

Initiating *In Situ* Burning of Difficult-to-Ignite Oil Spills via an Aircraft-Deployable Igniter System

Benjamin T. Goodman, Ph.D., Naval Air Warfare Center Weapons Division
Ross A. Davidson, Naval Air Warfare Center Weapons Division
Eric S. Sievert, Naval Air Warfare Center Weapons Division
Leslie Wood, Naval Air Warfare Center Weapons Division
Vincent H. Homer, Jacobs
1 Administration Circle MS 1109
China Lake, CA 93555

ABSTRACT 300203:

Igniting a crude-oil spill *in situ* is a two-step process. First, the oil must be heated above the fire point such that sufficient flammable vapors are present to allow sustained burning. Second, the flammable vapors must be ignited. Different crude oils have different fire points due to different chemical compositions and the fire point can change over time due to volatilization of the lighter components. Factors such as wind, current, water entrainment, oil spill thickness, and temperature can affect the heat transfer to the oil spill, preventing it from reaching its fire point. As such, a large amount of heat may not ignite an oil spill if it is not of sufficient duration because it does not first heat the oil to its fire point.

A light hydrocarbon such as diesel or gasoline is often used as an accelerant to ignite oil spills due to flexibility, low cost, and availability. The ignited accelerant creates a small pool fire in the middle of the larger oil spill that provides a sufficient heating rate over a sufficient duration. The heating rate of the initiating fire is proportional to the surface area of the burning accelerant. The duration of the initiating fire is proportional to the thickness of the burning accelerant. Surface area versus thickness can be controlled by use of a gelling agent. The largest challenge to deploying a liquid-accelerant igniter from an aircraft is safely lighting it in a manner that does not endanger the aircraft and will not extinguish when the igniter impacts the oil spill, especially when the oil spill is over water. A delayed-reaction, chemical ignition system paired with gelled accelerant in a manner that is suitable for deployment from aircraft is described. Test results of this ignition system against a weathered crude-oil surrogate are presented.

INTRODUCTION:

In situ burning of oil slicks is a mitigation technique for removing spilled oil from the environment by burning it in place. The advantages of *in situ* burning over other oil spill remediation techniques are: simple logistics, high elimination rates, high efficiency, versatility, and cost (Buist et al., 1994). The net effect of these advantages is that *in situ* burning can be applied more quickly than most other response methods and can prevent the situation from worsening due to oil slick spreading and other factors (Buist et al., 1994).

Crude oil is a naturally-occurring mixture of various hydrocarbons. Crude oils from distinct sources will have different compositions. Even refined oils contain a variety of different

hydrocarbon species and are created based on physical properties such as boiling point range and viscosity rather than a specific chemical composition. The hydrocarbons in oil burn only in the vapor phase and must evaporate first. The first step in igniting an oil slick is to raise its temperature to its fire point, the temperature at which sufficient vapors have evaporated to allow sustained burning. Crude oils from distinct sources will have different fire points. The fire point of an oil slick may change over time due to the volatilization of the lighter species in the oil. Factors such as wind, current, water entrainment, oil-slick thickness, and temperature can affect the heat transfer to the oil slick, preventing it from reaching its fire point. The different compositions and environmental conditions found in oil slicks can make *in situ* burning a complex problem.

In order to sustain burning, the initial fire started by an *in-situ*-burn oil-slick igniter must itself emit enough heat flux to initiate the adjacent oil. The heat flux reaching the surface of the oil has been found to be:

$$\dot{q}''_s = \frac{\chi \rho_\infty C_p (T_\infty g (T_f - T_\infty))^{1/2} d^{1/2}}{\pi} \quad (1)$$

where χ is the fraction of heat absorbed by the surface, ρ_∞ is ambient air density, C_p is the constant-pressure heat capacity for ambient air, T_∞ is the ambient air temperature, g is the acceleration of gravity (9.81 m/s^2), T_f is the flame temperature of the burning oil, and d is the diameter of the burning oil (Wu and Torero, 1998). χ is a function primarily of the absorptivity of the oil surface. χ is a small percentage (typically 1-3%) of the total heat radiated (Walton and Jason, 1999). Given specific oil and environmental conditions, the only means of making a fire self-sustaining is to ensure that the initial fire started by the igniter has a sufficient diameter. This is substantiated by research which placed an ignited “spot” of diesel bounded by a metal ring to fix its size within a larger pool of weathered crude oil and weathered-crude-oil surrogate floating on water (Putorti et al., 1994). The amount of heat flux to a surface from diesel fires of various sizes is shown in Figure 1. It was shown that various diameters of diesel would not ignite the surrounding oil, ignite it some of the time, or ignite it consistently. The time to ignition varied with the size of the diesel “spots.” The results also varied based on the oil or surrogate used. See Figure 2 for the results using SAE 30 motor oil as the weathered-crude-oil surrogate.

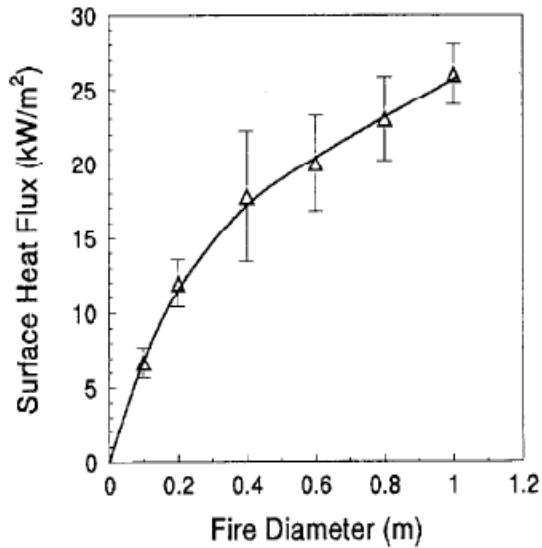


Figure 1. Surface heat flux from a diesel fire based on size (Putorti et al., 1994).

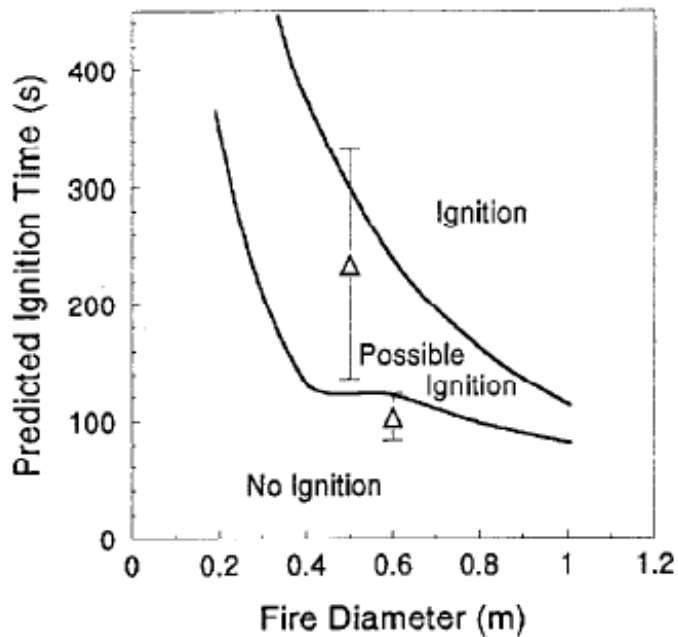


Figure 2. Ignition times for SAE 30 motor oil based on various diameters of diesel "spots" (Putorti et al., 1994).

Igniters deployed from aircraft have design limitations compared to those deployed from a ship or the ground due to extra safety precautions required based on the small size of the working area and limited escape opportunities. Typical safety precautions for aircraft include not allowing open flames or incendiary systems with the energy source stored with the igniter (e.g.,

an igniter that included an integrated, charged battery) within the cabin. Some of these concerns can be alleviated by using a sling system such that the igniter system is not carried within the aircraft itself and can be dropped in case of an emergency. The United States Forest Service (USFS) uses a device called a helitorch that is a sling-loaded ignition system that spreads droplets of gelled fuel as a way to ignite backfires and initiate controlled burns. It has been successfully used to ignite oil slicks *in situ* (Buist et al., 1994). However, slings are not practical for every igniter mission due to range reduction, launch-site layout, or the layout of intermediate staging sites.

DEVICE DESIGN:

One of the more common oil-slick igniter systems used from the ground or from a ship for *in situ* burning is a simple two-part improvised igniter which consists of a road or marine flare attached to a container of light, liquid fuel (typically diesel, gasoline, or a mixture) that is often gelled. These have the advantage of being made from inexpensive, readily-available commercial-off-the-shelf (COTS) components. They are initiated by using the striking mechanism of the flare or by using a match/torch. See Figure 3 for examples of this type of igniter. The pyrotechnic (flare) breaches the container, allowing the fuel to spread, and ignites the fuel. The fuel spread creates an initial fire of a size that provides sufficient heat to ignite the substrate oil around it in a sustainable manner. They function well for applications where they can be deployed by tossing or floating; however, they are not suitable for deployment from an aircraft due to the presence of an open flame during initiation.

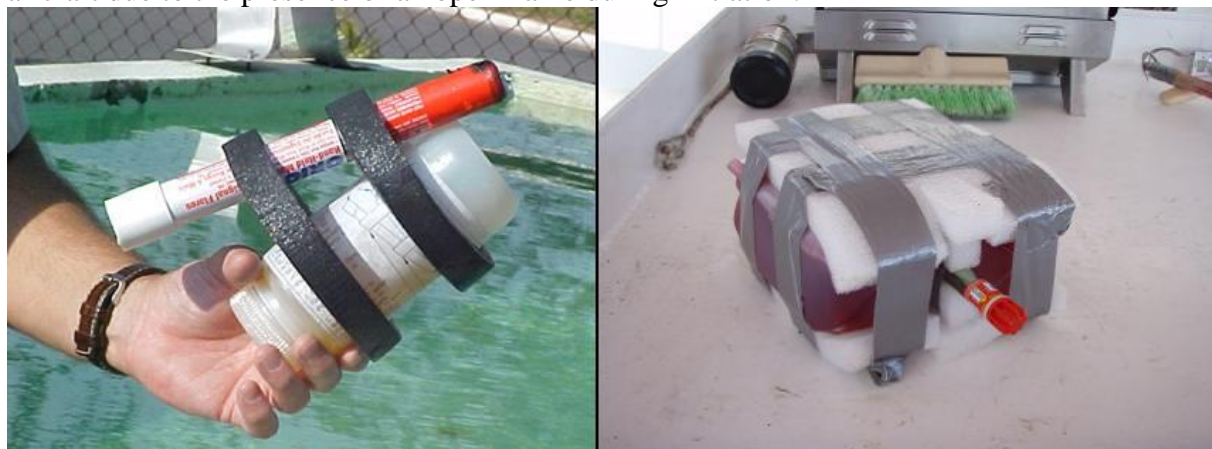


Figure 3. Hand-held (left) and 2-gallon (right) improvised igniters.

The proposed igniter is similar to the improvised igniters discussed above, but modified to be deployable by aircraft. The igniter system consists of three components: a two-part chemical initiator, a pyrotechnic booster, and a liquid fuel payload. See Figure 4 for a sketch of the proposed igniter.

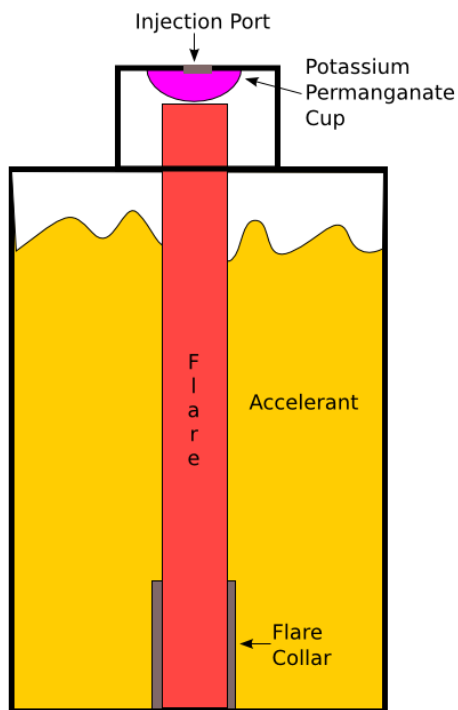


Figure 4. Proposed oil spill igniter sketch.

The chemical initiator is the potassium permanganate/ethylene glycol system. The USFS uses polystyrene balls or cups filled with potassium permanganate as a way to start backfires and controlled burns from the air. The potassium permanganate is injected with ethylene glycol immediately prior to deployment using a specialized dispenser. The potassium permanganate and ethylene glycol react exothermically. The reaction will ignite the capsule containing the potassium permanganate after a delay. The size of the delay depends on the particle size of the crystals and the ratio of the two components. The proposed igniter uses a capsule of the type that the USFS utilizes attached to the lid of the igniter container (see Figure 3). A prototype dispenser has been built that injects the proposed igniter and drops it for testing purposes. A dispenser that attaches to an aircraft door or window would allow the proposed igniter to be deployed from an aircraft. This chemical initiation system has two advantages: the time delay prevents igniting the system while still in the aircraft and the two components of the system are very stable and safe while separate.

The pyrotechnic booster is a common road or marine flare. The purpose of the booster is to bridge the gap between the initiator and the payload fuel. The flare is difficult to light accidentally, but once lit is difficult to extinguish. It ensures that the payload is ignited and also helps to release the payload by melting and burning the container holding the fuel. Using a flare has two advantages over a specialized pyrotechnic: it is inexpensive due to the high volume in which it is produced and it can easily be replaced or purchased on demand. Pyrotechnics-in-general have limited shelf life. The pyrotechnics typically used in oil-slick igniters in the past

(such as the Dome and Pyroid igniters) have had nominal shelf lives of 5 years although they were known to last longer when stored in Alaska and Northern Canada (Buist et al., 1994).

The payload of the igniter consists of a light, liquid fuel such as gasoline, diesel, or a mixture of the two. This light fuel is also known as accelerant because as it mixes with the substrate oil it lowers the fire point, decreasing the time to ignition. The fuel escapes through a hole made by the pyrotechnic and spreads to create a fire of sufficient size to sustainably burn the substrate oil slick. A gelling agent can be added to the fuel to increase its viscosity, if desired, in order to limit the accelerant from spreading and increase its burn time. The amount of payload fuel needed for the igniter depends on the fire point of the substrate oil slick. A higher fire point requires more heat to ignite which is provided by a larger-diameter accelerant fire. Liquid fuel has several advantages as a payload: it spreads, meaning that the payload can provide the size of fire necessary to provide sustainable ignition to the substrate oil slick; liquid fuel fires provide high heat flux due to radiation from their sooty emissions—while other fires can be hotter, the radiation view factor is not as high; and the liquid fuel mixes with the substrate oil slick at the edges, lowering the fire point.

RESULTS:

Two series of tests have been accomplished to date. The first series of tests was to determine the amount of accelerant needed to sustainably ignite a weathered-crude-oil surrogate floating on water. The second series of tests was to determine whether the ignition train (initiator to booster to payload) functioned. Additional testing is forthcoming to more fully evaluate the igniter.

In the accelerant quantity tests, SAE 30 motor oil was used as a surrogate for weathered crude oil. The motor oil was floated on water in an 8-ft diameter pool. These conditions were chosen as a difficult, but obtainable target and to compare results with Putorti et al. (1994). Tests were conducted with a fixed amount of 2:1 diesel:gasoline to simulate a fixed amount delivered by the igniter. The diesel was sweetened with gasoline to make it easier to ignite with a hand torch. Amounts of 325 ml, 400 ml, 600 ml, and 800 ml were tested without gelling agent. Amounts of 500 ml, 550 ml, 600 ml, and 850 ml were tested using the recommend amount of Flash 21 gelling agent. Heat flux from all tests were measured using a Medtherm 64P(ZnS)-50-24 Gardon gage positioned 22.5 in from the edge of the pool. Only the 800-ml ungelled and 850-ml gelled tests succeeded in sustained ignition of the substrate motor oil. Tests which ignited the bulk motor oil were extinguished using CO₂ in order to protect equipment. The heat flux from each of the ungelled tests is shown in Figure 5. The heat flux from each of the gelled tests is shown in Figure 6. The heat flux from using 600 ml of fuel with and without gelling agent is shown in Figure 7. The test set up was sufficiently different from Putorti et al. (1994) due to the unconstrained nature of the fuel in the present tests that comparison of data is difficult. As can be seen in Figures 5-7, the heat flux increased, peaked, and decreased without plateauing—unless the bulk oil ignited. Putorti et al. saw steady heat fluxes given the fixed diameter of the fuel spots in those tests. The other difference in the test set ups was the mixing of the accelerant with the bulk oil in the present tests around the edges of the accelerant spot. This appeared to facilitate ignition of the bulk oil around the edges of the accelerant spot. As can be seen in Figure 7, the

ungelled fuel burned hotter, but the gelled fuel burned slightly longer. This is consistent with the gelled fuel forming a thicker, smaller-diameter spot.

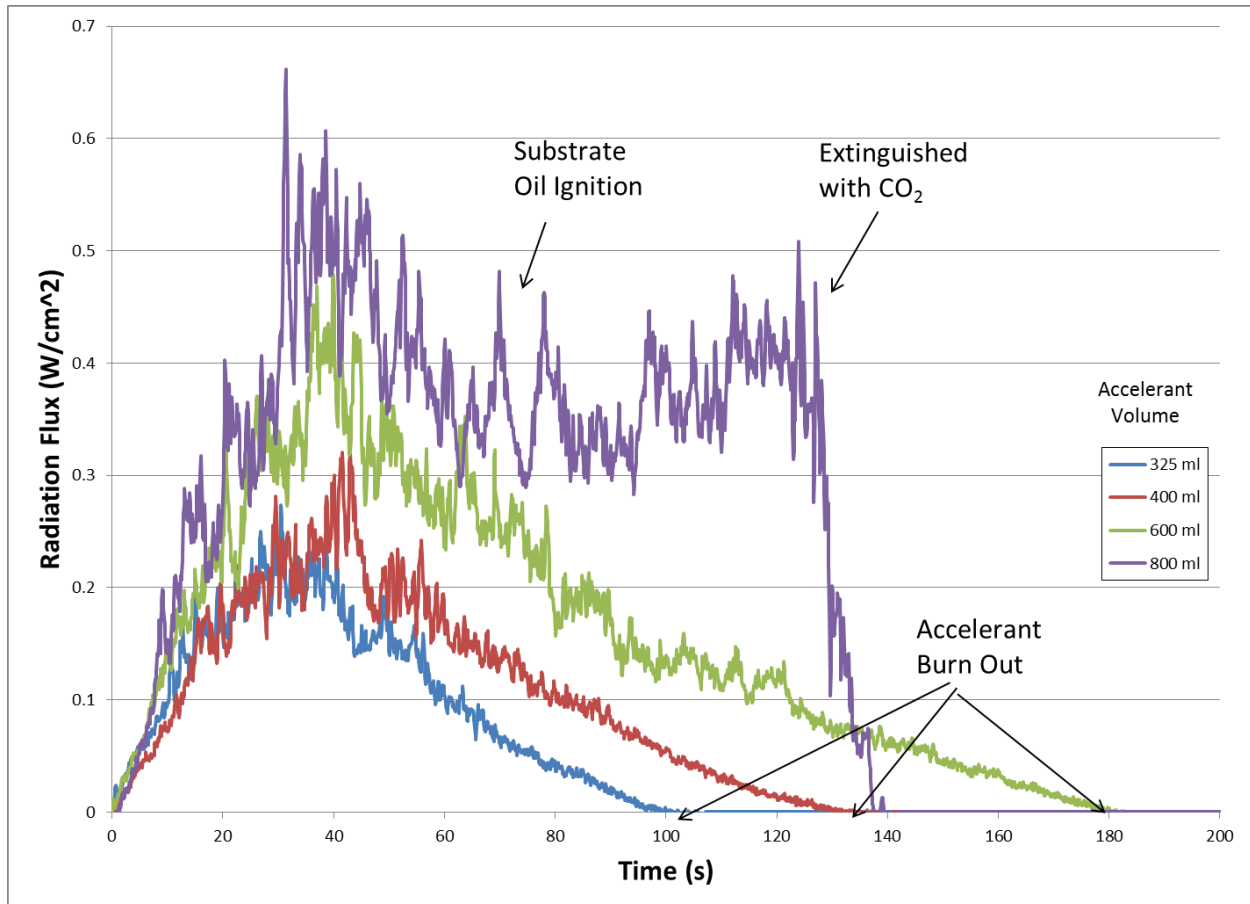


Figure 5. Heat flux produced by various amounts of 2:1 diesel:gasoline (no gel) on SAE 30 motor oil floating on water.

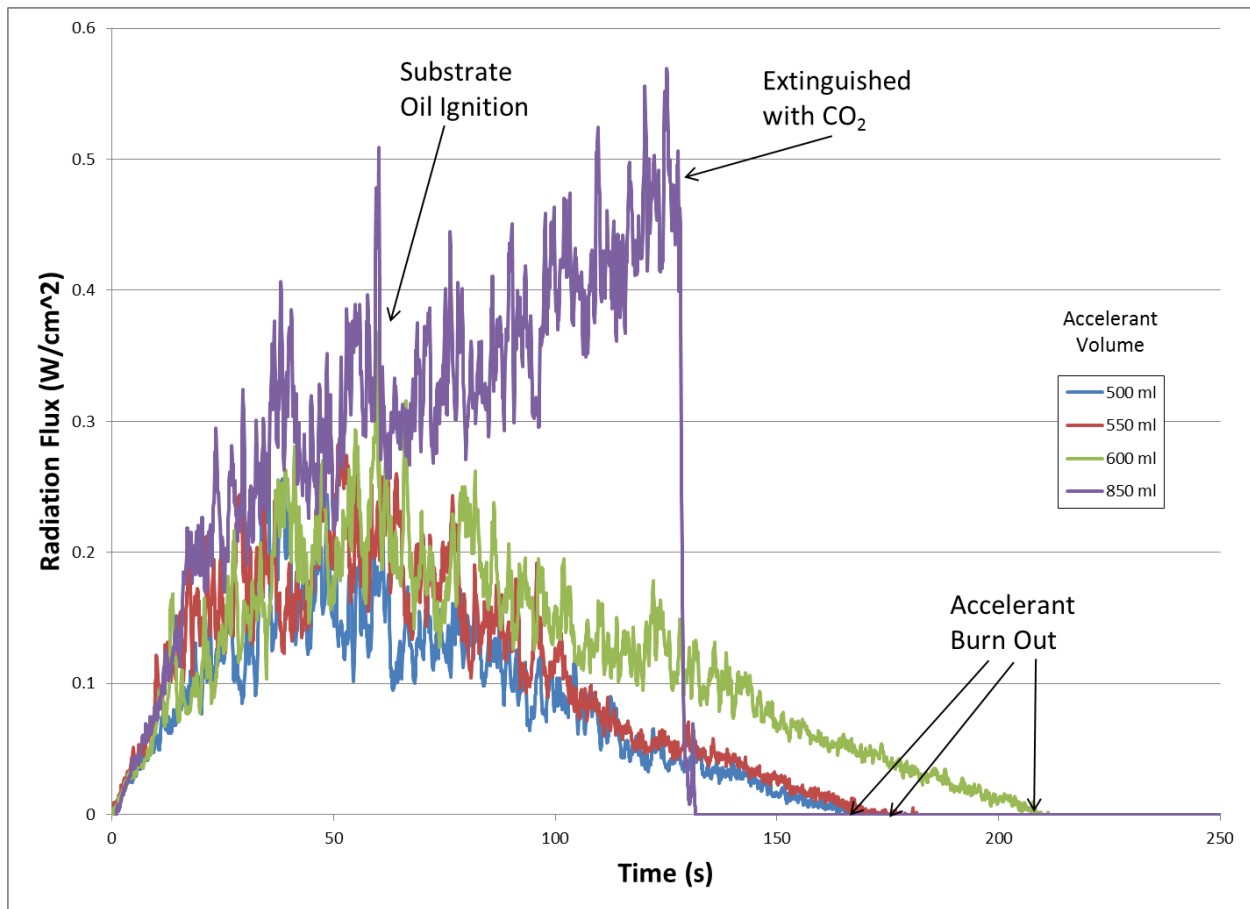


Figure 6. Heat flux produced by various amounts of 2:1 diesel:gasoline (gelled) on SAE 30 motor oil floating on water.

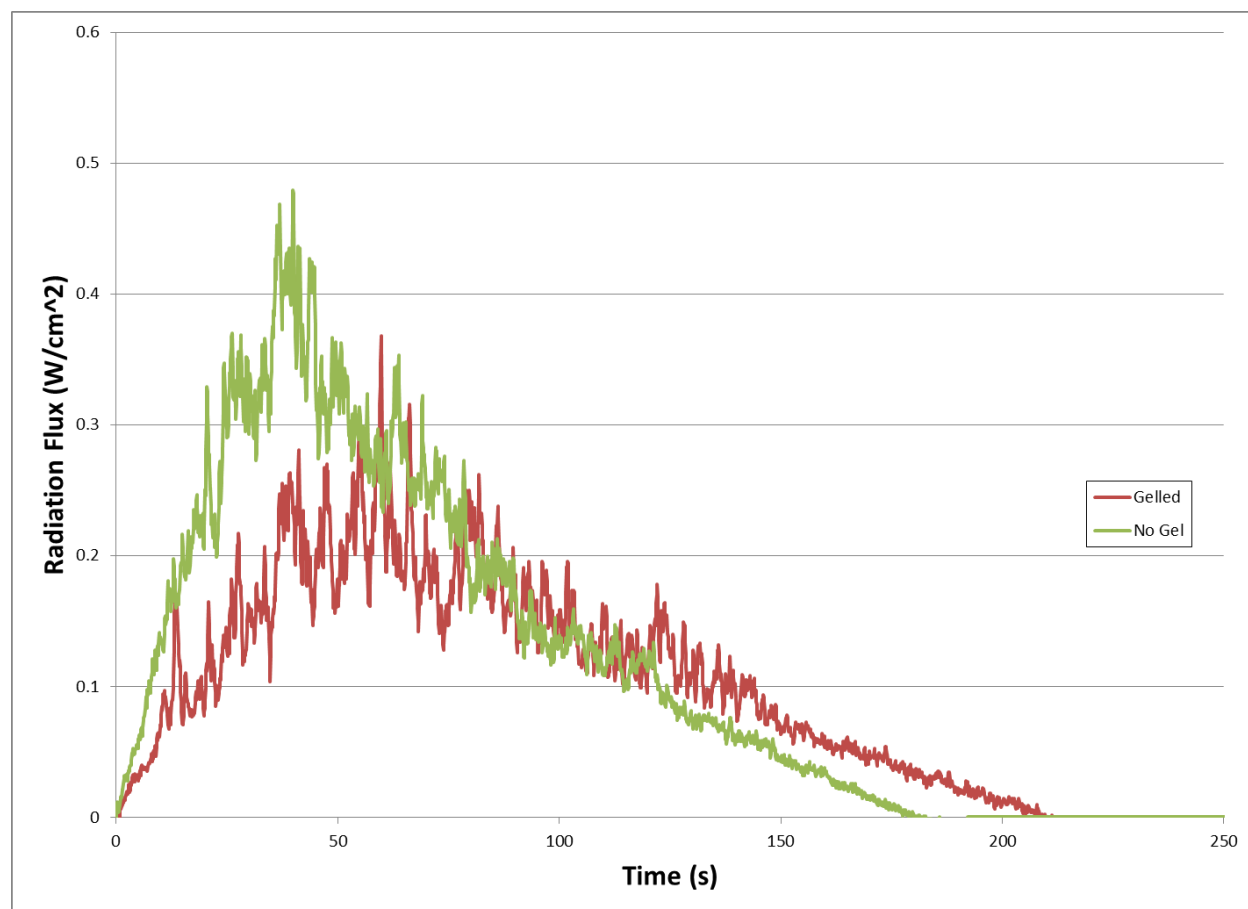


Figure 7. Comparison of heat flux from 600 ml of 2:1 diesel:gasoline with and without gelling (no substrate motor oil ignition).

In the second series of tests, 3 prototype igniters were constructed according to the schematic in Figure 3 and tested one by one. In each of the 3 tests, the initiator of the igniter was injected with ethylene glycol and the igniter was placed in a barrel of water. The igniter discharged its payload fuel which burned on the surface of the water in each test. See Figures 8-10 for photographs of one of the tests showing the various stages of the igniter life cycle. Three types of potassium permanganate capsules (Premo, SEI Dragon Egg, and Raindance R3) were also tested. See Figure 11 for a picture of various potassium permanganate capsules. The time delay between injection and visible flame through the injection hole varied from 12 seconds to 2 minutes depending on the capsule and the amount of ethylene glycol added. The 2 minute result was from the cup that visually contained the coarsest particles.



Figure 8. Initial flame from the initiator of the igniter (~2 min after injection).



Figure 9. Initial burn-through of the lid of the igniter caused by the pyrotechnic booster (~3 min after injection).



Figure 10. Burning of the payload liquid fuel spread from the igniter (~6 min after injection).



Figure 11. Premo, Aerostat, SEI Dragon Egg, and Raindance R3 potassium permanganate capsules

CONCLUSIONS:

The proposed igniter has the advantages of the commonly-used improvised oil-slick igniter and is able to be safely deployed from an aircraft. The ignition train of potassium permanganate/ethylene glycol initiator, road-flare booster, and accelerant (diesel and/or gasoline) payload allows for a consistent time delay and consistent ignition of the accelerant which spread out from the container. The proposed igniter is made from COTS components which makes acquisition and replacement easier than the specialty items with limited shelf life that were utilized in the past. Further research is needed to quantify the amount of accelerant payload needed under any given condition.

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