Halon Replacement Research at the Naval Research Laboratory

James W. Fleming, Paul Papas[a], and Ronald S. Sheinson
Navy Technology Center for Safety and Survivability
Naval Research Laboratory, Code 6185
Washington, DC, USA 20375-5342

Abstract

The Combustion Dynamics Section of the Navy Technology Center for Safety and Survivability is actively involved in addressing US Navy needs for fire protection, concentrating on the effectiveness of current and future fire extinguishing agents, with the responsibility to recommend and help design Navy shipboard total flooding fire suppression systems.

The program has recently been expanded to integrate investigations of more fundamental questions into laboratory research concerning agent effectiveness, particularly addressing the chemistry and physics of flame propagation, enhancement and inhibition. This expansion includes research in opposed jet reactors and in flat flames using laser based diagnostics to follow the behavior of laboratory flames under varying flow fields and chemistry and the modeling of these same systems. Other section and Center research areas, in addition to fire extinguishment testing, include liquefied agent pipe flow and gas phase distribution, the effects of obstacles on fluid flows, and solid aerosol and water mist experiments and modeling. This paper describes our progress in integrating our enhanced laboratory and modeling research program in support of existing applied programs related to fire suppression. This integrated R&D program will directly aid Halon replacement shipboard implementation and greatly aid continuing search for more optimum replacement agents and systems.

INTRODUCTION

The NRL Halon replacement research program is driven by US Navy needs, to recommend and help design Navy shipboard total flooding fire suppression systems [1-2]. Funding for these projects comes from the Naval Sea Systems Command and the Office of

---

[a] NRC/NRL Postdoctoral Associate 1994 - present

Research sponsored by Naval Sea Systems Command and Office of Naval Research

Naval Research. Ultimately, the product of this research will be an agent/system that suppresses fires and meets the requirements for weight and volume limitations, time for response, toxicity to personnel, etc. Currently there are no acceptable agents that can satisfy legislated environmental constraints and serve as drop-in replacements for existing Halon 1301 based Navy Ship platforms. It appears unlikely that there are suitable near term drop-ins. Compromises will be required. New systems will not only involve new agents but also redesigned delivery and storage facilities as well. The search for suitable agents should produce data on the effectiveness of a large set of agents and delivery systems as well as a list of scenarios where these systems will or will not be effective. In addition, the development and/or verification of a suitable chemical mechanism data base should also be accomplished. The chemical mechanism will be employed in agent/fire interaction models to predict selected agent behavior, amount of agent required for suppression, time for suppression, and areas of applicability. The ability to predict behavior for any agent with any fire scenario is the ultimate payoff.

The research program includes small scale laboratory evaluation of agents, intermediate compartment size evaluation under several realistic total flooding fire scenarios and full scale shipboard evaluation and verification. Laboratory experimental efforts which support the overall goal of the section span the range from agent efficiency measurements in atmospheric pressure cup burners to chemical mechanism Verification in low pressure premixed flames. Various optical techniques including emission, laser induced fluorescence (LIF), infra-red absorbance, and Raman spectroscopy will be employed. Such non-intrusive techniques allow for the identification and monitoring of flame species, characterization of agent/flame(fire) interactions, and the measurement of temperature. Detection of potentially problematic product species such as the acids (e.g. HF) will also be monitored.

LABORATORY FLAMES

A. CUP BURNER STUDIES

The need for alternatives to environment damaging Halon 1301 (CF_3Br) for fire suppression in military systems and other related industrial and commercial fire suppression is driving the search for other agents and/or extinguishment systems. Special consideration for military applications include highly flammable liquids in occupied spaces, purposely going in "harm's way," and the requirement to maintain operational capability on a moveable platform. To screen new compounds for their potential usefulness as suppression agents, experiments are performed in the NRL cup burner. The objective of these studies is to determine the effect of potential (and current) agents on extinguishing fires. Such studies not only allow for a ranking of the effectiveness of chosen agents, but also provide quantitative information on the chemical contribution to the extinction process versus the physical effect of the added agent [3]. In this way, cup burner experiments assist in screening/selecting potential replacements [4]. The concentration of hydrogen halide acid (HF) can also be measured for those fluorine containing agents. Since both laboratory and larger scale studies are in-house, there is potentially more interaction and information feedback possible than is often possible when similar efforts are carried out in separate facilities. This arrangement will enhance the technical interaction with outside laboratories (primarily combustion) which is critical in maintaining experimental expertise, knowledge, and technical relevance.

B. LOW PRESSURE PREMIXED FLAT FLAME STUDIES

Studies are planned to be carried out in low pressure premixed flat flames in order to gain a more complete understanding of the critical reactions in the combustion of fuel systems in the presence of flame suppressants. Information is required on the agent participation in the initiation, propagation, consumption and final release of energy and products in the combustion process. The information gained will allow a better understanding of agent/fire interaction and product formation. Although the chemical suppression effect of agents versus the physical effect can be quantified in the cup burner studies, understanding the reactions and species responsible for the chemical effect requires more fundamental studies. Such experimental studies are greatly aided by computer modeling.

Computer flame modeling requires a suitable chemical reaction mechanism including kinetic rate coefficients, and thermodynamic and transport data on the flame species. An assessment must be made as to how well the chemical mechanism is able to predict experimental observations for current systems. This is done at NRL in low pressure premixed flat flames. The low pressure environment provides the spatial resolution to allow the use of laser diagnostic probes to detail temperature profiles as well as monitor the behavior of the flame species responsible for the formation and characteristics of the flame. At low pressure (e.g. 10 torr), the contribution of chemical reactions to the flame development become comparable to and often dominate the contribution due to transport processes. Thus, the low pressure environment allows one to better study the relevant chemistry in these systems. Fuel consumption can be followed as well as the hydrocarbon radicals which result from the fuel decomposition. The fuel concentration as a function of height above the burner can be related to the flame speed and is another experimental parameter which aids in the assessment of the predictive capability of a chosen chemical mechanism. Low pressure flames have been successfully modeled by solving the one-dimensional equations of mass, momentum, and energy conservation as a function of height above the burner [5].

Premixed flames at 10 torr often display a flame zone 1 cm "thick." Thus, the spatial development of the flame zone can be easily probed using a variety of optical techniques: emission, laser induced fluorescence, multiphoton ionization, Raman scattering, Coherent anti-Stokes Raman Scattering, Degenerate Four Wave Mixing, and to some extent infra-red absorption. Each of these techniques has been employed in this environment.

There are several published chemical mechanisms for a limited number of systems which have been tested against a variety of experimental conditions. However, for many of the agent/flame systems that need to be investigated in this program, the "best" mechanism must still rely on estimates for many of the reaction rate coefficients. Sensitivity analysis and graphical display of specie production profiles will greatly assist in the assessment of the significance of a single reaction or set of reactions. Where experimentally feasible, critical reactions will be investigated experimentally in conjunction with the Chemical Dynamics Branch at NRL to provide rate coefficient information. This type of analysis can also be used to exclude reactions which are for the most part only minor players in the chemical reaction mechanism.

C. COUNTERFLOW DIFFUSION FLAME STUDIES

Laboratory investigations of premixed flames will provide quantitative information on the chemical and physical effectiveness of suppression agents. Experiments are also planned to investigate atmospheric pressure diffusion flames in a counterflow burner. The counterflow arrangement permits the examination of diffusion flames as a function of strain rate, i.e. velocity gradient in the flow field. Real fires can exhibit laminar (low strain rate) to highly turbulent (high strain rate) behavior. Agent suppression effectiveness varies as a function of the strain rate. Strain rate data is needed in order to model many systems, especially where there exists convective and forced ventilated flow fields.

The opposed jet counterflow configuration is well suited for producing diffusion (non-premixed), strained conditions which are characteristic of many practical fires. Experimentally, two opposing jets, one of fuel, the other oxidizer (and in our case with added agents) are ignited and form an essentially one dimensional flame with a stagnation plane at the "intersection" of the two gas streams. The configuration has been successfully modeled by solving the one-dimensional equations of mass, momentum, and energy conservation along the stagnation streamline. The maximum flame temperature of this counterflow diffusion flame will decrease with increasing strain rate. The extinction state is determined as the strain rate value at which any further increase will not sustain a stable flame. Laser Doppler Velocimetry (LDV) will be employed to map out the flow field and laser induced fluorescence probing will provide temperature as well as key radical concentration data. Although flames have been studied using this approach, there is minimal data on inhibited flames. Our studies will focus on providing data for this critical area.

AGENT DELIVERY SYSTEM DEVELOPMENT

There are other areas of technology that bear on fire protection, many of which are operating simultaneously in any given scenario. Such issues as agent flow properties; discharge time; fluid flow in pipes; nozzle type; agent distribution and the effect of inhomogeneities; the interaction of sprays, droplets, or solid particles with flame sheets; discharge turbulence and fire induced convection; fire type, size, and location; compartment size and boundary conditions; presence of obstacles; and influence of ventilation will potentially impact the performance of an agent delivery system. Many of these issues lend themselves to investigation using computer modeling/simulation. Detailed experimental results on agent discharge pipe flow characteristics, agent concentration distributions in the compartment as a function of time and location, extinguishment and reignition data, and acid (HF) concentrations as a function of time (including during the discharge interval) have been collected. In addition, characterization of water mist and pyrogenic solid aerosols have also been performed. We are actively addressing the understanding of several of these issues in collaboration with the NRL modeling community and outside laboratories.

FIRE EXTINGUISHMENT TESTING

In addition to the laboratory studies outlined above, Navy real scale fire extinguishment tests are conducted at the Chesapeake Bay Detachment facility (intermediate scale testing) and aboard the ex-USS SHADWELL (full scale testing). The real scale tests involve the coordination of a large number of personnel with varying technical backgrounds. The laboratory studies outlined above are designed to provide the required information and fundamental understanding about the anticipated behavior of agents/systems in these real scale tests and ultimately in use on actual Navy platforms.

SUMMARY

This paper has outlined a program integrating technology based studies that are planned to provide a better understanding of fire extinguishment processes relevant to Navy applications. This integrated research program will directly aid Halon replacement shipboard implementation and greatly aid continuing search for more optimum replacement agents and systems. These studies are to be carried out in laboratory scale burners. Flame modeling calculations will be an integral part of the expanded program. The ultimate goal of the program is to add a higher level of technical understanding and predictive capability to guide the Navy's short and long range fire protection research and development programs.

REFERENCES

1. 'Laboratory Through Full Scale: The Navy Halon Total Flooding Replacement Program", Ronald S. Sheinson, Preprints of the American Chemical Society Division of Environmental Chemistry, Washington, DC, August 21-26, 1994, pp. 759-762.
2. 'Fire Suppression Research in the U.S. Navy," Homer W. Carhart, Ronald S. Sheinson, Patricia A. Tatem, and James R. Lugar, Proceedings of the First International Conference on Fire Suppression Research, Stockholm, Sweden, 5-8 May 1992, pp. 337-357.
3. "Fire Suppression Agent Effectiveness Prediction and Implications for Fire Extinguishment Tests", Ronald S. Sheinson and Samuel P. Baldwin, Proceedings of the Eastern States Section, Combustion Institute, Princeton, NJ, 25-27 October 1993, pp. 483-486.
4. 'The Physical and Chemical Action of Fire Suppressants", R.S. Sheinson, J.E. Penner-Hahn, and D. Indritz, Fire Safety Journal, 15: 437-450 (1989).
5. 'Comparison of Species Profiles Between O, and NO, Oxidizers in Premixed Methane Flames," Bradley A. Williams and James W. Fleming, Combustion and Flame 100:571-590 (1995).