Cryogenic Flux Capacitor for Advanced Molecular and Energy Storage Applications

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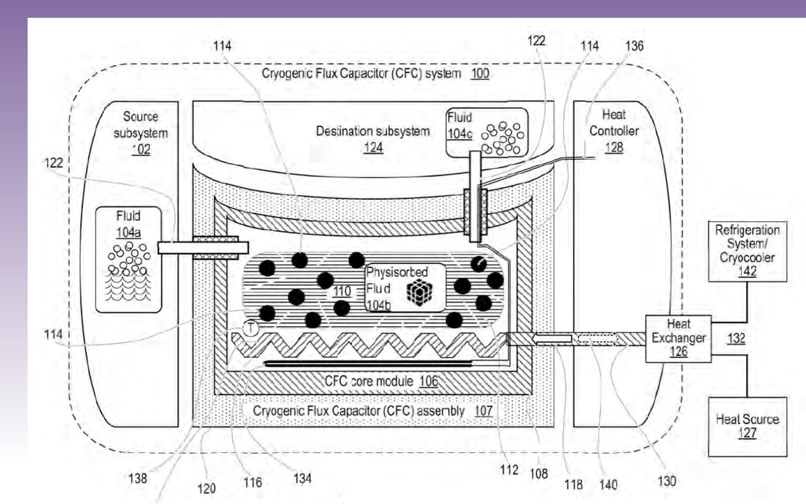
Introduction

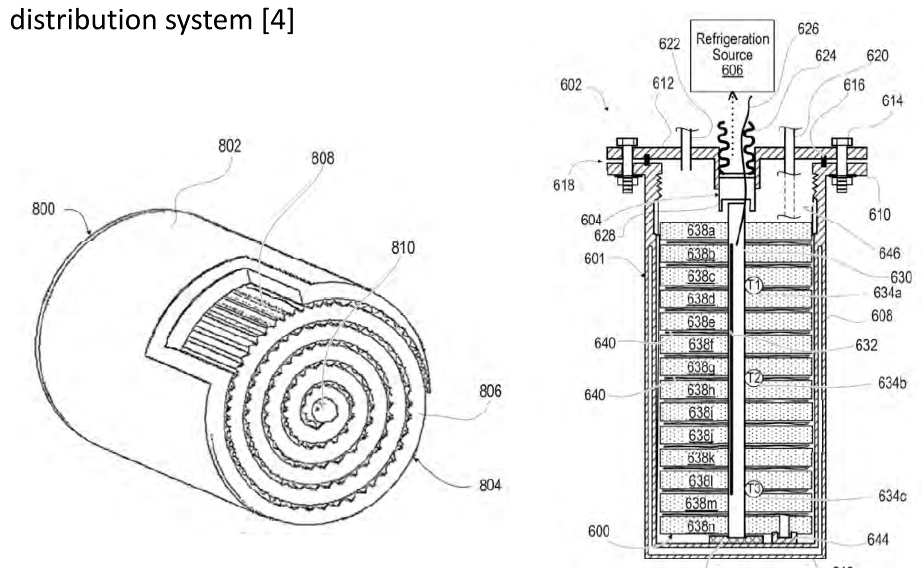
- <u>Traditional fluid storage in one of two ways:</u>
  1. **Low pressure, cryogenic liquids**
     - High energy and volume densities, low pressures
     - Complex, high mass, orientation and motion sensitive
  2. **High-pressure gases**
     - Flexible packaging, room temp, insensitive to orientation
     - Low energy density, high pressure, poor energy-to-mass ratio
- <u>CFC-based storage system</u> = middle ground

  New fluid system design possibilities for energy storage!
  Storage density of liquid without the complexity of liquid
- <u>Three broad CFC application areas:</u>
  1. **CFC-Life**: Breathing air or oxygen
  2. **CFC-Cool**: Refrigeration (air, nitrogen, argon, etc.)
  3. **CFC-Fuel**: Hydrogen, natural gas, oxygen, etc.

Cryogenic Flux Capacitor (CFC)



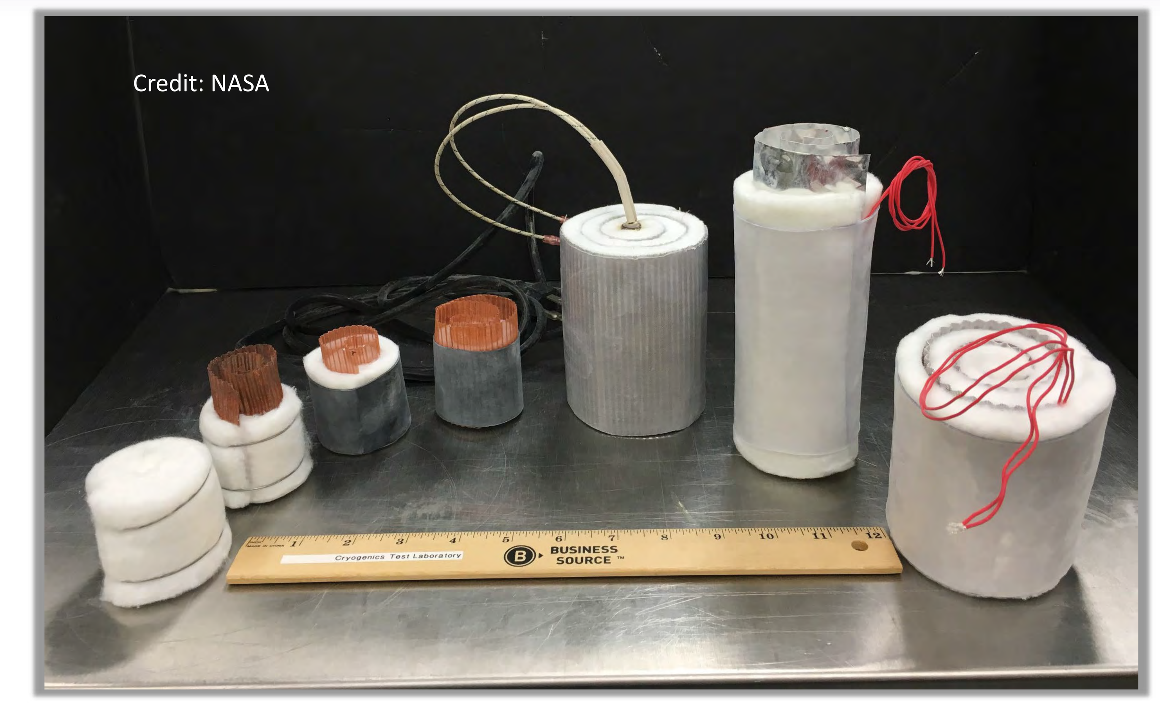
Generalized conceptual schematic for a CFC-based storage/supply distribution system [4]



Conceptual schematic of a CFC in parallel plate (left), and spiral configurations (right) [4]

CFC = integral thermo-mechanical fluid delivery system including the adsorbent matrix material, geometric thermo-fluid delivery membrane, and a heat conductive element for charging or discharging

- Solid-state (phase-less) cryogenic storage of fluid atoms or molecules via physisorption processes [1-3]
- Low or high pressure
- Fast charging/discharging on-demand
- Insensitive to dynamic applications or physical orientation
- Wet (i.e. liquid cryogen) or dry charging
- Fluid in (liquid or gas), gas out



Various prototypes of CFC core modules (spiral configurations with different conductors)

Aerogel Composite Materials Testing

<u>Characterization of matrix materials for CFC's</u>

- Mass uptake and boil-off calorimetry
- 4 different cryogens: LN_2, LO_2, LAr, L-Air
- 7 different aerogel composite blanket materials by Aspen Aerogels, Inc.

Physical characteristics of aerogel composite material test specimens

Material	Samples	Nominal Diameter	Avg. Thickness	Avg. Density	Avg. Volume	Avg. Mass
		mm	mm	g/cm³	cm³	g
Spaceloft White	5	76.2	4.8	0.146	21.8	3.19
Spaceloft Gray	5	76.2	4.8	0.148	21.8	3.23
Spaceloft Subsea	5	76.2	4.6	0.155	20.7	3.21
Spaceloft Subsea Gray	5	76.2	5.1	0.134	23.4	3.14
Pyrogel	5	76.2	4.9	0.236	22.2	5.24
Cryogel	5	76.2	4.3	0.167	19.6	3.28
ULD White	4	76.2	5.0	0.046	20.8	1.18

Cryoadsorption test data summary for aerogel composite materials

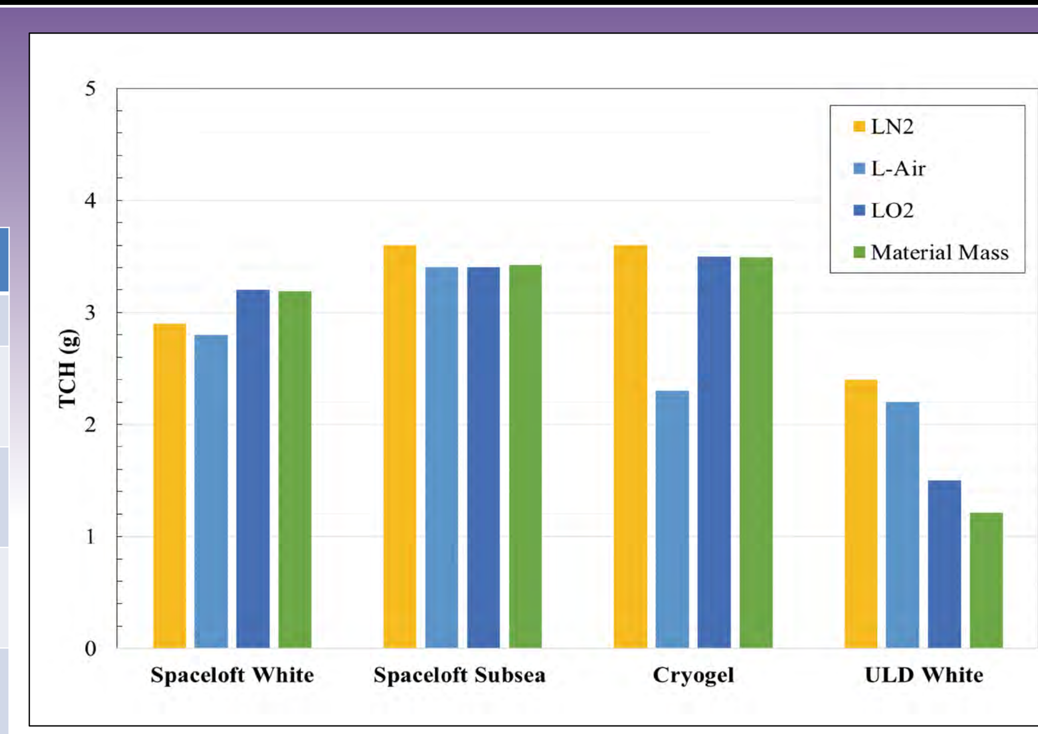
Material	Test – N_2			Test – Air			Test – O_2			Test – Argon		
	MR	VR	LVE	MR	VR	LVE	MR	VR	LVE	MR	VR	LVE
Spaceloft White	4.8	0.87	19.0	5.8	0.96	20.9	7.0	0.89	19.4	7.7	0.87	19.0
Spaceloft Gray	5.1	0.94	20.4	6.2	1.02	22.2	7.3	0.95	20.5	7.9	0.90	19.5
Spaceloft Subsea	5.2	0.99	20.5	6.2	1.09	22.5	7.4	1.00	20.7	7.9	0.94	19.4
Spaceloft Subsea Gray	5.4	0.90	21.0	6.2	0.96	22.5	7.6	0.90	20.9	8.3	0.86	20.1
Pyrogel XTE	3.1	0.90	19.9	3.9	1.04	22.9	4.6	0.95	21.1	5.2	0.91	20.1
Cryogel	5.2	1.00	20.2	5.7	1.07	21.0	7.1	1.03	20.3	7.4	0.95	18.6
ULD White	7.2	0.51	13.1	7.6	0.52	13.4	9.3	0.55	12.6	10.8	-	-

Liquid Volume Equivalent (LVE) = mass uptake / ρ_{NBP}

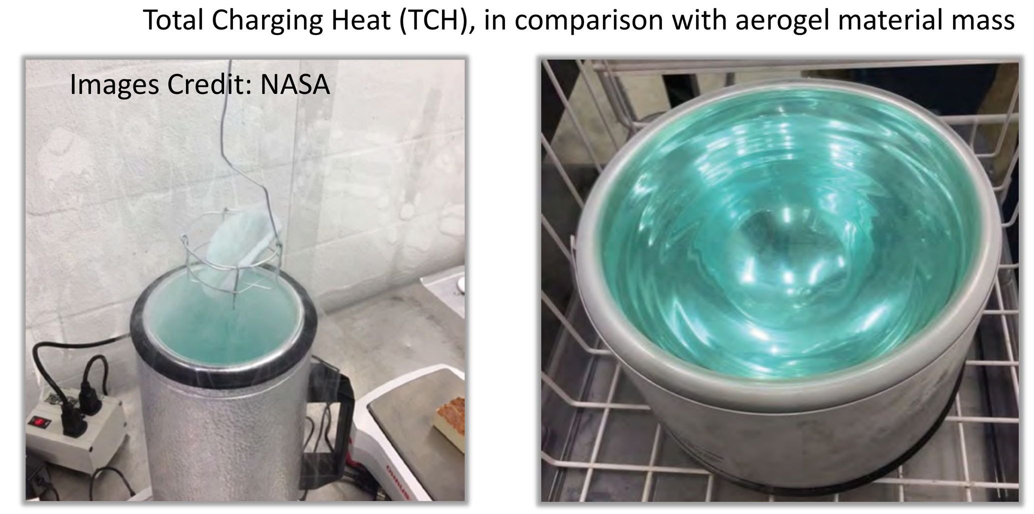
Volume Ratio (VR) = LVE / volume of material

Mass Ratio (MR) = mass uptake / mass of material

Total Charging Heat (TCH) = sensible cooldown heat + heat of adsorption



Total Charging Heat (TCH), in comparison with aerogel material mass



Aerogel specimen under LO_2 boil-off calorimetry testing used to calculate TCH

Conclusion & Status

- CFC technology <u>expands the design space</u> for fluid systems and energy storage applications
- Fluids can be practically stored and "un-stored" in a molecular surface adsorbed state at densities on par with liquid, at low to moderate pressure
- Extensive testing complete on aerogel composite blanket materials in different cryogens
- Applicable to a wide variety of industries and applications
- Current development of CFC-Life application for escape rebreathers [5]
- Patent pending and available for commercial licensing [4]

References

[1] Boer J 1966 The dynamical character of adsorption, Oxford Clarendon Press

[2] Williams, M K, Smith, T M, Fesmire, J E, Weiser, E S, and Sass, J P 2011 Foam / Aerogel Composite Materials for Thermal and Acoustic Insulation and Cryogen Storage, US Patent 7,977,411

[3] Williams, M and Fesmire J 2016 Aerogel Hybrid Composite Materials: Designs and Testing for Multifunctional Applications, NASA Tech Briefs Webinar

[4] Swanger A and Fesmire J 2019 Cryogenic flux capacitor for solid-state storage and on-demand supply of fluid commodities, US Patent Application 20190056064

[5] Swanger A, Fesmire J and Fernando R 2019 Oxygen Storage Module with Physisorption Technology for Closed-Circuit Respirators, Cryogenic Engineering Conference, Hartford, CT, USA

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