Engine Nacelle, Halon Replacement

Reconsidering Carbon Dioxide as a Fire Extinguishant

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FAA International Aircraft Systems Fire Protection Working Group,
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Reviewing Current Circumstances

CO_2 as a Fire Extinguishing Agent

1. CO_2 has been used in fire extinguishment systems for decades
   A. Pre-dates halons
   B. Mainly used now for ground-based industrial fire prevention applications
   C. Used in total-flood and local-application methods
      i. Total-flood & local-application ; engineered/pre-engineered systems
         a. "Low"- (refrigerated) & "high"-pressure storage
         b. Utilizes dedicated valve(s), plumbing, and nozzle(s) for injection
      ii. Local-application; engineered systems, hand-held fire extinguishers
   D. Broad-spectrum design guidance exists

2. Main extinction mechanism : oxygen denial to the "normal" fire

Reviewing Current Circumstances

As Used in Civilian Aviation

1. Used in "early" nacelle fire extinguishment systems
   - A. Reported investigations in a civilian-aviation framework : 1943[(3)] – 1959
   - B. "Early" aircraft propulsion notably different than that of today
     - i. Pistons versus turbine; i.e. piston-propeller vs. turboprop, turbo/fan jet
     - ii. Different fuels/lubricants, mechanical vibration patterns, etc.
     - iii. "Early" nacelles incorporated into aircraft wing structure; atypical today
   - C. Nacelle fire prevention concepts were in their infancy
2. Use eventually wanes; CO_2 likely perceived ineffective
   - A. Catastrophic loss from "early" nacelle fires occurred; quite atypical today
   - B. Halons come on line
3. Recognized as acceptable by the FAA
   - A. AC 20-100/1977[(1)]
   - B. Must satisfy 37%v/v CO2 for ½ sec in the powerplant fire zone

AC = Advisory Circular

Reviewing Current Circumstances

Environmental & Safety Considerations

1. Environment
   A. Now available in the open market place (dry ice, fire extinguishment, etc.)
   B. A by-product of varying degree; chemical synthesis through destruction
   C. Does not appear it will be regulated…
2. Safety
   A. Heavier than air at identical conditions
   B. Is an asphyxiant
      i. "Large" quantities threaten oxygen-based life forms
      ii. During its use as a fire extinguishing agent :
         a. Quantities can become "large"
         b. It has killed people
   C. Discharge produces cryogenic & electrostatic hazards

Reconsider CO_2 for the Fire Zone

Basis for this Reconsideration

1. Is a normally <u>un</u>occupied space, but operational review is prudent
   - A. Mechanics are inside the fire zone for maintenance
   - B. Into fuselage through ECS? other path? in threatening quantities?
2. CO_2 used when aviation design rationales were in their infancies
3. Literature offers a different concentration design value to consider
   - A. Halon 1301, per FAA AC 20-100/1977
     - i. 6%v/v halon 1301 for ½ sec in the powerplant fire zone
     - ii. 6%v/v halon 1301 ≈ inerting concentration[(2)] ≠ cup-burner concentration
   - B. For CO_2, by analogy to halon 1301:
     - i. Per FAA AC 20-100/1977 : 37%v/v CO_2
     - ii. Per Bulletin 627[(8)] : 22-32%v/v CO_2 = hydrocarbon inerting ≈ 28%v/v
     - iii. 37%v/v > 28%v/v…
   - C. Given all, take this difference, analytically extend it, & see what results…

ECS = Environmental Control System

Reconsider CO_2 for the Fire Zone

1. Reviewing figures 28 - 35 in Bulletin 627 shows alkane-series fuel/oxidizer systems inerted by CO_2 at 22 - 32%v/v CO_2
   - methane ≈ 22%v/v CO_2
   - ethane ≈ 32%v/v CO_2
2. The threat from flammable fluids found in the powerplant fire zone can be represented by selecting from materials reported in Bulletin 627; i.e. 32%v/v design concentration to be conservative
3. However, MPSHRe rev04 requires an initial design concentration based on an n-heptane-fueled cup-burner assay.
4. But, a chosen concentration is selected by similarity to inerting, not cup-burner, while maintaining the same fuel, n-heptane (C_7H_{16}); look at 28%v/v CO_2…

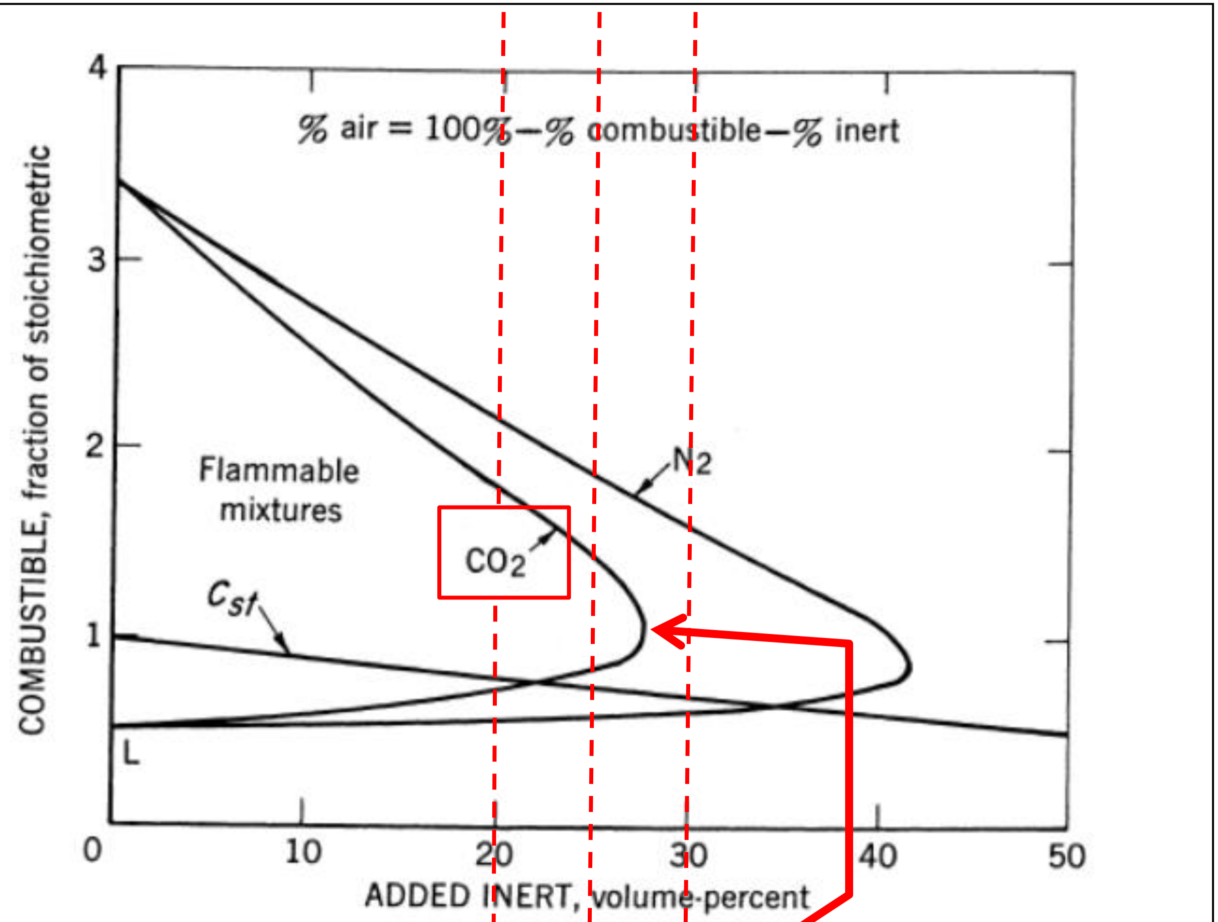


FIGURE 35.—Approximate Limits of Flammability of Higher Paraffin Hydrocarbons (C_nH_{2n+2}, $n \geq 5$) in Carbon Dioxide-Air and Nitrogen-Air Mixtures at 25° C and Atmospheric Pressure.

MPSHRe = Minimum Performance Standards for Halon 1301 Replacement in the Fire Extinguishing Agents/Systems of Civil Aircraft Engine and Auxiliary Power Unit Compartments

Reconsider CO_2 for the Fire Zone

<u>Simplistic</u> Analytical Review Regarding Powerplant Use

1. Consider design concentrations of CO_2 & halon 1301 :
   A. 37%v/v CO_2 => 6.2x larger than halon 1301 (37%v/v CO_2 / 6%v/v 1301)
   B. 28%v/v CO_2 => 4.7x larger
2. Hint from a vapor density ratio @ room conditions (25°C, 1 atm)
   A. Halon 1301 vapor is 3.4x times denser than CO_2 (6.17 kg/m^3 / 1.81 kg/m^3)
   B. So, *halon vapor is 3.4x heavier & CO_2 concentration 4.7 - 6.2x larger*...
3. Find a *simple* design-based mass ratio @ each CO_2 concentration
   A. For an arbitrary compartment of 10 m^3 @ room conditions
   B. To attain 6%v/v halon 1301, need 3.7 kg halon 1301
   C. To attain :
      i. @ 37%v/v, need 6.7 kg CO_2; mass ratio = 6.7 / 3.7 = 1.81; 81% more CO_2
      ii. @ 28%v/v, need 5.1 kg CO_2; mass ratio = 5.1 / 3.7 = 1.38; 38% more…

Reconsider CO_2 for the Fire Zone

***Simplistic* Analytical Review Regarding Powerplant Use**

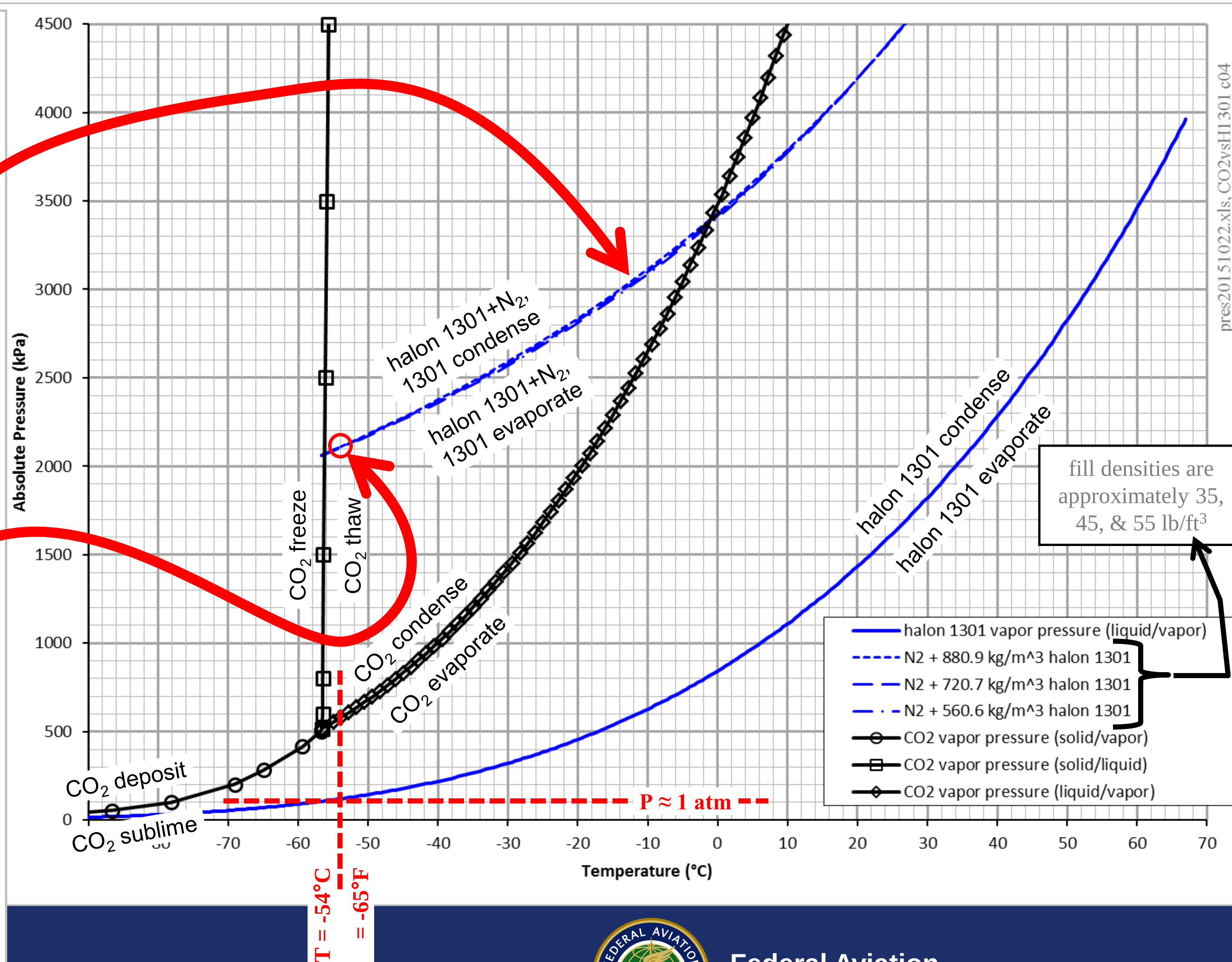
4. So, 28%v/v CO_2 looks possible & suggests something around a 38% increase in agent weight…

5. If 28%v/v CO_2 is analogous to 6%v/v halon 1301, what about CO_2 storage?

P(T), CO_2 & halon 1301

All P-T data shown for mixtures including N_2 are created from PROFISSY, as created/described by NIST(7).

1. Showing pressure-temperature (P-T) data for :
   - pure halon 1301
   - halon 1301 & N_2
   - pure CO_2
2. Typical halon 1301 storage in aviation is depicted by the "halon 1301&N_2" P-T traces
3. <u>Assume that the "cold" P-T data point is a system design point</u>; i.e. -54°C @ 2110 kPa (-65°F @ 306 psia)
4. For approximately -2°C and colder, liquid/vapor CO_2 has insufficient vapor pressure to equate to the halon 1301&N_2 state, so it also needs N_2
5. Unlike halon 1301, CO_2 does NOT need to boil @ 1 atm; the concern is now dry ice formation…



P(T), CO_2 & halon 1301

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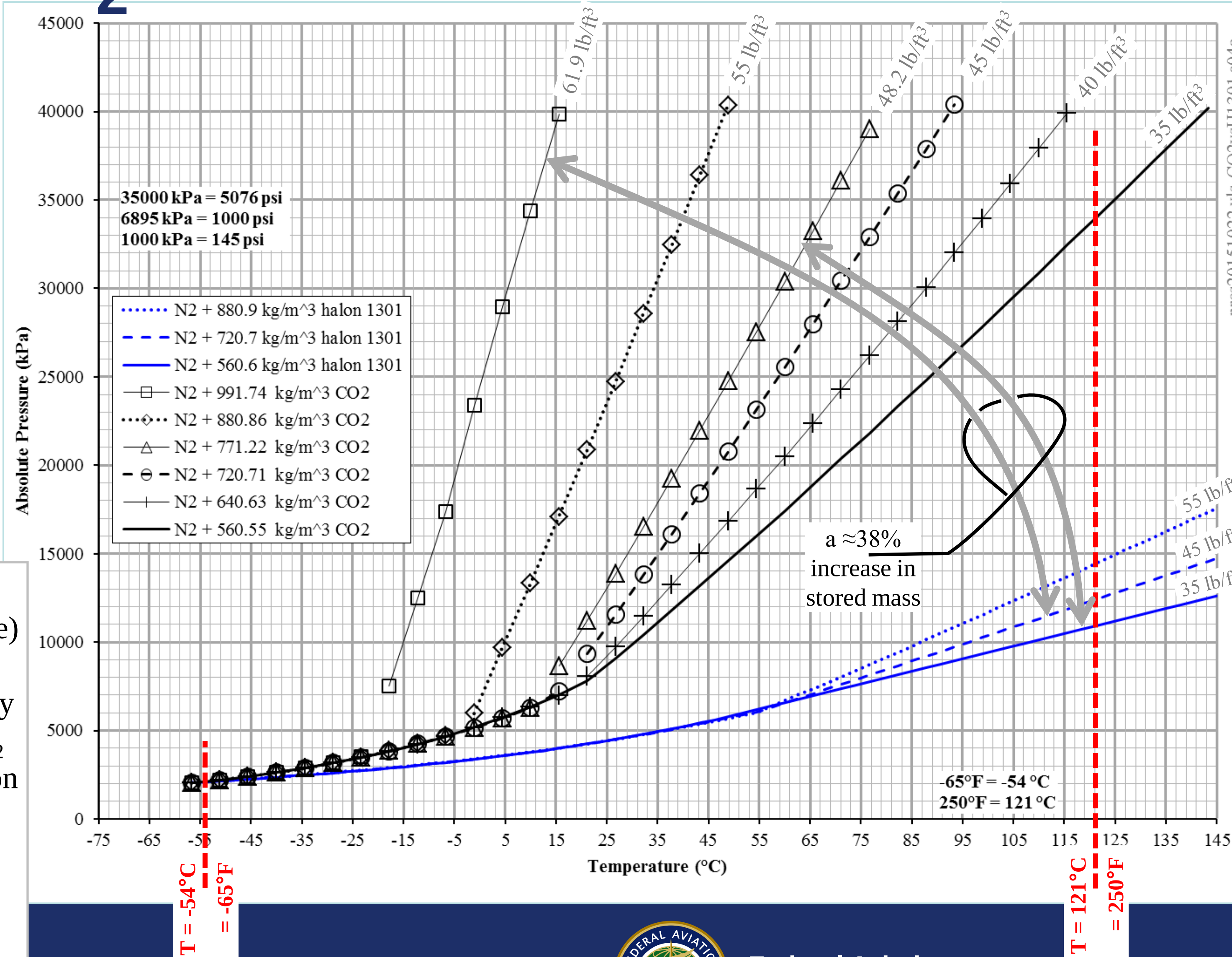

1. Showing P-T data for :
   - halon 1301 & N_2 (blue)
   - CO_2 & N_2 (black)
2. As seen here, fill density behaviors for CO_2 & N_2 are NOT similar to halon 1301 & N_2
3. Perhaps indicating a change in bottle design is required; a system weight penalty also ?

P(T), CO_2 & halon 1301

1. The volume increase of a fire extinguisher bottle to the next largest is 11-161% (per obsolete mil-C-22284A).
2. The volume increase to the next larger size bottle may or may not offset the mass increase when stepping from halon 1301 to CO_2.
3. Eliminating the P-T insult is unlikely.

fire extingiusher bottle volume (in^3)	volume ratio (larger/smaller)
86	n/a
224	2.605
378	1.688
536	1.418
630	1.175
945	1.5
1050	1.111

fire extingiusher bottle volume, halon 1301 (in^3) =	224
mass, halon 1301 (lb)	fill density, halon 1301 (lb/ft^3)
4.54	35.02
5.83	44.97
7.13	55

ratio to increase CO2 mass =	1.38	(achieving 28%v/v CO_2)	
fire extingiusher bottle volume, CO2 (in^3) =	224	378	536
mass, CO2 (lb)		fill density, CO2 (lb/ft^3)	
6.27	48.37	28.66	20.21
8.05	62.1	36.8	25.95
9.84	75.91	44.98	31.72

ratio to increase CO2 mass =	1.81	(achieving 37%v/v CO_2)	
fire extingiusher bottle volume, CO2 (in^3) =	224	378	536
mass, CO2 (lb)		fill density, CO2 (lb/ft^3)	
8.22	63.41	37.58	26.5
10.55	81.39	48.23	34.01
12.91	99.59	59.02	41.62

Reconsider CO_2 for the Fire Zone

Future Plans for Testing

1. CO_2 as a halon replacement candidate appears plausible
2. FAA Fire Safety will perform testing with CO_2
   - A. Will look at concentration ≈ 28%v/v CO_2 via MPSHRe rev04
   - B. Protocol of MPSHRe rev04 will be refined to minimize test count
   - C. Basis for refinement : CO_2 is already a recognized fire extinguishing agent
3. Activity to begin Q4/2015, end Q1/2016, & present in spring 2016
   - A. Get FAA-owned/modified Pacific Scientific Halonyzer 2 back online
   - B. Design/create CO_2 storage, conditioning, injection system
   - C. Perform FAATC NFS testing to affirm compliance with MPSHRe rev04
4. *Any other comments/contributions* ?

Thank you.

Appendix A. Sources.

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   link : http://www.osti.gov/scitech/servlets/purl/7328370/

Appendix B. Relating CO_2 & Halon 1301 Fire Extinguishment Quantities.

Simplistic means to equate fire extinguishment quantities of CO_2 & halon 1301.

1. Utilizing the following variable & subscript notations within formulas :
   A. symbol designations : P = pressure, T = temperature, V = volume, %v/v = volume fraction, m = mass, & ρ = density
   B. subscript designations & notation = _subscript
      i. subscript assignments & qualifiers
         a. a variable without a subscript indicates a total property; i.e. P = total pressure of the system
         b. "u" is the frx bottle's ullage, "d" is something dissolved, "f" is liquid, "g" is vapor or gas, "s" is saturated
      ii. examples : ρ_g = gas density, V_h1301g = halon 1301 vapor volume; m_CO_2 = mass of CO_2
2. Given conditions (created to compare each by mass at the same room conditions while satisfying fire suppression design rationales)
   A. V = 10 m^3, T = 25°C, & P = 1 atm = 101.325 kPa; no compartment leakages (arbitrary & convenient choices)
   B. design concentrations
      i. halon 1301 : 6%v/v, per FAA Advisory Circular 20-100/1977 & analogous to inerting as reported in literature
      ii. CO_2 :
         a. 37%v/v, per FAA Advisory Circular 20-100/1977 ≈ 6.2 * 6%v/v halon 1301
         b. 28%v/v, analogous to inerting as reported in literature ≈ 4.7 * 6%v/v halon 1301
3. Determining the respective substance quantities; generally : ρ_g = m_g / V_g => m_g = ρ_g * %v/v * V
   A. halon 1301
      i. ρ_h1301 (25°C, 1 atm) = 6.17 kg/m^3, US National Fire Protection Association (ρ_h1301 ≈ 3.4*ρ_CO_2 = 6.17/1.81)
      ii. m_h1301 = ρ_h1301 * V_h1301 = 6.17 kg/m^3 * 6/100 * (10 m^3) = 3.702 kg = 3.7 kg
   B. CO_2
      i. ρ_CO_2 (25°C, 1 atm) = 1.81 kg/m^3, US Department of Commerce/National Institute of Standards and Technology
      ii. mass CO2 :
         a. m_CO_2 (37%v/v CO_2) = ρ_CO_2 * V_CO_2 = 1.81 * 37/100 * (10) = 6.697 kg = 6.7 kg
         b. m_CO_2 (28%v/v CO_2) = ρ_CO_2 * V_CO_2 = 1.81 * 28/100 * (10) = 5.068 kg = 5.1 kg
4. Determining the comparative mass ratios
   A. @ 37%v/v CO_2, m_CO_2 / m_h1301 = 6.7/3.7 = 1.81; an 81% increase in mass larger than halon 1301
   B. @ 28%v/v CO_2, m_CO_2 / m_h1301 = 5.1/3.7 = 1.38; a 38% increase in mass…