C2Po2B-05: Tuning Hydrogen Boiloff via Inert Gas Insulation Purge in a Vapor Cooled Shielded Fuel Tank

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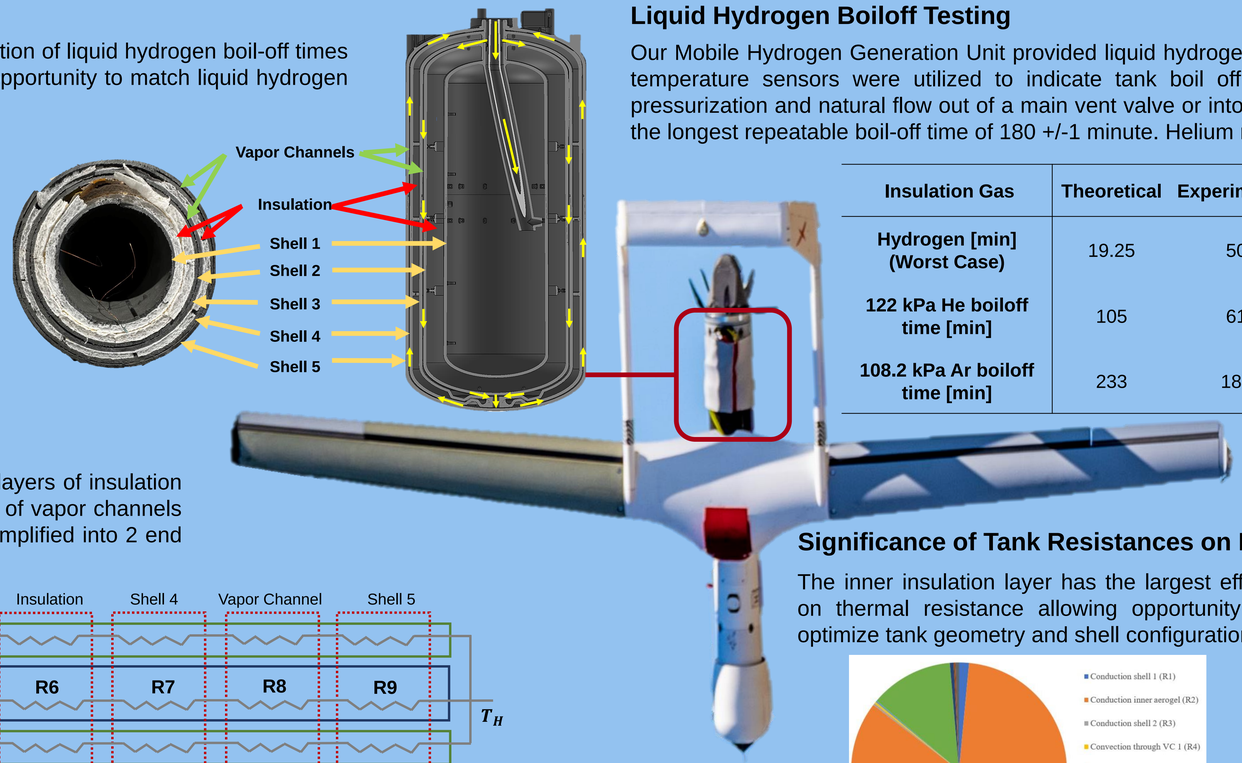
Vapor cooled shielded tank configurations allow for manipulation of liquid hydrogen boil-off times utilizing thermal conductivity of inert gases. This allows for opportunity to match liquid hydrogen boil off performance to the downstream fuel cell.

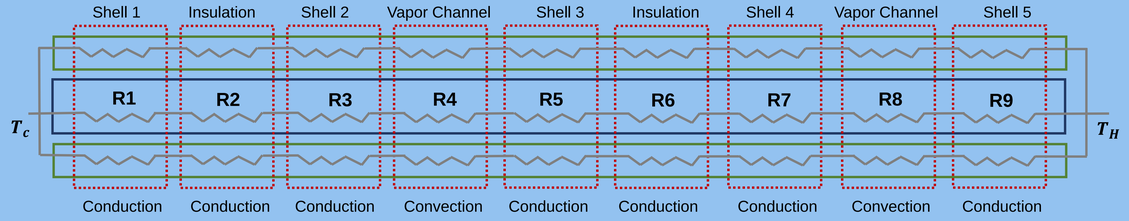
Tank Design

A vapor cooled shielded 3-D printed liquid hydrogen fuel tank was designed, built, and tested to integrate into Insitu's Scan Eagle 3 drone. The tank is comprised of 5 polymer matrix composite shells stacked and epoxy sealed within each other. There are 2 interconnected layers of insulation utilizing aerogel which are fully isolated from 2 hydrogen vapor layers.



Thermal Resistance Network

The tank is broken up into 9 resistances: x5 tank shells, x2 layers of insulation using thermal conduction of inert gas and aerogel, x2 layers of vapor channels using thermal convection of hydrogen. The tank geometry simplified into 2 end caps (green) and a cylindrical base (navy).

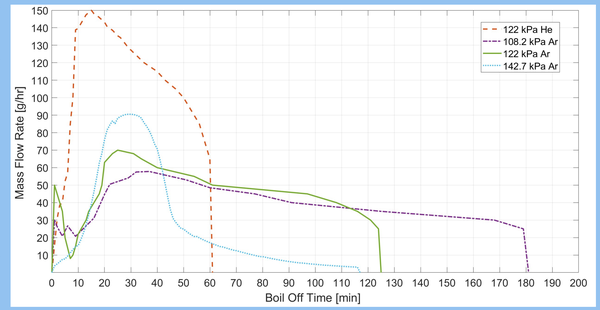


Each individual end cap and cylinder layer is combined in parallel, and each layer is added in series. Energy losses are calculated based off the change in temperature and total resistance. Mass flow rate is calculated based off the energy loss, heat of vaporization, heat capacity and temperature differential. Boil off time is calculated based off mass flow rate and total LH2 mass[1].

Liquid Hydrogen Boiloff Testing

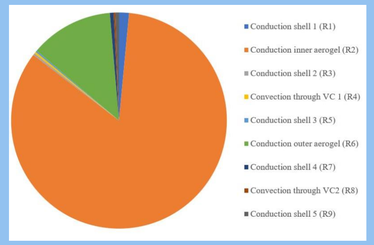
Our Mobile Hydrogen Generation Unit provided liquid hydrogen for tank and drone testing. A flow meter, pressure transducer, and temperature sensors were utilized to indicate tank boil off time from disconnecting the hydrogen supply from the tank to pressurization and natural flow out of a main vent valve or into the Scan Eagle 3 drone. Argon's low thermal conductivity produced the longest repeatable boil-off time of 180 +/-1 minute. Helium resulted in a 60 +/-1 minute boil off time.

Insulation Gas	Theoretical	Experimental
Hydrogen [min] (Worst Case)	19.25	50
122 kPa He boiloff time [min]	105	61
108.2 kPa Ar boiloff time [min]	233	181



Significance of Tank Resistances on Boiloff

The inner insulation layer has the largest effect on thermal resistance allowing opportunity to optimize tank geometry and shell configurations.



The manipulation of liquid hydrogen boiloff based on thermal conductivity of inert gas in the insulation layer resulted in successful flight of Insitu Scan Eagle 3 surveillance drone.

Acknowledgements: This work was funded and supported by Department of Defense, Insitu, Plug Power, and Mississippi State University
Drone and Mobile Hydrogen Generation Unit picture taken by Zach Zoeller.

[1] Crabb. C. 2022. Thermal Resistance Network for the Design and Testing of A Liquid Hydrogen Vapor Cooled Shielded Fuel Tank (In: *School of Mechanical and Materials Engineering:* Washington State University)