1/2°
TWO PLACE DECIMAL ±0.03
THREE PLACE DECIMAL ±0.010
MATERIAL

FILENAME:
1042950.DWG

APPROVALS		DATE
PREPARED	M. CARPINTERO	28MAR13
CHECKED	B. AVERY	28MAR13
ENGINEER	T. MOSKALUK	28MAR13
SUBMITTED:		

APPROVED BY ORDER OF COMMANDER USA AMCOM

U.S. ARMY AVIATION AND MISSILE COMMAND
REDSTONE ARSENAL, ALABAMA

HHFE EXTINGUISHER ASSEMBLY

SIZE	CAGE CODE	DWG NO.	REV
B	81996	1042950	

SCALE
SHEET 1 OF 1

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Figure 16. Top Level Drawing.

Potential Future Research

It would be beneficial to further investigate the approach of adding small particle SBCs to clean agents (including new agents not available during the work described in this paper). One of these newer clean agents (bromo-trifluoropropene - BTP) was not readily available for evaluation under this program. BTP is more environmentally friendly and has shown promise as a Halon replacement. Future work could provide an improvement in HHFE performance compared to that discussed in this paper. Other applications such as Halon replacement in aircraft engine/auxiliary power unit/cargo bay fire protection and flight-line fire suppression could be investigated. Future work could further refine the technology previously described while investigating novel delivery mechanisms, or improving existing delivery mechanisms and hardware.