Measurements of Some Thermodynamic Properties of Alternative Agent/Nitrogen Mixtures[1]

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ABSTRACT

This study is a continuation of a U.S. Air Force/Navy/Army and FAA sponsored program, currently being conducted at NIST, to further evaluate some thermodynamic properties of the four selected alternative agents for in-flight aircraft fire protection in both dry bays and engine nacelles. The four selected agents are HFC-227ea, CF_3I, FC-218, and HFC-125.

To prepare a conventional halon 1301 bottle for in-flight fire protection, the bottle is normally filled with liquid halon 1301 to about half of the bottle volume and is then pressurized with nitrogen at room temperature. Depending on the applications, the charge pressure can vary (from 2.4 to 4.1 MPa or higher). The purpose of using the nitrogen to increase the ullage pressure is to provide extra driving force to facilitate the expulsion of the liquid agent from the bottle upon release. However, depending on the location of the bottle aboard an aircraft (which in turn determines the ambient temperature of the bottle), the total pressure in the bottle will change because the vapor pressure of the agent and the solubility of the nitrogen in the liquid agent vary with temperature. In addition, the final pressure at elevated temperature also depends on the fill density of the bottle (i.e., how much agent is dispensed into the bottle). When the bottle is exposed to very high ambient temperature (e.g., near an engine), the bottle pressure can be very high such that the structural integrity of the bottle may be compromised. On the other hand, when the bottle experiences very low temperature (e.g., at high altitude), the bottle has to have sufficient residual pressure to discharge the liquid agent from the bottle when needed. Therefore, measurements of the lower and upper limits for the bottle pressure are necessary in order to determine whether existing halon 1301 bottles can be used for "drop-in" replacement agents or to provide safety guidelines on bottle design for retrofitting for the alternative agents.

This study consists of several parts. The first part involved measurements of the amount of nitrogen required to pressurize the bottle, filled with a pre-determined amount of agent, to a specified pressure at room temperature. The second part of this work dealt with measurements of the final pressure of an agent/nitrogen mixture when the bottle was exposed to different ambient temperatures (from -60°C to 150°C). Finally, measurements obtained from the above experiments were used to fit the binary interaction coefficients in the computer program PROFISSY (Properties of Fire Suppression Systems). The code was developed to calculate pressure-temperature characteristics for the four selected agents. Other agents can also be incorporated easily into the program.

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For measurements of the amount of nitrogen required to pressurize the vessel to a specified pressure and the thermodynamic properties of agent/nitrogen mixtures at -60°C, the experimental apparatus consisted of a stainless steel vessel equipped with a fill valve, a thermocouple and a pressure transducer. The experimental procedure is as follows. The set-up was evacuated for at least 10 minutes, and the vessel was then filled with an amount of agent equivalent to half or two-thirds of the vessel volume. By immersing the vessel in dry ice, liquid agent was dispensed into the vessel by condensing gaseous agent from the supply bottle. Attempt was made to remove noncondensible gases, if there were any, in the liquid agents by boiling off the liquid agent under low pressure and recondensing the agent vapor by using a liquid nitrogen trap. For CF_3I, an additional purification step was taken which involved passing of CF_3I vapor through beds of molecular sieves and potassium hydroxide before the agent vapor was condensed for collection. The vessel was then pressurized with nitrogen to either 2.75 or 4.1 MPa. Agitating the vessel constantly during pressurization facilitated reaching of the final equilibrium pressure. The amount of nitrogen was determined by weighing the apparatus. This amount corresponded to the sum of the nitrogen mass in the vapor phase as well as that dissolved in the liquid agent. The vessel was then immersed in a low temperature bath at -60°C. The final internal pressure of the vessel was recorded from the pressure transducer read-out when the internal temperature of the vessel had reached thermal equilibrium with the temperature of the bath.

For high temperature measurements, a high pressure stainless steel vessel with sight glass windows together with a pressure transducer and a circulating pump were used. The windows on the vessel and pump facilitated the filling of the vessel and the mixing of nitrogen with the agent respectively. The entire set-up was placed inside a temperature-controlled oven and heated to 150°C. The final pressure in the vessel was then recorded. The same pressures and fill densities as those in the cold temperature experiments were used.

The binary interaction coefficients in the computer code PROFISSY were then determined by matching the experimental results with those calculated by assuming different values for the binary interaction coefficients. Once the right binary interaction coefficients are established, the code can be used to generate pressure-temperature characteristics for the agent/nitrogen mixtures. Only four pieces of information are required to run the program: (1) agent mass, (2) vessel volume, (3) fill temperature, and (4) either nitrogen mass needed to pressurize the vessel or the fill pressure of the vessel.