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FIRE SUPPRESSION RESEARCH IN THE UNITED STATES: AN OVERVIEW

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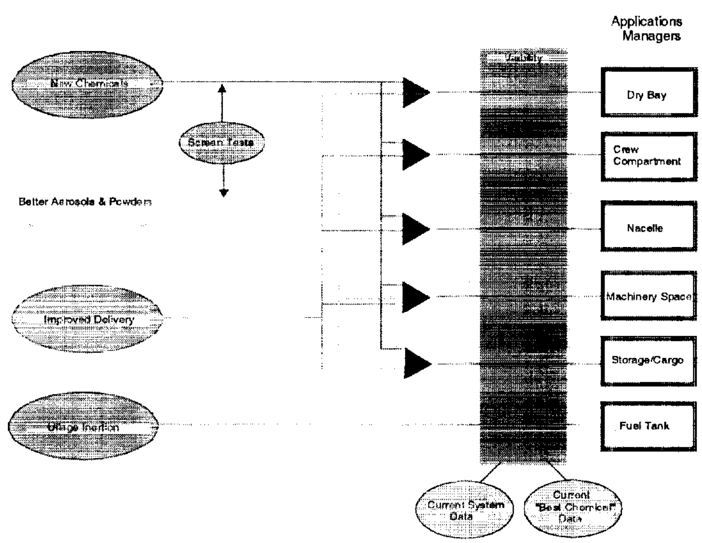
ABSTRACT

Since the 14th UJNR meeting, significant progress has been made in understanding fire suppression. Most of this has been derived for halon-like applications, with some efforts on suppression by water and water-based solutions.

1. HALON ALTERNATIVES

Most U.S. research on halon alternatives is sponsored by the Department of Defense (DoD) Next Generation Fire Suppression Technology Program (NGP). This program has the goal of developing by 2005 halon 1301 replacement technologies for aircraft, ships, and land combat vehicles (Figure 1). Beginning in FY2000, the NGP will focus on fire suppression needs for aircraft dry bays and engine nacelles: new chemicals, verified precepts for improved suppressant delivery, and validated modeling to guide the selection of optimal dispensing conditions, nozzle locations, etc. Additional information on the NGP can be found at www.dtic.mil/ngp/ and in the endnotes in [1,2]. Much of the overall U.S. research progress has been reported in the Proceedings of the annual Halon Options Technical Working Conference [3,4].

Figure 1. NGP Research on Retrofitable Fire Suppression Technologies



In searching for new chemicals that perform as well as CF_3Br but without the environmental limitation, a comprehensive view of fire suppression has emerged. Catalytic agents, such as CF_3Br and metal compounds, reduce the superequilibrium levels of flame radicals toward equilibrium levels. Adding heat capacity reduces the flame temperature and thus the flame reaction rates below the level needed to sustain combustion. Thus there is a non-linear relationship between the chemical (catalytic) and thermal contributions of a suppressant.

There are new findings on several promising suppressant chemicals:

$H_3COC_4F_9$ (HFE-7100) was shown to be an efficient non-chemically-active suppressant [5]. About twice the mole percent of the gas as halon 1301 vapor is needed to suppress a flame. As an aerosol, only half the halon 1301 vapor level is needed.

Small mole fractions (*ca.* 10^{-4}) of $Fe(CO)_5$ are near the ideal limit at reducing premixed flame velocities [6,7]. At higher concentrations the agent becomes less efficient, as the active iron species condense to form relatively inactive particles. Ferrocene is nearly identical, indicating no dependence on the binding of the iron. Manganese-containing compounds behave similarly, but are 5-7 times less efficient at reducing burning velocity.

Also of interest are tropodegradable bromocarbons [8]. Bromoalkenes will have atmospheric lifetimes of a few days. A series of bromofluoroalkenes and bromofluoroamines generally had cup burner extinguishment values below about 0.04 mole fraction in air. Rats exposed for 30 min to 0.05 mole fraction (in air) of four of the compounds (1-bromo-3,3,3-trifluoropropene, 2-bromo-3,3,3-trifluoropropene, 4-bromo-3,3,4,4-tetrafluorobutene, and 2-bromo-3,3,4,4,4-pentafluorobutene) showed no ill effects. The Ames tests were also negative.

A set of efficient, accurate screening tests for new suppressant chemicals is near completion:

The Dispersed Liquid Agent Screen (DLAS), based on the Tsuji diffusion burner, is now in use both to obtain suppression efficiency data and as a research tool. [9]. The Transient Application, Recirculating Pool Fire (TARPF), a screening tool for the effectiveness of suppressants that are impulsively discharged [10], is nearly complete. An injection system for the effluent from solid propellant gas generators has been tested.

A tiered screening system for environmental impact, toxicity, and materials compatibility has been developed [12]. A physiologically based pharmacokinetic (PBPK) model of a human system to describe the short-term inhalation of volatile halogenated hydrocarbons and their transport to the bloodstream is nearing completion. Development of a computational screen for a suppressant's atmospheric lifetime and infrared absorption is continuing. Calculations for the reactions of OH with several fluoroethanes and the ethers derived from them have reproduced the experimental trend [13].

The suppression of ignition in electrically energized equipment is a problem of high impact. The temperature of a metal surface needed for ignition of ethylene/air mixtures rose in the presence of a number of thermally active suppressants (N_2, IG-541, HFC-23, HFC-227ea, FC-218, and FC-3-3-10). Near 1000 °C surface temperature, the ignition prevention levels of all these agents exceeded current design concentrations [14].

Nearly all current suppressants of interest emerge from pressurized storage containers as liquids or powders, along with a gaseous component. The properties of the aerosol determine efficiency of transport effectiveness to the fire, of suppression of gaseous and condensed-phase fuels, and of ignition prevention.

Studies of water droplets injected into non-premixed flames have identified the optimal droplet diameter ranges for suppression. Droplets with diameters ≤ 18 μm evaporated, a desirable behavior; many with diameters ≥ 30 μm survived and were much less efficient at suppression. Droplet diameter variation was found to have a minimal impact on flame spread rate across a PMMA surface. However, buoyancy has a significant impact on the droplet velocities and diameters [15].

It is possible to adsorb a suppressant onto an inert host for transport to the fire: a mass fraction of 33 % of $Fe(CO)_5$ onto zeolites and up to 200 % aerogels. At 250 °C a large fraction of the $Fe(CO)_5$ is desorbed. Flame tests will determine whether the desorption is fast enough.

The complement to identifying new agents is improving their transport to the fire site.

Replacement fluids must function within the existing distribution plumbing for cost reasons. A new computer code for prediction of two-phase fire suppressant flows plus pressurizing gas in distribution piping is now nominally complete, and a test facility has been constructed to verify the results. Measurement capabilities include instantaneous mass flow of fluid during transient discharge from the source vessel, fluid temperatures along the discharge pipe, and void fraction. Numerous data have been collected using HFC-227ea.

Halon 1301 systems are overdesigned to effect good agent distribution in cluttered spaces. For new agents, these penalties need to be quantified for different fuels and obstruction shapes. A model based on a well-stirred reactor accurately captures the experimental time for agent entrainment into the recirculation zone. A suppression system should provide a critical agent concentration for at least 3-4 times this mixing time [16].

NGP research is developing new types of solid propellant gas generators (SPGGs) that have high flame suppression efficiency, yet little negative impact on the environment or the weapons system. The first of these formulations are aimed at both reducing SPGG combustion temperatures and increasing flame suppression efficiency.

The success of new technologies requires instrumentation to identify their effectiveness.

NGP researchers have developed a time-resolved (10 ms), multi-point, fieldable, fiber-coupled, near-infrared tunable diode laser-based sensor for measurement of combustible mixtures of oxygen and hydrocarbon fuels (heptane and JP-8) before, during and after the fire suppression event of 250 ms duration.

Research is also continuing on developing instrumentation for measuring agent concentration with a 10 ms time response, fast enough for quantification of the transient agent concentration during the suppression of the fastest fires involving military systems [17].

A decision to retrofit a fire suppression system (or not) must address a number of objective cost factors and subjective value factors. Accordingly, the NGP is developing a methodology to quantify a fire suppression technology by its total life cycle cost and to enable superimposing on this a subjective value system [18].

Research on fuel tank inerting has been limited. The Air Force is considering the use of CF_3I.

II. WATER AND WATER-BASED SUPPRESSANTS

There has also been research progress in learning how aqueous suppressants are effective and applying the new knowledge to their selection and use.

Computational modeling of sprays of sprinkler droplets has been used to learn about their penetration of fire plumes. Increasing droplet size is more effective than increasing spray momentum [19]. New work [20], reported in this proceedings, is underway to model and predict the water density resulting from a discharged sprinkler.

Prompted by observations that residential sprinkler delivery rates have dropped below the norm, additional research and testing has been performed [21]. Modifications to the delivery criteria and test procedures are pending at UL and NFPA.

The first validated prediction tool for multiple sprinkler activation was produced [22]. The study included the interactions with vents and draft curtains.

Other sprinkler-related research issues under consideration include: measurement of the corrosion of sprinkler piping systems, understanding the effect of ceiling height on sprinkler performance, and evaluating the available tools and technology for designing performance based sprinkler systems.

Aqueous solutions of protein-based foams and gels are sprayed onto surfaces (such as exterior walls of houses) as a temporary measure to prevent ignition from exterior fires. Testing methodologies for these solutions have also been evaluated for their ability to differentiate their effectiveness on Class B and Class D fires relative to water [23,24]. Laboratory experiments have provided guidance for capitalizing on their thermal and ablative properties [25].

REFERENCES

1. Gann, R.G., "Next Generation Fire Suppression Technology Program (NGP): 1998 Technical Highlights," NISTIR 6366, National Institute of Standards and Technology, Gaithersburg, 9 p., 1999.
2. Gann, R.G., "Next Generation Fire Suppression Technology Program (NGP): 1999 Annual Report," and contained references, National Institute of Standards and Technology, Gaithersburg, in press, 2000; also available from the NGP web site.
3. *Proceedings of 1998 Halon Options Technical Working Conference,* New Mexico Engineering Research Institute, Albuquerque, 1998.
4. *Proceedings of 1999 Halon Options Technical Working Conference,* New Mexico Engineering Research Institute, Albuquerque, 1999.
5. Pitts, W.M., Yang, J.C., Huber, M.L., and Blevins, L.G., "Characterization and Identification of Super-Effective Thermal Fire Extinguishing Agents—First Annual Report," NISTIR 6414, National Institute of Standards and Technology, 58 pp., 1999.
6. Babushok, V.I., Tsang, W., Linteris, G.T., and Reinelt, D., "Chemical Limits to Flame Inhibition," *Combustion and Flame* **115**, 551-560, 1998.
7. Rumminger, M., Reinelt, D., Babushok, V., and Linteris, G. T., "Numerical Study of the Inhibition of Premixed and Diffusion Flames by Iron Pentacarbonyl," *Combustion and Flame* **116**, 207-219, 1999.
8. Tapscott, R.E. and Mather, J.D., "Tropodegradable Fluorocarbon Replacements for Ozone Depleting and Global Warming Chemicals," *Journal of Fluorine Chemistry*, submitted for publication, 1999.
9. Yang, J.C., Donnelly, M.K., Prive, N.C., and Grosshandler, W.L., "Dispersed Liquid Agent Fire Suppression Screen Apparatus," NISTIR 6319, National Institute of Standards and Technology, 1999.
10. Grosshandler, W.L., Hamins, A., McGrattan, K.B., and Presser, C., "Transient Agent, Recirculating Pool Fire (TARPF) Suppression Screen," in Beall, K, ed., Annual Conference on Fire Research: *Book of Abstract*, NISTIR 6242, National Institute of Standards and Technology, Gaithersburg, MD, 1998.
11. Vinegar, A., Jepson, G., Cisneros, M., Rubenstein, R., and Brock, W. "Setting Safe Exposure Limits for Halon Replacement Chemicals Using Physiologically-based Pharmacokinetic Modeling," *Inhalation Toxicology,* in preparation.
12. Nyden, M.R. and Skaggs, S.R., "*Screening Methods for Agent Compatibility with People, Materials, and the Environment*," NISTIR 6323, National Institute of Standards and Technology, 1999.
13. Orkin, V.L., Villenave, E., Huie, R.E., and Kurylo, M.J., "Atmospheric Lifetimes and Global Warming Potentials of Hydrofluoroethers: Reactivity Toward OH, UV Spectra, and IR Absorption Cross Sections," *J. Phys. Chem. A*, in press, 1999.

14. Braun, E., Womeldorf, C.A., and Grosshandler, W.L., " Suppression Concentration of Clean Agents Exposed to a Continuously Energized Heated Metal Surface," *Fire Safety journal* **33**, 141-152 (1999).

15. Oke, H.P., Sojka, P.E., and Sivathanu, Y. R., "Flame Spread over Polymethylmethacrylate with Opposed Air Flow," *Fire Safety Journal*, submitted for publication, 1999.

16. Takahashi, F., Schmoll, W. J., Strader, E., and Belovich, V. M., "Suppression of Step-Stabilized Nonpremixed Flames," *Combustion and Flame,* accepted for publication (1999).

17. McNesby, K.L., Skaggs, R.R., Miziolek, A.E., Clay, M., Hoke, S., and Miser, C.S., "Diode Laser-Based Measurements of Hydrogen Fluoride Gas During Chemical Suppression of Fires," *App. Phys. B* **67**, 443-447, 1998.

18. Bennett, M.V., "Use of the Department of Defense Operational Requirements-Based Casualty Assessment (ORCA) Software System to Determine Occupant Response to Fire and the Extinguishment Process," *Human Behavior in Fire, Proceedings of the First International Symposium*, Belfast, Northern Ireland, 1998.

19. Nam, S., "Numerical Simulation of the Penetration of Sprinkler Sprays," *Fire Safety Journal* **32**, 307-329 (1999).

20. Sheppard, D.A., Gandhi, P.D., and Lueptow, R.M., "Understanding Sprinkler Sprays: Trajectory analysis," this proceedings.

21. Bill, R. and Anderson, S., "An Evaluation of the UL 1626 Residential Sprinkler Fire Test," FMRC report 0003000723, 1999.

22. McGrattan, K.B., Hamins, A., and Stroup, D., "Sprinkler, Smoke and Heat Vent, Draft Curtain Interaction – Large Scale Experiments and Model Development," NISTR 6196-1, National Institute of Standards and Technology, 1998.

23. Madrzykowski, D., and Stroup, D.W., "Demonstration of Biodegradable, Environmentally Safe, Non-Toxic Fire Suppression Liquids," NISTIR 6191, National Institute of Standards and Technology, 1998.

24. Grand, A.F., "A Study of the Effectiveness of Fire Resistant Durable Agents on Residential Siding Using the ICAL Apparatus," this proceedings.

25. Tafreshi, A.M., and di Marzo, M., "Foams and Gels as Fire protection Agents," *Fire Safety Journal* **33**, 295-306 (1999).