PERFORMANCE DATA ON COLD TEMPERATURE DISPERSION OF CF_3I

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INTRODUCTION

Trifluoroiodomethane (CF_3I) has been proposed as a potential replacement for Halon 1301 in aircraft engine nacelle and dry bay fire protection applications [1, 2]. The potential use of CF_3I in fuel tank ullage inerting has also been considered recently [3]. Before CF_3I can be considered as a potential drop-in replacement. several operational issues need to be addressed or re-examined. The proposed work is intended to examine one important aspect related to the application of CF_3I: cold temperature discharge of CF_3I into a sub-zero environment.

Table 1 lists some of the physical properties of CF_3I and CF_3Br. Since CF_3I has a normal boiling point of −22 °C, the dispersion of CF_3I into air at temperatures down to −40 °C may not be as effective as halon 1301 which has a normal boiling point of −57.8 °C. Although discharge of cold CF_3I (chilled to about −40 "C) into a compartment at ambient room temperature has been examined at NIST [2], the discharge of cold CF_3I into a cold compartment has not been performed, or at least has not been documented in open literature. In order to assure that there is no substantial deterioration in dispersion performance of CF_3I under cold temperature applications. discharge tests in a simulated fire compartment at the lowest temperatures expected in service should be conducted.

TABLE 1. SELECTED PHYSICAL PROPERTIES OF CF_3I AND CF_3BR [2].

Agent	Molecular weight (kg/mol)	T_b (°C)	T_c (°C)	P_c (MPa)	ρ_c (kg/m^3)	ΔH_v (kJ/kg)
CF_3I	0.196	−22.0	122.0	4.04	871	106
CF_3Br	0.149	−57.8	67.0	4.02	145	111

T_b is the normal boiling point: T_c is the critical temperature; P_c is the critical pressure: ρ_c is the critical density: ΔH_v is the latent heat of vaporization at T_b.

An example is used to illustrate the importance of studying the discharge and dispersion of CF_3I in a sub-zero environment. Consider a 3 L container with 4.5 kg of CF_3I pressurized with nitrogen to 4.12 MPa (600 psia) at 22 °C. If this container with agent is cooled down to −40 °C, the final pressure of the container is estimated to be 2.8 MPa using the computer code (PROFISSY) developed by the National Institute of Standards and Technology [2]. Assuming the discharge of the liquid agent from the container is an isentropic process from the initial container pressure to atmospheric pressure, the final states of the agent can be calculated using the computer code (FISSYCS), which is a derivative of PROFISSY [2]. Table 2 tabulates the calculated results. Comparing the two initial conditions, the liquid fraction (the percent of agent/nitrogen mixture still remained in liquid phase after the isentropic expansion process) is substantially higher at

-40 °C. Such a high liquid fraction should have a significant effect on the subsequent evaporation and dispersion of the agent/nitrogen mixture.

Irrespective of the break-up mechanisms, the liquid core from the discharge nozzle will be disintegrated subsequently into small droplets. At 22 °C, the liquid droplets rapidly evaporate into vapor, thus facilitating the agent dispersion. However, at −40 °C, the liquid droplets evaporate slowly, and a two-phase (droplet-gas) flow persists longer, thus hindering the effective dispersion of agent droplets especially when baffles are present. This point is further illustrated in Figure 1, which shows the calculated evaporation time as a function of ambient temperature for three initial droplet diameters when the ambient agent mass fraction is zero. The evaporation time was calculated using the classical d^2-law for droplet evaporation [e.g., 4]. For simplicity and illustrative purposes, neat CF_3I droplets were used in the calculations. When the ambient agent mass fraction is not zero, the evaporation time of an agent droplet is longer because of the reduction in the concentration gradient for mass transfer. Figure 2 shows the effect of ambient CF_3I mass fraction on the evaporation time of a 100 µm droplet. A mass fraction of 0.316 corresponds to twice the cup-burner value (mole fraction of 0.032 [1]) of CF_3I. Note that in an actual discharge, the agent droplets will not be evaporating at zero ambient agent mass fraction.

To examine the dispersion of CF_3I in a cold environment, a new experimental facility will be designed and built. The experimental apparatus, the test matrix, and the test procedure to conduct the proposed discharge tests at sub-zero temperature are described in detail below.

TABLE 2. LIQUID FRACTION OF CF_3I/N_2 MIXTURE AFTER ISENTROPIC EXPANSION TO 0.101 mpa.

Initial conditions	Liquid fraction (%)
4.12 MPa, 22 °C	70
2.8 MPa, −40 °C	90

PROPOSED EXPERIMENTAL APPARATUS AND TEST PROCEDURE

The proposed experimental apparatus will be a simulated engine nacelle with airflow and with an annulus cross-sectional area and length scalable to a real nacelle. Figure 3 is a schematic of the proposed experimental fixture, which consists of a compartment with baffles, an agent release port, observation windows, and sampling ports. The compartment has a configuration and dimensions commensurate with a typical engine nacelle. The annulus has an inside diameter of −0.5 m and an outside diameter of ~1 m, resulting in a cross-sectional area of -0.59 m^2. The length (−2 m) of the compartment is comparable to the distance between the agent injection port and the downstream end of a typical engine nacelle. The compartment is made of stainless steel sheet metal.

The entire test facility will be placed inside a large environmental chamber. Agent discharge experiments will be conducted at the lowest achievable temperature (-40 °C) in the environmental chamber. Thermocouples will be placed on several locations inside the simulator to ensure

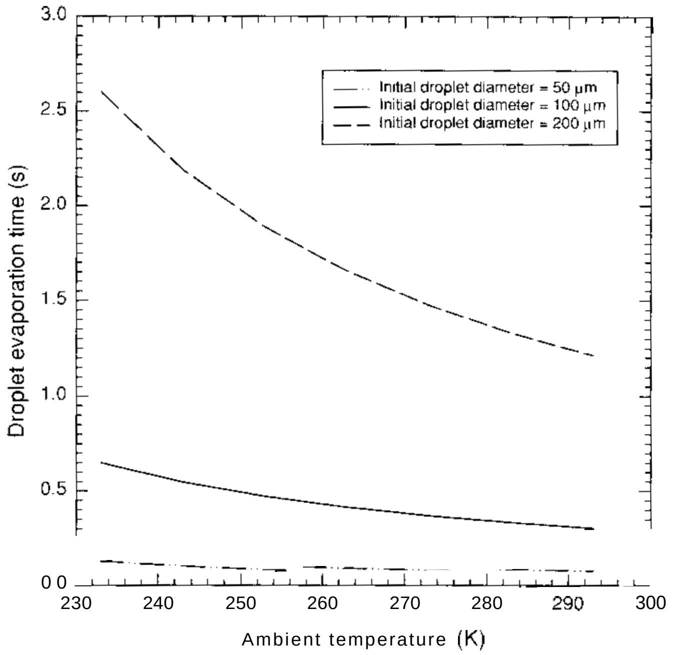

Figure 1. Evaporation time of a CF_3I droplet as a function of ambient temperature when the ambient agent mass fraction is zero.

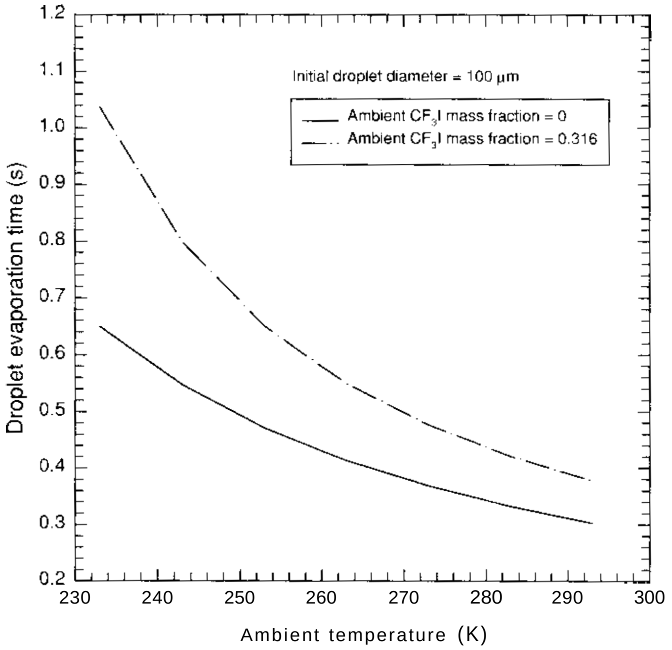

Figure 2. Effect of ambient agent mass fraction on the evaporation time of a 100 μm CF_3I droplet at various ambient temperatures.

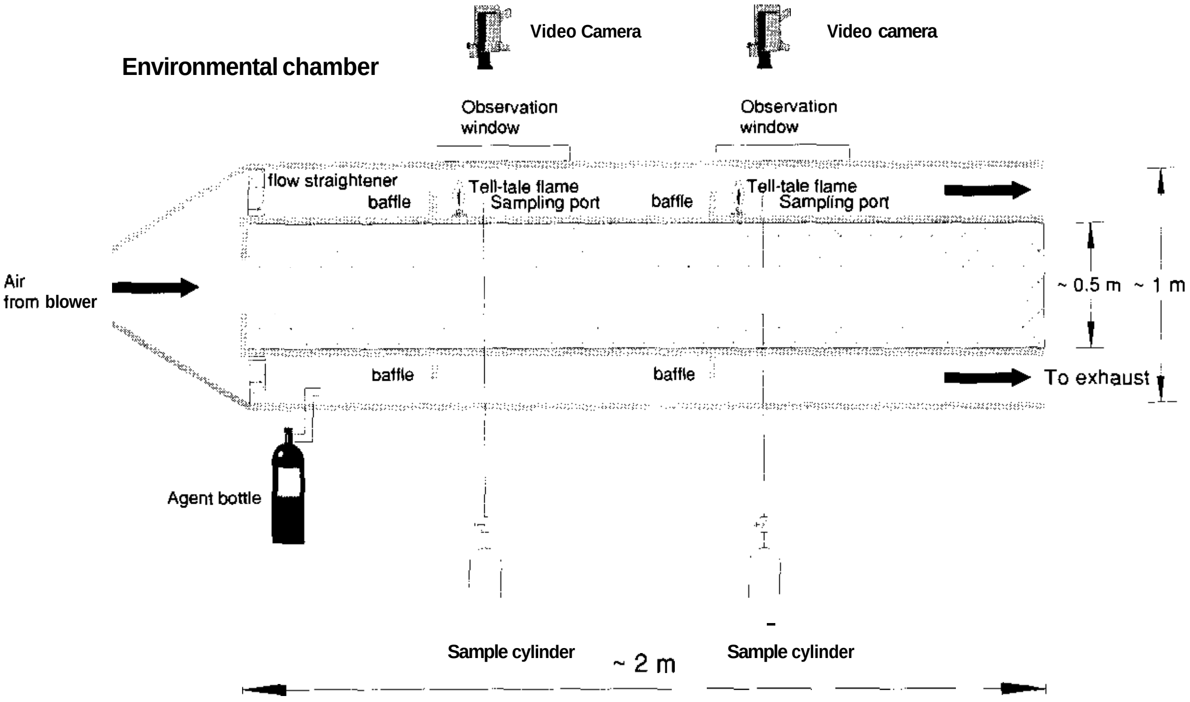

Figure 3. Proposed experimental apparatus for cold temperature agent dispersion.

thermal equilibrium with the compartment environment before a test is performed. Air flow through the compartment will be provided by a variable-speed blower.

The observations of the extinction of several tell-tale gaseous jet flames placed strategically at several locations in the compartment with video cameras will be used to assess *qualitatively* how well the agent is dispersed. These flames, which will be lit (possibly remotely) immediately before the discharge of CF_3I, are used as markers to detect the amval of the agent to these locations. Extinction of a flame indicates the presence of sufficient agent concentration at that location. In addition, samples will be collected for –0.5 s immediately after agent discharge at locations close to the tell-tale flames using evacuated sample cylinders and subsequently analyzed for CF_3I using an FTIR. The integrated temporal CF_3I concentration measurements will be used to evaluate the uniformity of the agent dispersion in the compartment.

Experiments using pure nitrogen will also be conducted to separate the effect of the pressurization gas (nitrogen) on flame extinction alone. If the flames cannot be extinguished by pure nitrogen, then one can infer that the extinguishment of these small flames is due to the presence of the agent. Baseline suppression performance will also be established using a room temperature environment.

Given the simulated nacelle volume, the amount of agent required for a fixed injection period (–0.5 s for typical nacelle applications) can be estimated using the generic nacelle modeling results in Gann [2]. The preparation of CF_3I/dissolved nitrogen mixtures follows the procedure as described in Gann [2]. The release of the agent can be achieved using one of the several mechanisms (e.g., a Marotta valve or a squib). Agent injection time will be tailored using an orifice plate at the exit of the valve. Table 3 lists the proposed experimental matrix. Two representative air flows (~1 kg/s and –0.3kg/s) will be used in the tests.

TABLE 3. PROPOSED EXPERIMENTAL MATRIX FOR COLD TEMPERATURE AGENT DISPERSION.

Initial conditions of vessel (half filled)	Conditions of vessel before discharge	Conditions in simulated fire compartment
22 °C and 4.12 MPa	–40 °C at prevailing P^{*}	22 °C
22 °C and 4.12 MPa	–40 °C at prevailing $P^{\S}$	– 40 °C §
22 °C and 4.12 MPa	22 °C and 4.12 MPa	22 °C (baseline)
22 °C and 2.15 MPa	–40 "C at prevailing P^{*}	22 °C
22 "C and 2.75 MPa	–40 °C at prevailing $P^{\S}$	– 40 °C §
22 °C and 2.75 MPa	22 °C and 2.75 MPa	22 °C (baseline)

* Dry ice will be used to chill the vessel.

§ Tests will he performed in an environmental chamber.

The deliverables of the proposed research will be the performance data on CF_3I dispersion in a clustered compartment at –40 "C. The results from the CF_3I dispersion tests under –40 °C will determine if CF_3I can be effectively dispersed in an engine nacelle under temperature well below its normal boiling point.

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