U.S. Army Research, Development and Engineering Command

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Effect of Various Preparation Methods on Live-Fire Fuel Characteristics

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Background/Issue statement

- 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

Issue statement cont.

- 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

JLF-Sponsored Investigation

- 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

Joint Live Fire
Ground Systems

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

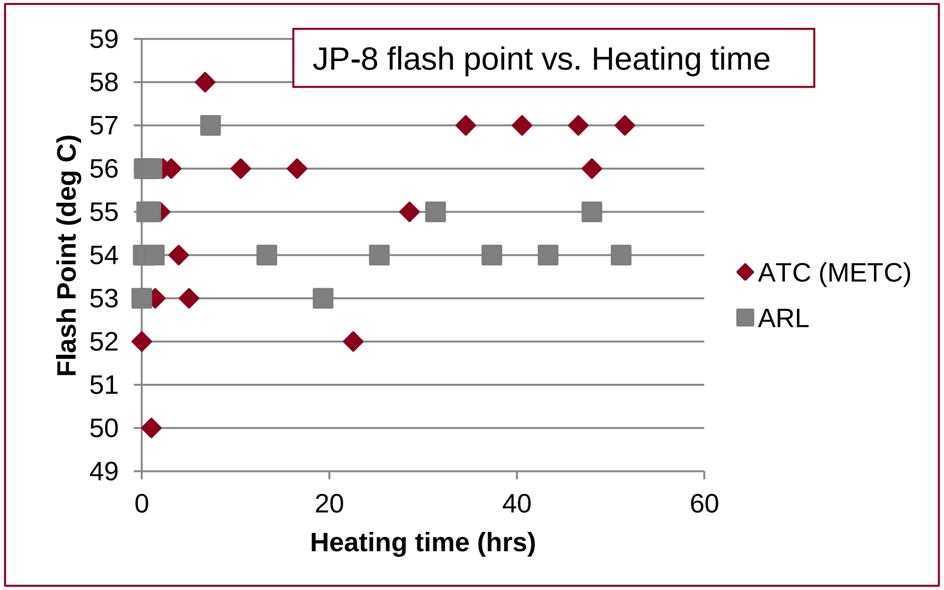
- The entire trailer is controlled manually via an input panel, and is wirelessly connected to a command center

- Typical procedure is to heat a 55-gallon barrel for 48 hours to ensure thorough transition to 190 deg F

Phase 1 Set-up cont.

- 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

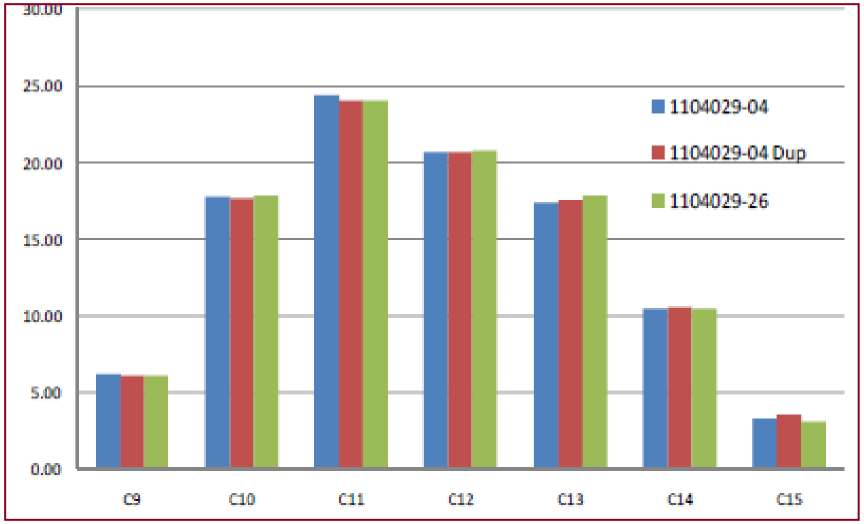
Phase 1 Results

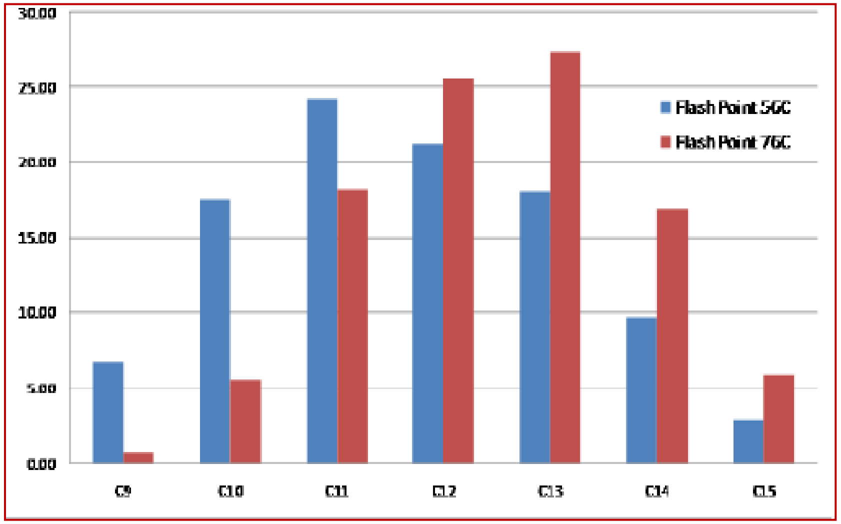


- As expected for a closed-loop system, there was no observable trend in the data for the ARL heating system
- However, there was also no significant trend in the flash point data for the METC-heated fuel, despite noticeable hydrocarbon condensation on the METC
- This suggests that either volatile molecules 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.

Carbon-based molecule prevalence by % of GCMS peak area





- 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

Phase 1 Results cont.

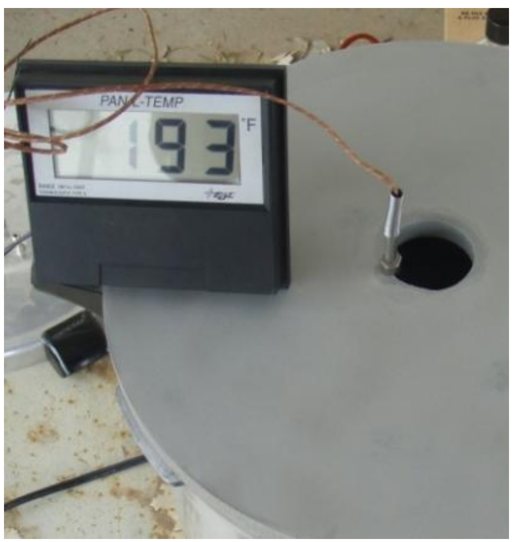
- Comparison of ARL and ATC-METC results show little difference in the property-maintenance effectiveness of the heating methods despite the METC being an indirect heat, open-loop system

- 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

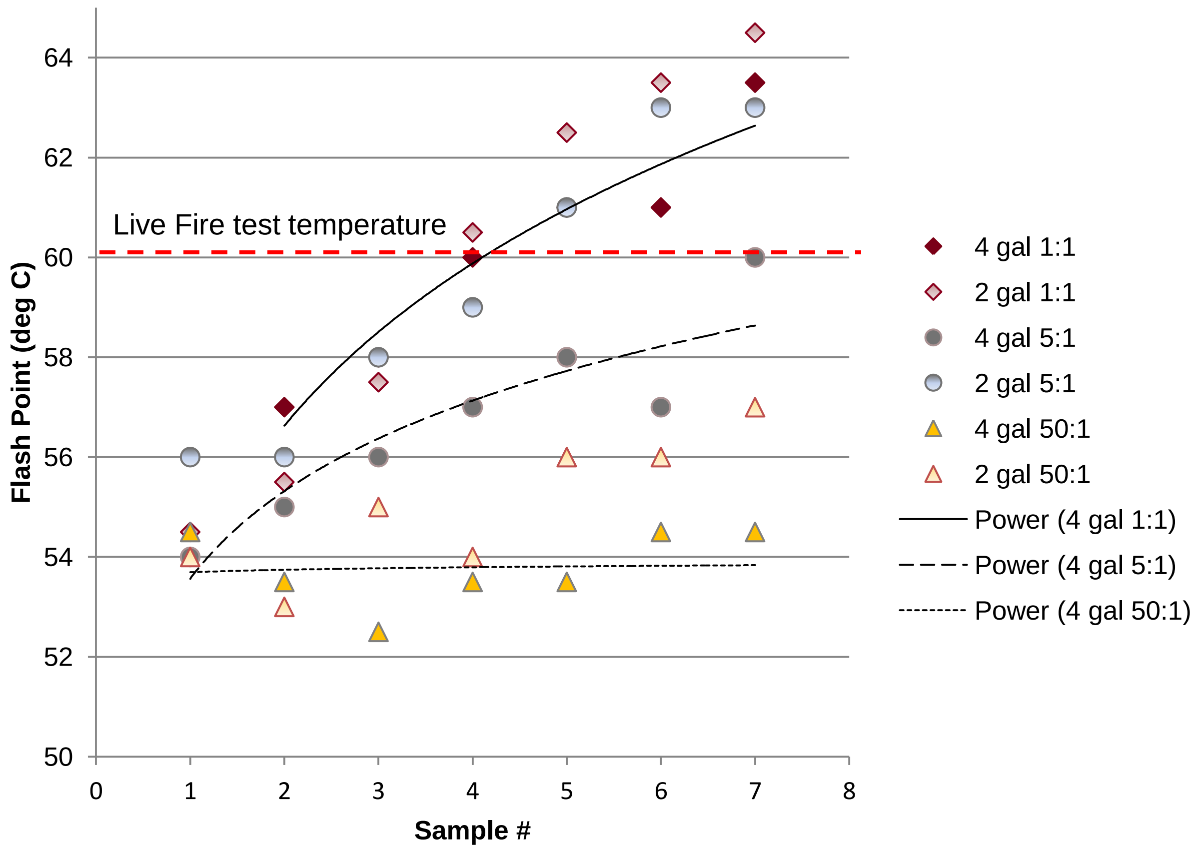


- Phase 2 was designed to determine the circumstances under which significant fuel degradation might occur

- 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



Phase 2 Results cont.

- 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

Wrap-up

Questions?