FLAME SUPPRESSION EFFECTIVENESS OF HALON ALTERNATIVES[1]

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The elimination of new production of halon 1301 has forced the manufacturers, owners, and users of aircraft to search for an alternative. The program described here developed performance screens for candidate agents as a means to identify the best chemicals for subsequent full-scale aircraft fire extinguishment evaluation at Wright-Patterson Air Force Base[2]. The discriminating factors could be lumped into four categories: agent dispersion characteristics, required storage volume, environmental factors, and operational issues. The results presented in this abstract are limited to the flame suppression experiments, which directly impact the storage volume of agent required. However, the dispersion of the agents in cold-flow experiments varied more extensively than the amount of the agent required for flame suppression. The behavior of the chemical as it leaves the storage vessel (typically pressurized with N_2 at 4.1 MPa) and subsequently flashes or breaks into droplets, evaporates, and mixes with ambient air is critical, and can render an agent which requires less mass to extinguish a laboratory flame less effective in suppressing an actual aircraft fire. The reader is referred to the thorough discussion by Pitts et al.[3] for details of the agent dispersion screening process.

Four different flame suppression facilities were designed with the objective of examining the flame extinction properties of the agents over the whole range of conditions likely to be encountered by aircraft in flight: (1) an opposed-flow diffusion flame (OFDF) burner, (2) a cup burner, (3) a turbulent spray burner, and (4) a detonation/deflagration tube. A core of eleven gaseous fluorocarbons (FCs), hydrofluorocarbons (HFCs), and hydrochlorofluorocarbons (HCFCs) were examined in all four facilities and compared to the performance of N_2 and CF_3Br. Iodotrifluoromethane and sodium bicarbonate powder were examined in three of the flames, and twenty additional compounds were evaluated in the cup burner alone. Air was the oxidizer and the fuels included ethene, propane, heptane, JP-5, JP-8, and two hydraulic fluids. While the absolute amount of agent necessary to quench the flames varied with the operating conditions in each facility, a single parameter called the volume factor, VF, was chosen to compare the relative suppression performance of the various agents. VF is an estimate of the liquid volume in the storage vessel for a given agent normalized by the liquid volume of halon 1301, and is found from the respective saturated liquid densities and the measurements of mass fraction, Y_i, found in each laboratory burner.

The cup burner apparatus produces a co-flowing flame burning gaseous and liquid fuels, and can handle gaseous, liquid and powder suppressants. CF_3I and the bromine containing compounds were generally very effective on both a mole and a mass basis. The absolute agent concentration at extinction was found to agree well with measurements made in the OFDF[4]. The turbulent spray burner was useful for comparing the performance of extinguishing agents in transient operation, with the agent delivery system able to control accurately the injection period between 20 and 910 ms. Of the chemicals evaluated in the turbulent spray burner, $NaHCO_3$ was the only compound more effective than halon 1301, and CF_3I required the least mass and volume of the gaseous agents. The gaseous agents performed better in the turbulent spray burner relative to halon 1301 than was

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[2] *Evaluation of Alternative In-flight Fire Suppressants for Full-scale Testing in Simulated Aircraft Engine Nacelles and Dry Bays*, W.L. Grosshandler, R.G. Gann and W.M. Pitts, editors, NIST Special Publication 861, Gaithersburg, MD, April 1994.

[3] "Fluid Dynamics of Agent Discharge," W.M. Pitts, J.C. Yang, G.Gmurczyk, L.Y. Cooper, W.L. Grosshandler, and C. Presser, Section 3, *ibid.*

[4] "Flame Suppression Effectiveness," A. Hamins, G. Gmurczyk, W.L. Grosshandler, R.G. Rehwoldt, I. Vazquez, T. Cleary, C. Presser and K. Seshadri, Section 3, *ibid.*

predicted from cup burner measurements. The experimental conditions in the deflagration/detonation tube differed significantly from those found in the other burners. The main qualitative difference was the occurrence of a strong shock wave ahead of the flame which influenced the chemical state of the pure combustible mixture in the driver section and the mixture containing an agent in the test section.

Table 1 compares the volume factors for each apparatus (sodium bicarbonate is expressed on a mass basis). The OFDF values were found from the ambient temperature experiments with JP-8, taken at a strain rate of 100 s^{-1}. The cup burner values were measured with heptane as the fuel. For the spray burner, VF was calculated from the mass of agent injected in the ambient temperature JP-8 experiments. The performance in the detonation tube was based upon the average of the mass of agent required to reduce the pressure ratio by one half and to 10% of the maximum increase, with data restricted to the lean experiments. The uncertainty in the values of VF is estimated to be ± 10%.

The following observations summarize the results of the flame suppression study:

- The relative ranking of the agents depends upon whether one uses a mass basis or a volume basis.
- The relative ranking of the agents varies only slightly among the three non-premixed burners, but a substantially different ranking results from the premixed deflagration/detonation apparatus.
- The relative ranking of the agents is not much affected by the fuel type or air temperature.
- The quantity of agent required to suppress a flame varies with the type of burner generally in the following order: cup burner ≈ low strain OFDF > spray burner > high strain OFDF > deflagration tube.
- The quantity of agent required to suppress a non-premixed flame varies somewhat with the type of fuel in the following order: propane > heptane > JP-8 > JP-5 > HF-5606 > HF-83282.
- The quantity of agent required to suppress the turbulent spray flame increases with decreasing rate of agent injection.
- The quantity of agent required to attenuate the shock wave speed and pressure ratio in the deflagration/detonation tube varies with equivalence ratio, sometimes increasing as one goes from lean to stoichiometric and sometimes decreasing.

Table 1. Volume factors for flame suppression in different apparatus

Agent	OFDF	Cup Burner	Spray Burner	Deflag. Tube
$NaHCO_3$ (mass)	0.23	0.45	0.85	--
CF_3I	--	0.9	0.8	1.4
HCFC-124	2.5	2.2	1.8	1.5
HCFC-22	3.0	2.8	1.8	2.5
HFC-236fa	3.1	2.3	1.8	1.4
HFC-227	3.2	2.4	1.8	1.4
FC-218	3.6	2.8	2.1	1.2
FC-3110	3.9	2.6	2.1	1.4
HFC-134a	4.0	2.8	2.0	1.8
HFC-125	4.1	2.8	2.0	1.7
FC-318	4.1	2.6	2.0	1.4
HFC-32/125	5.3	3.5	2.5	2.5
FC-116	7.1	6.0	4.0	2.5