SCREENING METHODS FOR NEW FIRE SUPPRESSION TECHNOLOGIES

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Introduction

The search for alternatives to halons for fire suppression applications has identified not only new compounds (*e.g.*, hydrofluorocarbons) which have physical properties similar to the bromochlorofluorocarbon family, but also inert gaseous agents that are released from a solid state (e.g., solid propellant gas generators or SPGGs) and condensed phase agents that may be misted or generated pyrotechnically. Industry is already investigating innovative ways that these multiple technologies can be blended or hybridized to create an optimum fire fighting agent/release mechanism for specific applications. The traditional cup burner method is unable to evaluate these not-in-kind replacement systems. This paper examines two new concepts for testing liquid aerosol and SPGG fire suppression technologies. The first concept is for a bench-scale suppression screen suitable to compare the ability of dispersed fluids with differing chemical and physical properties to extinguish a laboratory flame; the second is for a facility to test SPGG-based agents and release mechanisms. The following desirable attributes have been kept foremost in mind during concept formulation:

- **applicability** - Results of bench-scale tests must transfer to pilot-scale simulators of actual field situations.
- **amenability to analysis** - Initial and boundary conditions of the flame and flow system and characteristics of the agent must be controlled to permit analysis of the facility, interpretation of the results, and scientifically sound explanations of anomalous behavior.
- **repeatability** - Replicate tests must produce outcomes similar enough to minimize uncertainty limits.
- **flexibility** - Different types of chemicals, aerosols and discharge principles must be accommodated in a consistent manner.
- **operability** - The apparatus and operating procedure must be such that data can be acquired safely, efficiently and with a minimum of agent, enabling duplication of the facilities at other government and industrial laboratories.

Dispersed Liquid Agent Fire Suppression Screening

Since the objective of this study is to design a bench-scale apparatus suitable for evaluating fire suppression efficiencies of new advanced liquid agents, it is imperative that a laboratory burner and a liquid/aerosol delivery system be carefully selected. The rationale for the selection of these two major components are discussed bellow.

<u>Burner</u> Counterflow diffusion flames have been used extensively to study relative effectiveness of various gaseous and powder flame inhibitors (see *e.g.*, Tsuji, 1982). There are basically two configurations of counterflow diffusion flames: (1) a diffusion flame established between two opposed gaseous jets, one being fuel and the other being oxidant, and (2) a diffusion flame formed in the forward stagnation region of a porous spherical or cylindrical burner placed in a uniform oxidizer flow, with fuel

principle, may be superior to water. The amount of water required is estimated based on the assumption that the limiting oxygen concentration to sustain combustion is approximately 15 % (by volume). In the estimation, water is treated as an inert diluent vapor. The thermal effect due to water droplet evaporation is not taken into account; hence, the calculation is considered very conservative.

The total volumetric flow (Q_{total}) is equal to the duct cross-sectional area ($L{\cdot}W$) times the average velocity (V), which is also equal to the sum of the volumetric oxygen (Q_O), nitrogen (Q_N) and water vapor (Q_w) flows. Using the burner dimensions and flow velocity mentioned above, and noting that $Q_O = 0.15\ Q_{total}$, and $Q_N = (0.79/0.21)\ Q_O$, then the required value for Q_w can be calculated to be 0.447 L/s. Assuming an ideal gas mixture, the water mass flow rate (m_w) is then equal to 0.359 g/s. According to the design by Takahashi *et al.*, (1994) the equivalent liquid water mass flow can be achieved by using a piezoelectric droplet generator with 20 orifice openings, each with a diameter of 34 μm.

Past studies with gaseous agents have shown the importance of uniform agent/air mixing and the velocity gradient at the flame front on the extinction process. Aerosol uniformity measurements will be made within the burner using either a PDPA (Phase Doppler Particle Analyzer) or stroboscopic microphotography, and the air and fuel flows will be precisely monitored to ensure the above effects can be separated from the physical/chemical effects of the different aerosols.

Operation The focus of the initial effort will be on fluids (pure or in mixtures) which can be formed into well characterized aerosols at conditions close to room temperature and pressure. They will be suspended in air streams at modest velocities and transported to the propane diffusion flame. A stable, stagnation point flame will first be established in a steady flow of air, the desired droplets/aerosol will be introduced at a fixed concentration, and the strain rate ($2V/R$, where V is the external air flow and R is the radius of the burner), will be increased until the flame is blown off of the stagnation point. If a stable turbulent wake flame is established, the agent concentration will be increased further until the flame is totally extinguished. The maximum concentration of the suppressant as a function of strain rate at a fixed fuel ejection velocity can then be determined.

Extinction experiments will be conducted with and without obstacles (e.g., uniform screens or cylinders) in the air stream just ahead of the flame. This will further complicate the flow but may be necessary to more closely emulate a cluttered environment. In order to characterize and calibrate the performance of the burner, gaseous agents will also be used. This will allow comparisons of the performances of gaseous agents with those of aerosols.

SPGG-Based Fire Suppression Screening

The test fixture envisioned for evaluating solid propellant gas generators and hybrid extinguishers represents an intermediate-scale screening method. It differs from the Tsuji opposed flow flame burner described above in that, not only is its physically larger, it is intended to screen fully functional extinguishers.

Potential applications of SPGGs and hybrids include the following: engine nacelles and military aircraft dry bays, locations not adversely affected by hot effluent such as paint spray booths, restaurant kitchen ranges, total flooding in un-occupied spaces like aircraft cargo compartments, protection of machinery with a directed discharge, etc. The fire environments can be broken into forced flows (e.g., engine nacelles, spray booths, kitchen range ducting) and otherwise quiescent situations (e.g., cargo compartments, directed discharges) In the forced flow scenario, the flow assists in the mixing and transport of agent to the fire location, but it also carries the agent away from the fire. In the quiescent environment, the mixing and transport of the agent to the fire zone depends almost entirely on the momentum of the effluent with obstacles and wall boundaries impacting the flow.

Standards exist for prescribing an inert or chemically active agent in enclosures (National Fire Protection Association, 1996) where design concentrations and holding times (the minimum time period the design concentration must be maintained) are specified for different agents and fire scenarios. Two facets separate typical SPGGs from the "clean agents" addressed in NFPA 2001: the elevated temperature and the composition of the effluent. In addition, hybrids could contain solid or liquid particulates. These factors pose problems regarding the use either of the cup-burner or of an explosion flask for obtaining inerting concentration. A recognized equivalent measure of extinction and/or inerting concentration is needed for total flooding design.

If the only application of the SPGG or hybrid system were a total flooding scenario, a suitable test fixture could be a fire established in a small enclosure, but blocked from direct impact of the discharge. Scaling based on the volume of the enclosure to be protected would provide the design criterion. However, applications such as engine nacelle protection where an air flow is always present are quite different. There is no accepted NFPA test for evaluating agent effectiveness for a fire established in a forced flow. The NIST turbulent spray burner and the Walter Kidde Aerospace baffle stabilized pool fire configuration (both described by Hamins *et al.*, 1995) are forced flow apparatuses that do provide measures of effectiveness. With these systems, the effects of flow velocity, agent concentration, and discharge duration can be explored. The results may be generalized to allow for comparisons to different scenarios. Of these two facilities, the baffle-stabilized pool fire is more attractive because it appears to be more difficult to extinguish. The mixing time scale is longer and the minimum agent concentration is higher than for the turbulent spray flame.

A wind tunnel configuration is proposed to provide the forced flow and to facilitate the mixing of the SPGG discharge. Figure 2 is a schematic. The SPGG is discharged into a plenum and mixed with incoming air. The air will be provided from a compressed air bottle farm, or compressor at sufficient delivery pressure so that the SPGG discharge, itself, does not effect the air flow. From the plenum, the flow then moves into a duct that holds the test section. The duct will have a movable floor to control the cross sectional area which will readily change the flow velocity at the test section for a given volumetric flow. Temperature and axial velocity measurements will be made at a number of locations in the duct. The duct will have windows at the test section location for visible observation of flame extinction.

The baffle-stabilized pool fire will follow the design of Hirst and Sutton (1961) with some modifications. In their design, the flame is stabilized in the recirculation zone in the wake of a bluff body (the baffle). Such a flame will persist in that location at a free stream velocity much higher than the blow off velocity of a boundary layer flame. The design proposed here is a rear-facing step configuration. In this case, the flame is stabilized by the recirculation zone in the wake produced by the step. The step height will be adjustable. The benefits of this design are: (1) the flow is less complicated, (2) fewer solid or liquid particles will be lost since the forward stagnation zone is eliminated, and (3) it allows for the test section to be narrower in the vertical direction which will reduce the duct blockage. Figure 3 is a schematic of the test section. The step, between 5 mm and 25 mm high, is imbedded in an airfoil with an elliptical nose that extends the width of the duct (about 300 mm). The forward base of the step is the location of the pool, proposed to be about 120 mm square. The pool may actually be a flat sintered metal burner with gaseous or liquid fuel fed at a specified rate. This would eliminate fuel being blown out of a pan, and the heat release rate of the fire could be controlled. In addition, orientation could be changed without fuel spillage.

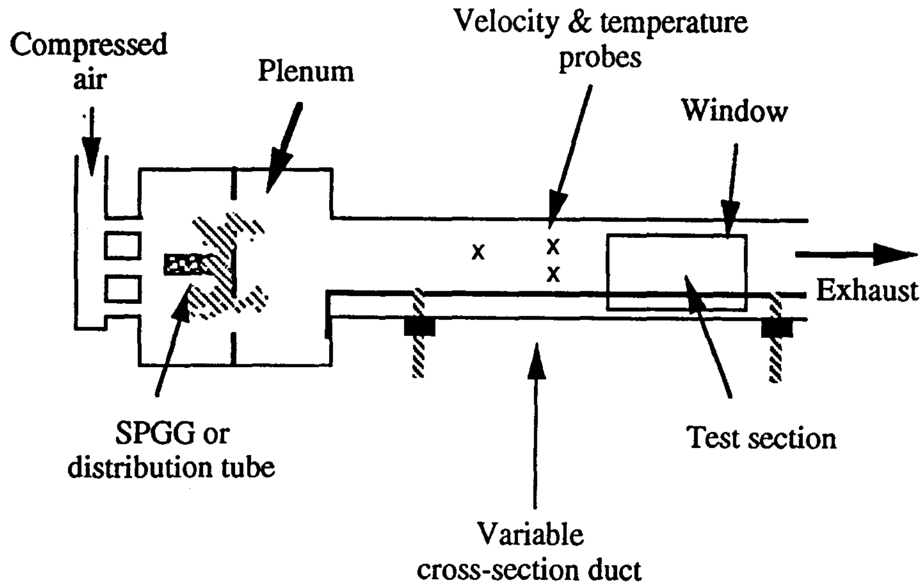

Figure 2. Schematic of the proposed SPGG wind tunnel test apparatus.

The test fixture will be put through a series of tests with inert compressed gases (such as nitrogen) with tighter flow control to probe sensitivities to the operating parameters such as fire scenario (including fuel and step height), velocity, duct cross-section, inert concentration and discharge duration. The results will be used to characterize the dynamics of the recirculation/fire zone in terms of a characteristic mixing time for flame extinction. Hamins *et al.* (1995) proposed the following equation for extinction of spray flames and baffle-stabilized pool fires:

$$X_{\infty} = X_c(1 - e^{-\Delta t/\tau_f}) \qquad (1)$$

where X_{∞} is the agent concentration at extinction for very long injection time (the minimum agent concentration), X_c is the agent concentration for a time duration of Δt that puts the fire out, and τ_f is the characteristic mixing time for flame extinction. Each fire scenario will have a different characteristic time which is strongly influenced be the step height, flow velocity, and duct cross-section. It may also be a function of fuel and heat release rate.

For a SPGG, the number of moles and temperature of the effluent, and the discharge time are important and can be tailored to some extent. While propellent formulations may be proprietary, the effluent most likely will be specified by the manufacturers. Consider two "fictitious" SPGG canisters, each with a propellant weight of 454 g. The effluent composition for the first is 60% N_2, 30% CO_2, and 10% water, and for the second it is 80% N_2, 10% CO_2, and 10% water. Inerting volumetric concentrations for these components rank as $N_2 > H_2O > CO_2$. The number of moles produced is 14.4 moles for the first case and 16.0 moles for the second. The burn time for the first canister is 1 s and for the second is 1.5 s, thus the molar flow is 14.4 moles/s for the first and 10.7 moles/s for the second. The temperature of the effluent will affect the extinction process. Thus, the chemical constituents, mass flow, volumetric flow, and effluent temperature will impact the extinction process of a test fire. The test fixture proposed will account for these effects such that comparisons can be made on a common basis.

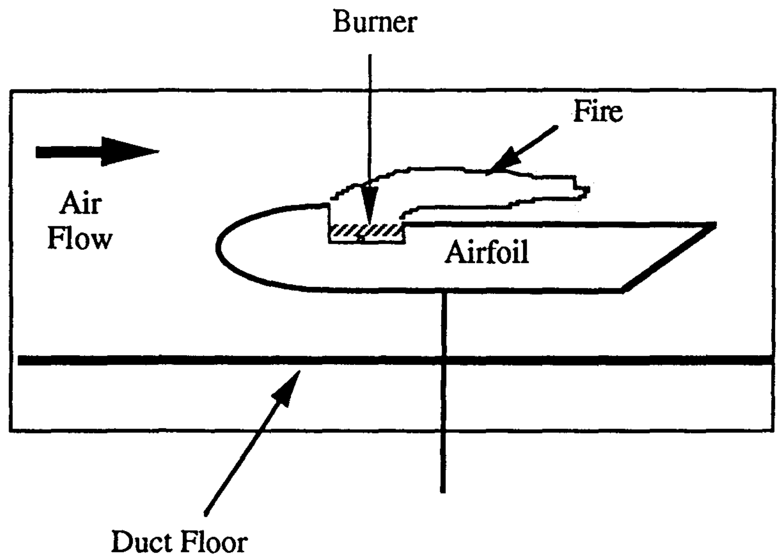

Figure 3. SPGG test section.

Assume, now, that a number of canisters of each formulation are available to test, and each burns such that the molar flow is constant over the burn time. For the first formulation, a number of tests are performed and the critical air flow is found below which the flame will be extinguished during a canister discharge. The characteristic mixing time (τ_f) in Equation (1) is a function of velocity, and since its functionality will be determined with the compressed gas experiments, it is known. The agent concentration is known and discharge duration is fixed. Thus, X_∞ (the minimum agent concentration) can be calculated. For the second canister, the molar flow is lower, but the discharge duration is longer. The critical air flow below which the flame is extinguished is obtained after a number of discharges. Again, given the velocity, the characteristic mixing time is obtained, and with the agent concentration and discharge duration, the minimum agent concentration is calculated. For this simple case, it is expected that the minimum agent concentration for the first canister is lower than the minimum agent concentration for the second canister. If the canister discharge rate is not constant (which it is likely not to be), the analysis is somewhat more complex.

Evaluations of SPGGs for directed discharge applications must proceed on an *ad hoc* basis. The nature of the effluent flow is as important (or more so) than the chemical constituents. Proper discharge nozzle design, which depends on the application, in addition to sufficient agent mass flow are required for such cases. The test fixture proposed here will still be valuable in screening particular formulations for their efficacy once they reach the fire zone.

Closure

There remains a risk that the aerosol and SPGG screening facilities developed in this research may be incompatible with a particular agent or discharge design. Because the field application may be so specialized or complex, there is also the risk that the results of the screen may not properly predict full-scale performance. These risks do not argue against the development of smaller-scale screens, but in fact support them, since what is learned in the laboratory experiments can be applied towards the design of meaningful intermediate-scale facilities and full-scale test programs.

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