ABSTRACT

INERTING CONCENTRATIONS OF FIRE EXTINGUISHING AGENTS ON LITHIUM BATTERY FLAMMABLE GASES

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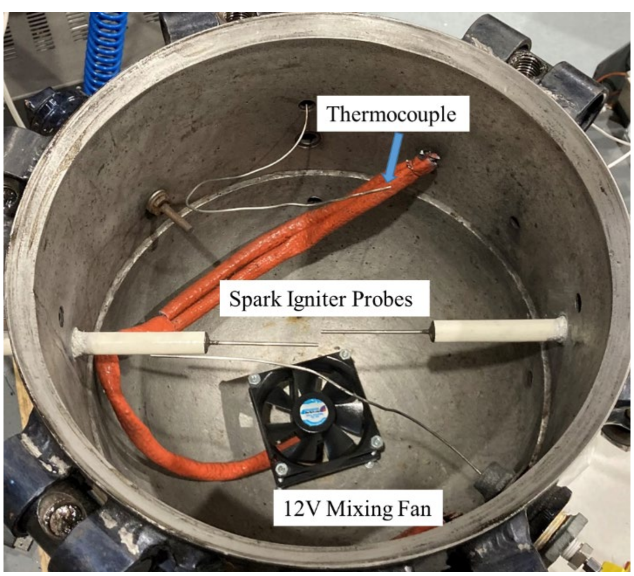
There are many types of commercially available fire extinguishing agents used for a wide range of applications. The specific extinguishing agent used for a given application depends on the fire threat and design criteria. For class-C cargo compartments on aircraft, a gaseous flooding agent is used. Halon 1301 is currently the sole extinguishing agent being used in class-C aircraft cargo compartments. It requires a replacement due to its harm to the environment.

The fire threat within cargo compartments is changing compared to the threat that existed when aircraft class-C cargo compartment requirements were first established. The quantity of lithium batteries being shipped in cargo compartments is increasing each year. Lithium batteries can spontaneously catch fire or undergo thermal runaway where they release a significant quantity of flammable gas composed of hydrogen, carbon monoxide and hydrocarbons.

The objective of this study was to evaluate the effectiveness of Halon 1301 and some of its potential replacements against several flammable gases including lithium battery thermal runaway gases.

Experiments were performed in a 21.15-liter pressure vessel with a gas inlet port, a spark igniter to initiate reactions, a mixing fan, and pressure sensors used to measure gas quantities and quantify pressure rise.

Simulations were conducted in Cantera, a chemical kinetics modeling software, to find laminar flame speed and adiabatic flame temperature for various gas mixtures. Those parameters were used as an estimate to predict inerting concentrations needed for the various gas mixtures. The kinetic, thermodynamic, and transport mechanisms used in the simulations were taken from literature.



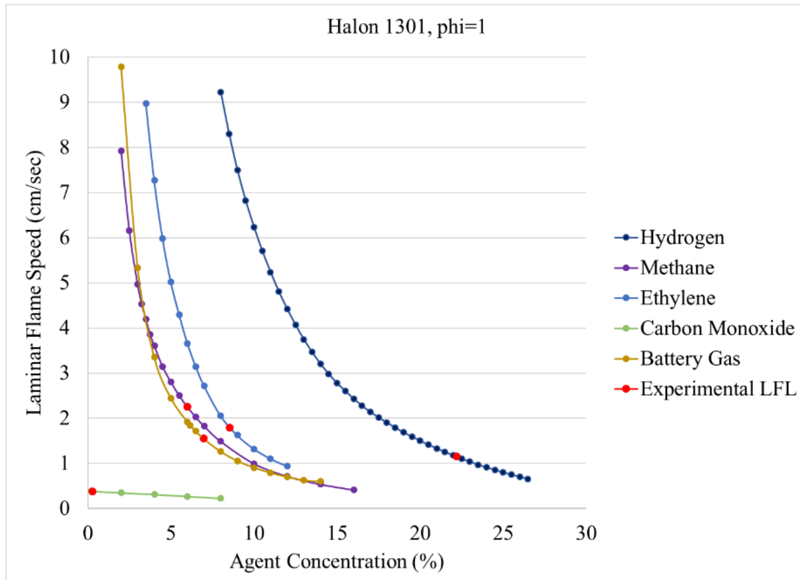
First, experiments were performed that compared and verified pressure-rise bell curve profiles for various flammable gases with air. Repeatability experiments were also performed with methane to verify that pressure rise profiles could be repeated with minimal error.

Next, experiments were performed with sub-inerting concentrations of Halon 1301 with hydrogen and sub-inerting concentrations of CO_2 with hydrogen to explore any possible over-pressure events.

Finally, experiments and simulations were performed with Halon 1301 and various potential replacements to Halon 1301 to find their inerting concentrations against various individual flammable gases and mixed flammable gases vented from lithium battery thermal runaway. Simulations were also performed to predict the effectiveness of various extinguishing agents at elevated temperatures and decreased pressures.

Initial results showed that the test setup produced repeatable data and that the flammable gas bell curves were consistent with literature. Later, experiments with Halon 1301 and hydrogen produced overpressures for certain concentrations but carbon dioxide with hydrogen did not.

Results from the final portion of this study showed that laminar flame speed and adiabatic flame temperature were reasonable predictors of extinguishing agent inerting concentrations. Halon 1301 was found to be extremely effective against carbon monoxide ignition compared to other extinguishing agents, however it was also least effective against hydrogen than all other flammable gases tested.



Results showed that nitrogen and carbon dioxide were 1.45% and 1.31% more effective against lithium battery gases at sea level pressure than at altitude. When carbon dioxide and nitrogen were compared, at altitude, 28.57% more carbon dioxide than nitrogen was required to inert battery gas on a mass basis. However, on a volume basis, 34.3% more nitrogen was required than carbon dioxide.

For most gas combinations, the greatest concentrations of extinguishing agent was required at a flammable gas equivalence ratio of one. Exceptions to this were mixtures of hydrogen with carbon dioxide, hydrogen with Halon 1301, and 2-BTP/CO_2 with hydrogen, methane, ethylene, and battery gas.

Simulations predicted that a much greater quantity of extinguishing agent would be required at elevated temperatures of 200°C compared to 25°C. Up to 7% more Halon 1301, 6.7% more 2-BTP/CO_2, 10% more CO_2 and 10.9% more N_2 would be required to inert battery gas.

At altitude pressure of 25,000 feet, the difference was less pronounced. Experimental results showed that only 1.45% and 1.31% more nitrogen and carbon dioxide was required to inert battery gas. Simulations were conducted to predict the required inerting concentrations of other agents and mixtures. The results also showed that there was an insignificant difference between required inerting concentrations at sea level vs. altitude.