WRAPPED MULTILAYER INSULATION

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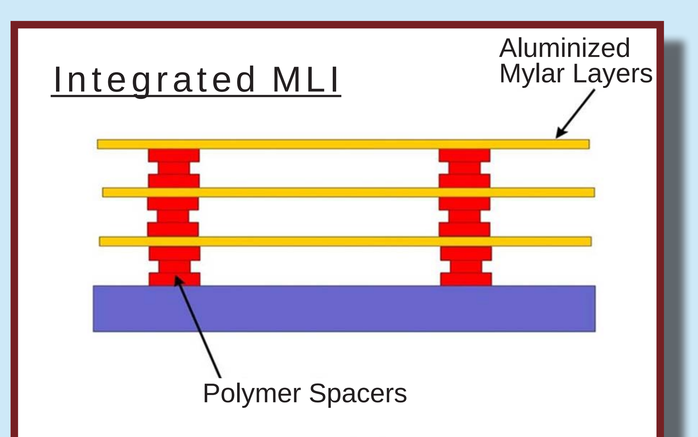
Introduction

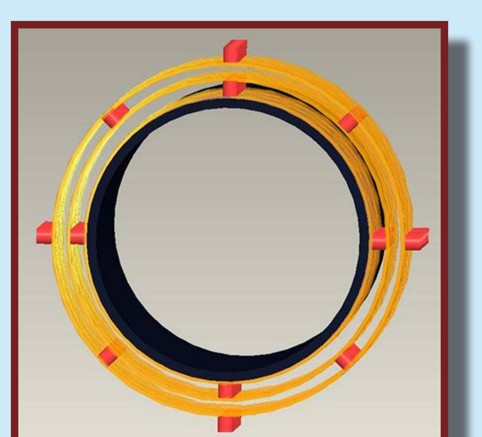
Next generation NASA vehicles (Heavy Lift Launch Vehicle and orbiting fuel depots) need improved cryogenic propellant transfer and storage for long duration missions. Current cryogen feed line Multi-Layer Insulation performance has typically 10 times higher heat leak than tank MLI insulation. In cryogenic space craft propulsion systems, piping heat leak can be 50 – 80% of the tank heat leak. During each shuttle launch 40 – 50% of LH_2 is lost, about 150,000 gallons of LH_2, due to piping transfer, chill down and ground hold. Many cryogenic systems require thermal insulation on piping and tubing containing cryogenic fluids. Wrapped Multilayer Insulation (wMLI) is a high performance multilayer insulation designed for cryogenic piping that uses an innovative discrete spacer technology to control layer spacing/density and reduce heat leak. This paper reports on the initial development of wMLI and its demonstration as a feasible technology.

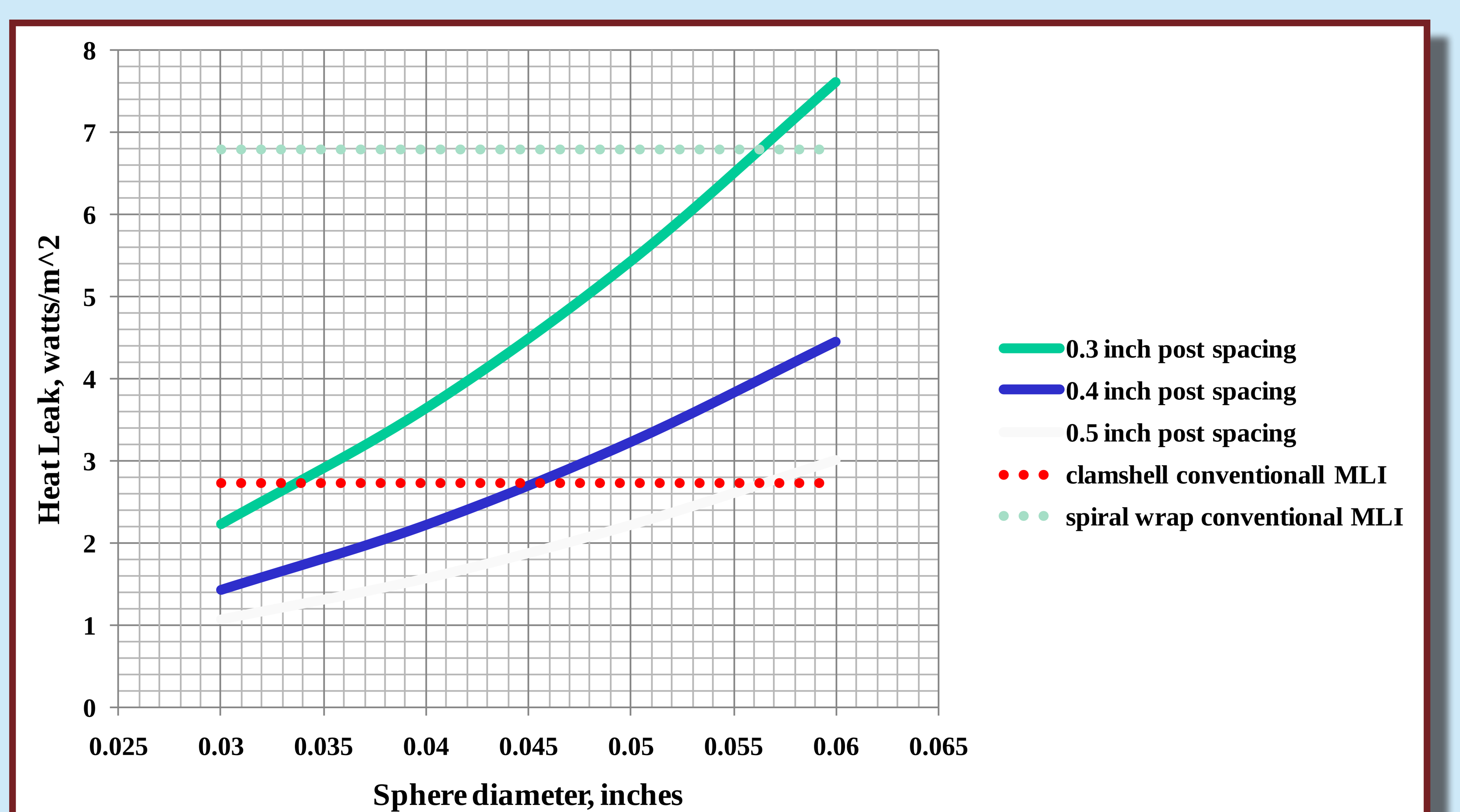
With new developments in cryogenic flight systems, higher performing insulation systems may play a key role in providing zero or very low boiloff to reduce operation cost, increase loiter times or allow heavier payloads to higher orbits. Better insulated piping could provide more efficient cryogenic fluid transfers, useful in spacecraft that use continuous circulation cryogenic RCS, necessary supporting technology for orbiting fuel depots, and beneficial new technology for Ground Support Equipment for cryogen transfers to launch vehicles or liquid hydrogen fueled aircraft.

wMLI is an insulation system with engineered layer spacing, in which layer density and inter-layer heat leak are controlled via low contact area, low thermal conduction spacers. wMLI has a number of applications throughout government, national security and commercial sectors. Vacuum insulated pipe has a fairly broad market in industry and use, and wMLI may be a superior solution to current available technologies.

Integrated Multi-Layer Insulation, the parent discrete spacer technology, see figure below left, consists of layers of metalized polymer film separated by ultra low thermal conductance micromolded polymer spacers enabling low heat leak from layer to layer, precise control over layer spacing, in a very robust bonded up structure. Integrated MLI has been prototyped and tested showing a heat leak 37% less per layer than conventional netting-spacer MLI.







wMLI advantages over conventional wrapped MLI

- Higher performance than spiral wrapped or advanced 'clamshell' netting MLI.
- Nearly 4x lower heat leak per layer than spiral wrapped MLI.
- More predictable performance; layer density is precisely controlled.
- More robust; IMLI spacers and layers are bonded together in a robust blanket.

Wrapped MLI Prototypes

Wrapped MLI was modeled to have good performance, see Table 1, of 6.5 W/m². Modeling indicates heat leak will be sensitive to the spacer size, geometry and spacing (see graph below left.) Phase I prototypes used a simple solid glass sphere, with a high solid conductance through the spacer. Phase II prototypes with custom polymer spacers of more ideal geometry are modeled to have a heat leak through the system as low as 2.8 W/m² for a 5-layer blanket, or 43% of the Phase I prototype's heat leak.

wMLI thermal performance was measured using LN_2 calorimetry (images below of tubing test fixture) and had a measured heat leak of 7.3 W/m² (5 layers, 76K, 294K, 1cm thick). See Table 2. wMLI 5-layer wrapped blankets on 0.75" diameter piping have demonstrated nearly 4X better thermal performance than spiral wrapped conventional MLI.

NASA applications

- Cryogenic propellant piping insulation for NASA vehicles, including heavy lift launch vehicles, cryogenic landers, cryogenic upper stage launch vehicles and orbiting fuel depots.
- Cryogenic piping insulation for Ground Support Equipment for launch facilities, cryogenic upper stages and LH_2 fueled aircraft.

Non-NASA applications

- Ground Support Equipment for commercial launch facilities and cryogenic upper stage launch vehicles such as Atlas Centaur and Delta Cryogenic Secondary Stage.
- Cryogenic fluid handling piping such as Vacuum Insulated Pipe.
- Insulated cryogenic hoses for cryogen transfers to/from cryogenic dewars and tanks for research, medical and industrial uses.
- LN_2 handling applications for food and beverage industries for inerting and pressurizing.
- LNG industrial insulated transfer pipes.
- Spiral wrapped insulation for commercial dewars.

Table 1: MLI Modeled Performance, For 5 layers, 100K to 300K

Test Article	Heat Leak, W/m²	Effective Emissivity
Spiral MLI	28.4	0.030
Clamshell MLI	5.2	0.023
wMLI, glass spheres	6.5	0.020
wMLI, polymer spacers	2.8	0.0064

Table 2: Wrapped MLI Measured Performance versus Spiral Wrapped & Clamshell conventional MLI

Test Article	Effective Layers	Heat Leak, W	Heat Leak, W/m²	Effective Emissivity	Conductivity mW/m*K
wMLI	5	0.75	7.34	0.017	0.024
Spiral MLI	10	1.36	13.3	0.032	0.050
Clamshell MLI	5	1.00	9.82	0.023	0.017

Table 3: Comparison of Wrapped MLI and conventional Vacuum Insulated Pipe, On 3" diameter piping, 77K to 295K

Test Article	Effective Layers	Heat Leak, W/m
wMLI, Phase I	10	0.94
wMLI, estimated Phase II	10	0.18
Foam Insulated Pipe	N/A	7
Vacuum Insulated Pipe	N/A	0.5 - 1

Conclusions

Wrapped Integrated MultiLayer Insulation prototypes were designed, fabricated, installed on piping and tested, and had a measured heat leak of 7.3 W/m² for a 5-layer wrapped blanket (10mm thick, 77K to 295K). Spiral wrapped conventional netting MLI was tested and had a heat leak of 26.7 W/m² (equivalent 5 layer blanket.) The Wrapped MLI concept, which uses Quest's and Ball Aerospace's innovative discrete spacer technology to control layer spacing and reduce heat leak, was successfully demonstrated feasible. wMLI provides 3.6 times better thermal insulation for cryogenic piping per layer than current conventional cryo feed line insulation.

Modeling indicates wMLI could be further developed in a Phase II program with custom, tooled discrete polymer spacers to obtain 3-fold lower heat leak. Thermal modeling estimates performance and effect of sphere diameter, spacing and material, and will be used to guide Phase II R&D. Thermal conductivity was estimated for a 5-layer, 10mm solid glass sphere wMLI prototype at 5.7 W/m², which compares reasonably well to the measured heat leak of 7.3 W/m². Heat leak through the insulation system is dominated by the contact area of the spacer to mylar layers, and spheres were not an optimal design for minimizing contact resistance. Modeling of hollow, molded polymer spacers estimates heat leak through a wMLI piping insulation system could achieve 0.7 W/m² (20-layers, 77K to 295K).

wMLI developed during Phase II could have 9 times lower heat leak than spiral wrapped MLI on tubing. This advantage could be used to reduce the number of layers, reduce cost or reduce heat leak. Reduced number of layers would result in reduced mass and reduced cost. More efficient piping insulation at the launch pad could reduce the 40 - 50% boiloff loss of LH_2 experienced during each launch.

Better insulated piping could provide more efficient cryogenic fluid transfers, useful in spacecraft that use continuous circulation cryo RCS, necessary supporting technology for orbiting fuel depots, and beneficial new technology for Ground Support Equipment for cryogen transfers to launch vehicles and next generation Vacuum Insulated Pipe for industrial cold transfer lines.