Mixing and Evaporation of Potential Halon 1301 Replacement Agents Following Release from Pressurized Bottles'

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ABSTRACT

The mixing and evaporation behavior of releases of potential halon-replacements for fire suppression have been investigated as part of a USAF-administered Halon Replacement Project. Ten agents have been considered: FC-31-10, FC-318, HCFC-124, HFC-227, HFC-134a, FC-218, HCFC-22, HFC-125, HFC-32, and HFC-32/HFC-125 azeotrope. For comparison purposes, halon 1301 has also been investigated.

The weighed amount of agent to be tested was placed in a 500 cm^3 vessel constructed from either plexiglass or stainless steel. The vessel was equipped with a burst disk designed to release at a preset pressure which was generally **4.1** MPa (41 atmospheres). After filling with the agent, an experiment was initiated by pressurizing the vessel with nitrogen to the bursting pressure.

A number of diagnostics were used to characterize the dynamics and mixing behavior outside the vessel. High-speed films provided visualization of the flows. A laser extinction technique allowed measurements of the velocity for the downstream edge of the released material. Dynamic pressure transducers located near the vessel orifice and on the flow centerline 1.3 m downstream of the vessel provided qualitative characterization of the degree of vaporization. **A** sonically-choked hot-film probe provided additional characterization of the flow at the downstream location.

The results show that the velocities for the agent flows as well as their mixing behaviors are strongly dependent on the degree of superheating of the agent. A new mechanism for agent dispersion involving the impingement of a high-speed nitrogen flow on the liquid stream has also been identified. The degree of vaporization for a given downstream position is found to depend on the degree of superheating, the Jakob number, and the molar density of the liquid.

It is shown that effective dispersion and evaporation of these agents is enhanced by high superheats, high Jakob numbers, and a low molar density for the liquid.

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AGENTS INVESTIGATED

AGENT	FORMULA	B.P. (°C)
HFC-236fa	$CF_3CH_2CF_3$	-1.5
FC-31-10	C_4F_{10}	-2.1
FC-318	cyclo-C_4F_8	-5.8
HCFC-124	$CHFClCF_3$	-12.0
HFC-227ea	C_3HF_7	-15.2
HFC-134a	CH_2FCF_3	-26.2
FC-218	C_3F_8	-36.8
HCFC-22	CHF_2Cl	-40.7
HFC-125	CHF_2CF_3	-48.4
HFC-32/ HFC-125	CF_2H_2/ CHF_2CF_3	-52.5
halon 1301	CF_3Br	-58.0

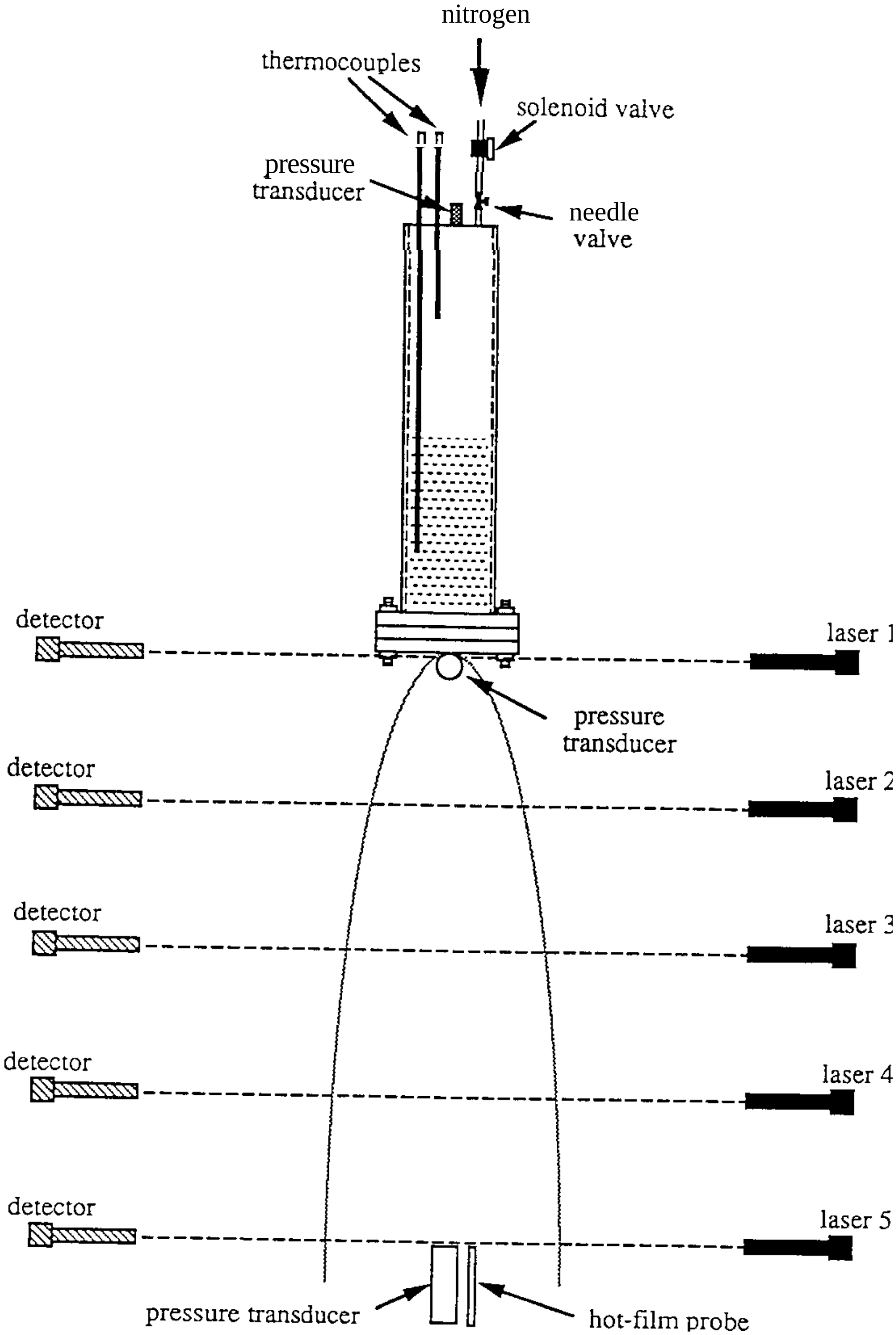


Figure 1. Experimental arrangement.

EXPERIMENTAL MEASUREMENTS

- Release from 0.5×10^{-3} m^3 vessel equipped with pressure-actuated burst disk. Experiment initiated by adding nitrogen to vessel.

- High-speed Photography.

- Pressure Measurements.
  - Piezoelectric pressure measurements within vessel.
  - Piezoelectric transducer facing flow located 13 mm downstream and 46 mm from flow centerline.
  - Piezoelectric transducer facing flow located on centerline 1.3 m downstream of vessel.
  - External gauges record dynamic pressures.

- Laser Extinction Measurements.
  - Series of five lasers and detectors spaced nominally 0.3 m apart which pass through the flow centerline perpendicular to the flow.
  - Calculation of average velocity of two-phase flow between the laser beams.

- Aspirated Hot-Film hemometer.
  - Located on jet centerline 1.3 from vessel.
  - Responds to variations in temperature and composition.
  - High heat losses as the result of evaporation in probe of two-phase flow.

- Data recorded at 25 kHz using computer data acquisition.

OBSERVATIONS FROM HIGH-SPEED FILMS OF RELEASES NEAR VESSEL EXIT

- Rapid radial expansions of two-phase flow at start and end of agent release.

- High-boiling point agents flows develop into a liquid stream.

- Low-boiling point agents vaporized very rapidly on leaving vessel and create two-phase flows with wide spreading angles.

- Only low-boiling agents cause dynamic pressure increases at the near-field pressure transducer during the early expansion period. Strong flashing behavior is required. Rapid spreading of all agents near the end of the liquid release results in large dynamic-pressure increases. This observation is attributed to the interaction of the two-phase jet flow with a high-speed nitrogen flow which develops immediately following liquid release.

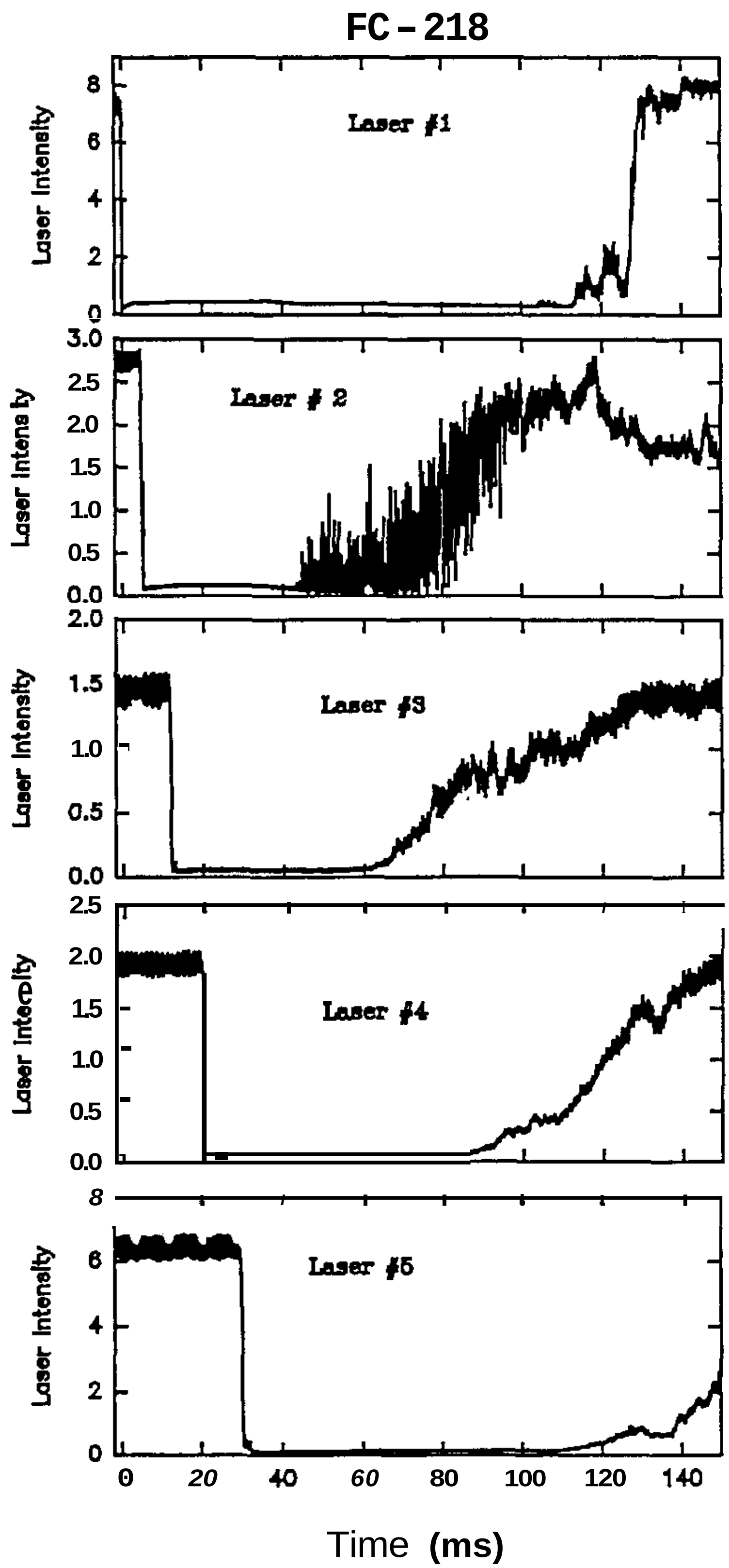
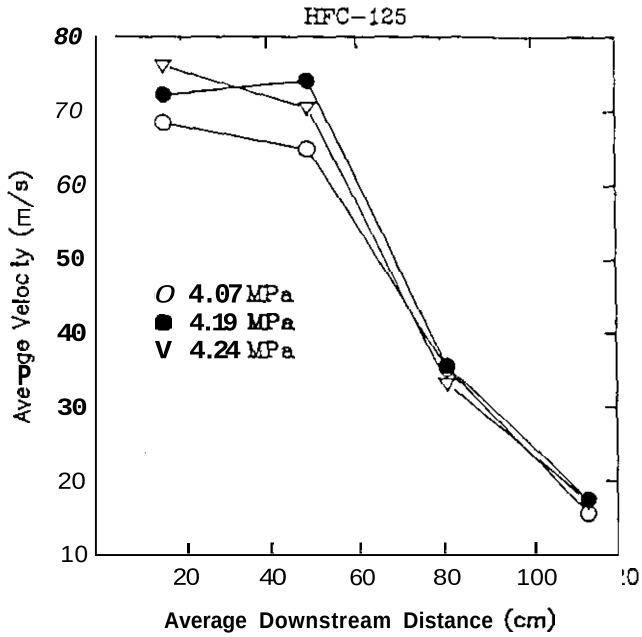
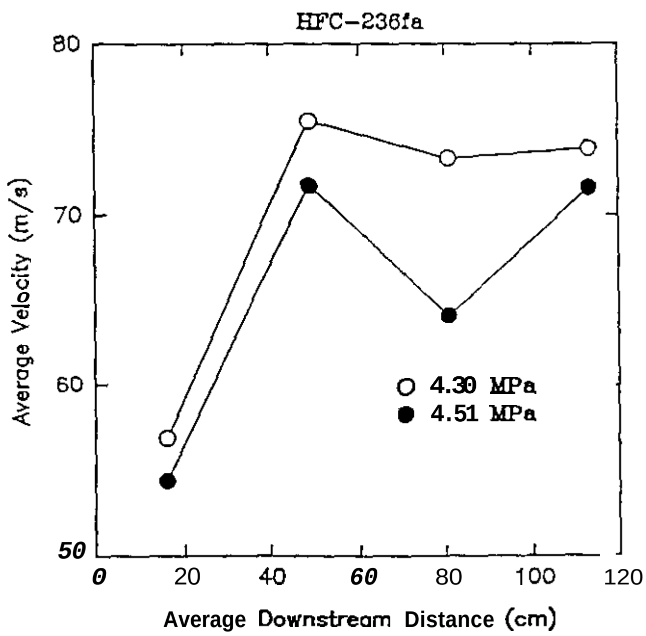


Figure 2. Laser extinction measurements following release of FC-218 from a vessel pressurized to 4.1 MPa. Zero time is when the disk burst. Lasers are separated by nominally 0.3 m. Laser #1 is located just downstream of the vessel exit orifice.



Fiyrc 4. Average velocities as function of downstream distance for releases of HFC-125. Velocity near vessel is considerably higher than the liquid flaw velocity through the vessel orifice.

Similar behaviors were observed for the four low boiling-point alternative agents--FC-218, HCFC-22, HFC-125, and the HFC-125/HFC-32 mixture–as well as halon 1301.



Fiyrc 3. Average velocities as function of downstream distance for releases of HFC-236fa. Velocity near vessel is roughly equal to the liquid flow velocity through the vessel orifice. Note that velocities increase well downstream of the vessel.

Similar behaviors were observed for the six highest boiling-point alternative agents--HFC-236fa, FC-31-10, FC-318, HCFC-124, HFC-227ea and HFC-134a.

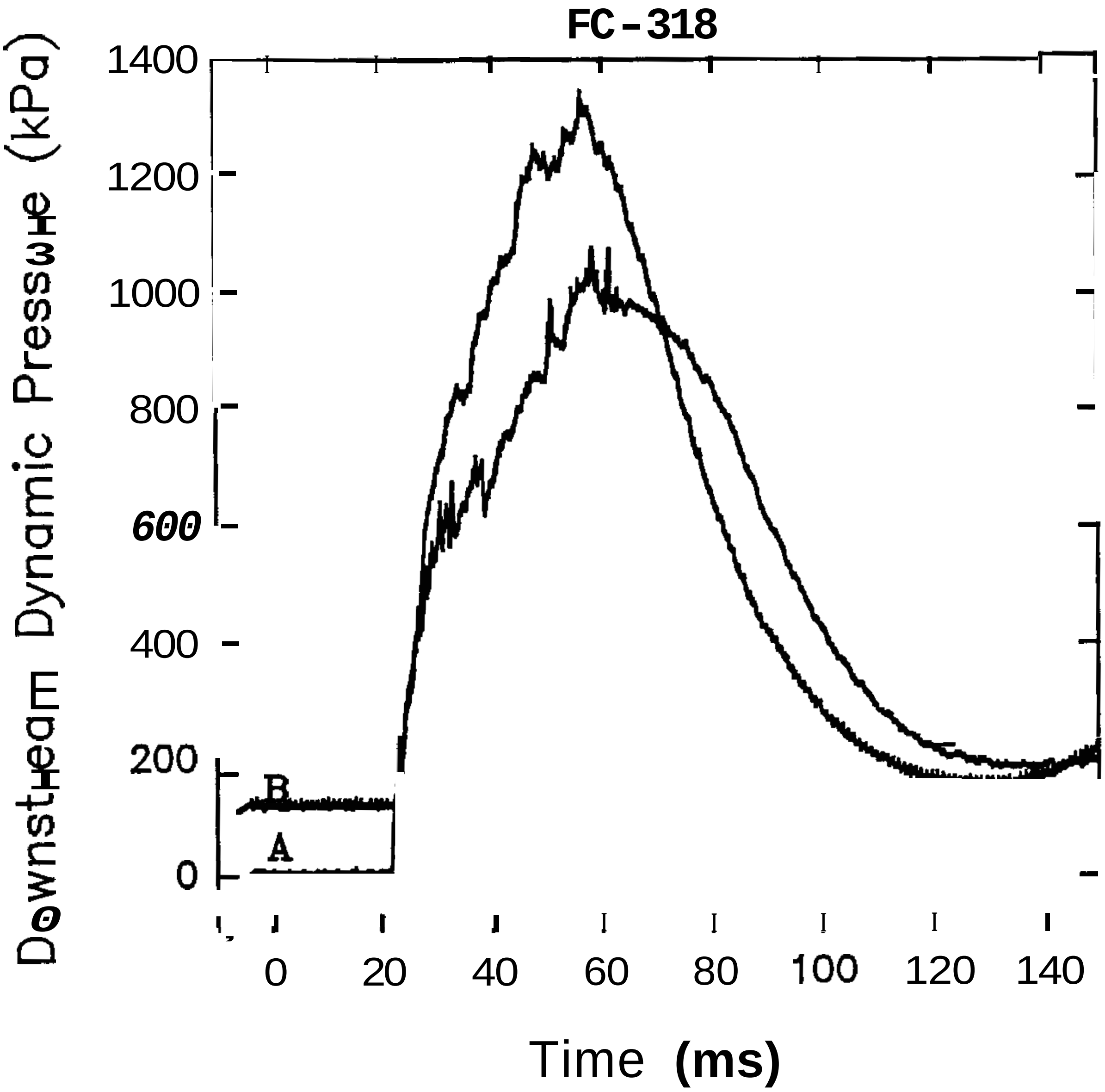


Figure 5. Dynamic pressures measured 1.3 m from the vessel following releases of FC-318 from pressurized vessels. Note that curve B is offset by 100 kPa. High dynamic pressures indicate that a large fraction of the agent reaching the measurement position is in a liquid state.

Similar behaviors were observed for the six highest boiling-point alternative agents--HFC-236fa, FC-31-10, FC-318, HCFC-124, HFC-227ea, and HFC-134a.

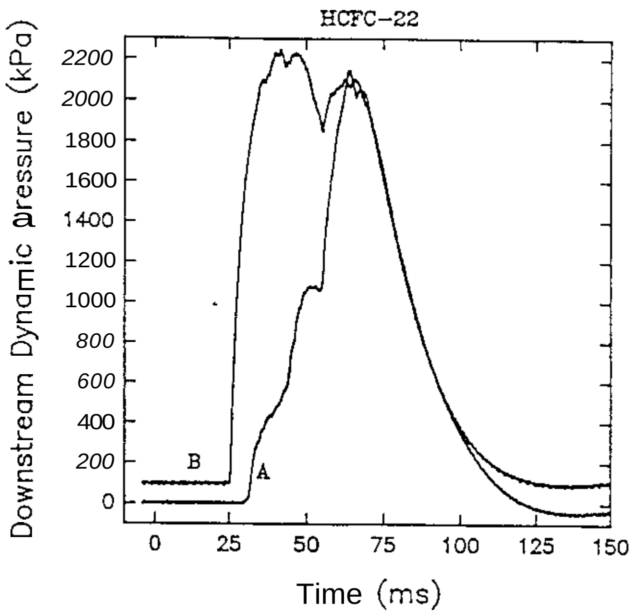


Figure 7. Dynamic pressures measured 1.3 m from the vessel following releases of HCFC-22 from pressurized vessels. Note that curve B is offset by 100 kPa. The extremely high dynamic pressures indicate that a large fraction of the agent reaching the measurement position is in a liquid state.

Similar dynamic pressure behaviors were observed for the two low boiling-point alternative agents HCFC-22 and the HFC-125/HFC-32 mixture. Contrast the behavior with that for FC-218 in Figure 6.

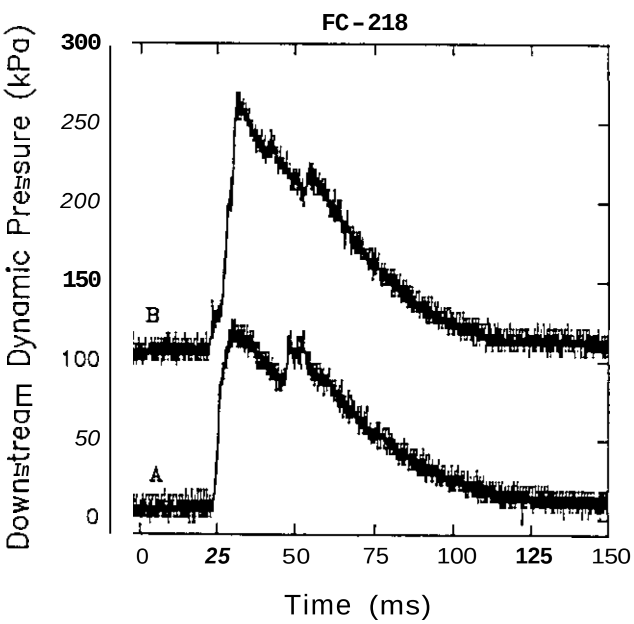


Figure 6. Dynamic pressures measured 1.3 m from the vessel following releases of FC-218 from pressurized vessels. Note that curve B is offset by 100 kPa. Relatively low dynamic pressures indicate that a large fraction of the original agent has been vaporized.

Similar dynamic pressure behaviors were observed for the low boiling-point alternative agent HFC-125 and halon 1301. Contrast the behavior with that for HCFC-22 in Fiyrc 7.

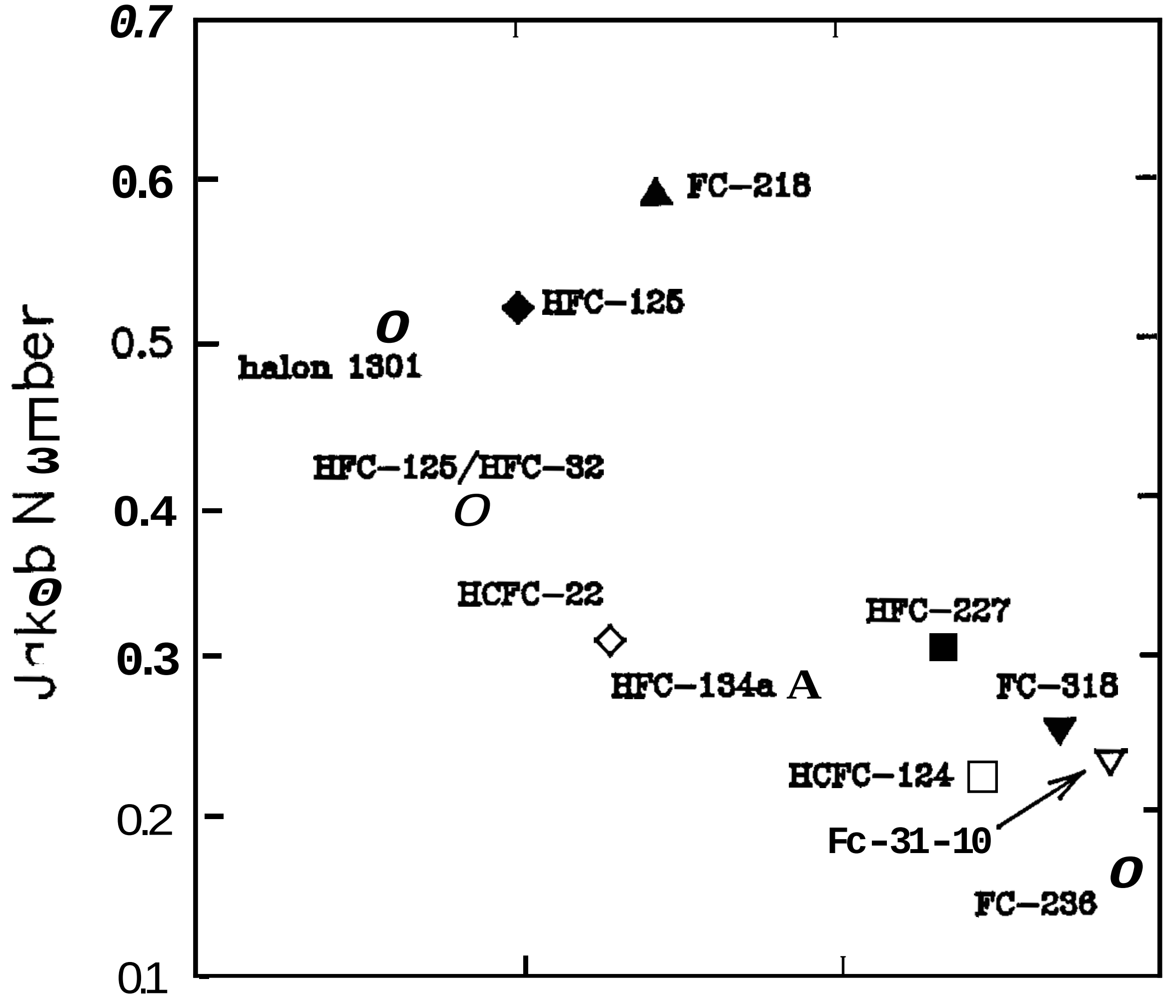


Figure 8. Jakob number as a function of boiling point for room temperature release of alternative agents and halon 1301. The Jakob number (Ja) is the ratio of the sensible heat within the liquid, which can be extracted from the liquid by cooling to its boiling point for the ambient pressure, and the heat of vaporization, ΔH_{vap}, for the liquid. In other words, it is the maximum fraction of a liquid which can be vaporized adiabatically.

Moles in Liquid for 2/3-Full Vessel of Low-Boiling Point Alternative Agents and Halon 1301

Agent	Moles in Liquid
FC-218	2.3
HCFC-22	5.2
HFC-125	3.3
HFC-125/HFC-32	4.6
halon 1301	3.6

Due to the larger gas volumes of released HCFC-22 and the HFC-125/HFC-32 mixture, less air will be entrained and vaporization due to heat transfer from the entrained air will be reduced compared to that for FC-218, HFC-125, and halon 1301.

CONCLUSIONS

- Rapid dispersion of two-phase flow takes place when strong and rapid flashing occurs. Flashing times decrease and flashing strength increases with the degree of superheating (i.e., difference between agent liquid temperature and ambient agent boiling point). Lower boiling-point agents are more efficiently dispersed.

- Rapid vaporization of liquid agent aided by high Jakob number.

- Number of moles in liquid determines vaporized gas volume. Mixing with the ambient surroundings, which supplies heat for the vaporization of the liquid fraction of a two-phase flow, increases with decreasing agent gas volume.

- Due to low overheats and Jakob numbers, higher boiling-point agents were not well dispersed or vaporized during the experiments.

- Lower boiling-point agents showed very different vaporization behaviors due to differences in Jakob numbers and liquid molar volumes. FC-218 and HFC-25 were efficiently vaporized in a manner similar to halon 1301. HCFC-22 and the HFC-125/HFC-32 mixture were vaporized much less efficiently due to their lower Jakob numbers and higher number of moles in the liquid phase.

- Based solely on dispersion and vaporization criteria, **FC-218 and HFC-125 should be superior to the other proposed alternative agents for rapid fire suppression.**