Effect of Various Preparation Methods on Live-Fire Fuel Characteristics

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14 Mar 2012
The US Army Research Laboratory (ARL), Survivability/Lethality Analysis Directorate (SLAD), routinely performs ballistic testing on air and ground systems in accordance with Live Fire requirements for Army materiel development and acquisition programs.

One question that is often addressed in Live Fire testing is whether threat engagements are likely to cause a (sustained) fire in the target:

- Internal or external fires can cause critical levels of secondary damage to the system and its occupants.
- This is especially pertinent when testing components like fuel bladders, fluid lines and hoses, and engines.

Fuel, such as JP-8, will typically be pre-heated to a temperature above its flash point to reflect operational conditions and ensure that a fire is possible if ignition occurs during a Live Fire test.
• There is no universal SOP for how this pre-heating should occur

• To avoid overpressurization danger, fuel heating systems often have blow-off valves or open-air (vented) components

• The risk exists that the most volatile molecules in the fuel mixture are evolving out of the fuel during pre-heating, effectively inerting the fuel before the test

• The question this project addressed is whether typical systems for pre-heating JP-8 in advance of Live Fire tests effectively maintain the characteristics of the fuel, and how this effectiveness could be verified during Live Fire programs
• Joint Live Fire-Ground sponsored a one-year project to determine the effects of various fuel preparation methods in use at Aberdeen Proving Ground (APG) on the properties and composition of JP-8

• The second phase of the work was a basic study of how differently shaped open-air heating containers affect fuel properties

• The third and final phase of the work was a survey of other Live Fire-related defense installations to compare JP-8 heating and property verification methodologies
Phase 1 Experimental Set-up

- APG’s Aberdeen Test Center (ATC) uses a Mobile Environmental Test Center (METC) to indirectly heat fuel prior to use.

- The storage compartment (upper right) exchanges air with a heating compartment behind the rear wall.

- The entire trailer is controlled manually via an input panel, and is wirelessly connected to a command center.

- Typical procedure is to heat a 55-gallon barrel for 48 hours to ensure thorough transition to 190 deg F.
• ARL’s System Engineering and Experimentation Branch (SEEB) uses a closed-system heat exchanger

• The fuel reservoir (right) holds about 50 gallons of fluid; several gallons are pumped via insulated line to the heating element (left) where a heat exchanger is controlled

• Input and output fuel temperatures are continuously displayed; heating lasts until the input temperature is at the level (190 deg F) required for testing
As expected for a closed-loop system, there was no observable trend in the data for the ARL heating system. However, there was also no significant trend in the flash point data for the METC-heated fuel, despite noticeable hydrocarbon condensation on the METC. This suggests that either volatile molecules were not evolving from the entire fuel volume, or were not doing so in significant quantities. Gas chromatography analysis of the outlying samples would reveal degradation.
Phase 1 Results cont.

- The outlying specimens from the METC (left, low sample duplicated) show no discernible change in chemical composition in gas chromatography/mass spectrometry (GCMS) analysis.
- By contrast, a comparison (right) of completely fresh (blue) and “cooked-off” (red) JP-8 shows drastic loss of lower-length hydrocarbon molecules.
- Therefore, it appears that changes in flash point in the METC samples are simply due to noise in the flash point test.
• Comparison of ARL and ATC-METC results show little difference in the property-maintenance effectiveness of the heating methods despite the METC being an indirect heat, open-loop system

• GCMS tests show that there is an observable correlation between organic molecule concentration and flash point, and that the METC system does not cause a significant change in concentrations

• Therefore, it appears that:
  – either the fuel container, or the METC itself, does not allow enough air circulation to cause significant evaporation of volatile molecules
  – or that the fuel depth in the drum does not allow enough molecules to evolve from deep in the fuel reservoir to affect the drawn samples’ flash point

• Phase 2 testing was conducted to test the effects of both increasing the free-air exposure of the fuel surface and decreasing the depth of the fuel
Phase 2 Experimental Set-up

- Phase 2 was designed to determine the circumstances under which significant fuel degradation might occur

- An off-the-shelf pressure cooker vessel was used as a generic heating reservoir in a parametric study of preparation environments
  - Open-system direct heating using electrical resistance range
  - 1:1 (no lid), 5:1, and 50:1 ratios of fuel surface area to lid hole size
  - Four-gallon (full) and two-gallon depths let us compare volume to surface area ratios

- Fuel was heated to 190 deg F for seven hours in each case
Phase 2 Results

- Flash Point (deg C)
- Sample #
- Live Fire test temperature

- 4 gal 1:1
- 2 gal 1:1
- 4 gal 5:1
- 2 gal 5:1
- 4 gal 50:1
- 2 gal 50:1

- Power (4 gal 1:1)
- Power (4 gal 5:1)
- Power (4 gal 50:1)
• Only in the most dramatic case (1:1, no lid) did the fuel’s flash point rise above the Live Fire test temperature among the four-gallon tests.

• Little to no fuel degradation was observed in the case of the 1.5” lid hole and full (4 gal) reservoir, despite a seven-hour cook time.
  – This suggests that:
    • Volatile compounds do not “bubble out” of the entire volume efficiently.
    • There needs to be a great deal of atmosphere exposure for volatiles to convect out of the reservoir in a significant quantity.

• Uniformly, shallower volumes and wider holes correlated to greater degradation.

• Conclusions:
  – Both APG heating systems are effective at maintaining fuel properties.
  – Avoid testing pool fire ignition by filling large, shallow pans before heating.
Phase 3: Survey

- An informal survey was conducted of Department of Defense installations that conduct ballistic testing at least occasionally.

- Potential participants selected for variety of climate conditions.

- Participating installations:
  - China Lake NWC (California)
  - Wright-Patterson AFB (Ohio)
  - Cold Regions TC (Alaska)
  - Eglin AFB (Florida)

- Questions focused on:
  - Is fuel pre-heated before testing, and in an open or closed system?
  - How often is fuel re-used, after heating and after storage in vehicle?
  - How often is fuel checked to verify properties?
Selected Survey Take-aways

- Most facilities use reasonably closed-loop heat exchangers for fuel preparation
  - One-way valves allow for venting of overpressure, but not continuous air exchange
  - Assuming the overpressure gases would be predominantly high-volatility compounds, experiments at APG show that overpressure is not a major concern, so presumably not a lot of gases are escaping (venting)
  - Eglin AFB uses a climatic chamber; the openness of the system depends on the specific container used

- Fuel re-use is very common:
  - Typically, a large volume is heated and only a small percentage of that is used in the testing
  - Unused fuel is recycled into the storage reservoir for subsequent re-heating

- Fuel characteristic testing is typically at the discretion of the testing authority
  - No SOP exists; long intervals can elapse between fuel tests
Overall Conclusions and Recommendations

- A closed-loop heating system is not required for preserving the properties of unused JP-8 during Live Fire testing pre-shot preparation.

- Significant savings (time, energy, manpower) are possible in the preparation processes of several facilities, including APG.

- Since fuel is often re-heated (or even pumped into and out of the test fixture) several times during its useful lifetime, more systematic evaluation of its properties is recommended.

- Live Fire tests that comment on the propensity of a target-threat interaction to cause a sustained fire should note the temperature of the fuel at test time and the flash point properties of a relevant sample.
Questions?