To Compare the Performance of MLI Materials for LN_2 Tank

Mevada Vishalkumar Prakashbhai[1], Ritesh A. Panchal[2]

[1] P. G. Student, Mechanical Engineering Dept., Hansaba College of Engineering & Technology, Gujarat, India

[2] Assistant Professor, Mechanical Engineering Dept., Hansaba College of Engineering & Technology, Gujarat, India

ABSTRACT

The present era of multilayer insulation is to prevent LN_2 for its heat transfer rate at temperature range approximately 77 K to 300 K. New researches developing new methodology to decrease maximum heat transfer rate of LN_2. The poor performance of MLI for older insulation materials produces heat leak. The target for the new insulation system is a value of thermal conductivity (k) below 4.8 mW/m-K at vacuum level (from 1 to 10 torr) and boundary temperatures approximately 77 K to 293 K and to compare the performance of their. The corresponding parameters of MLI were analytically calculated and its results using for LN_2 tank will be compared against experimental data.

Keywords:- *MLI Materials, LN_2 Tank, Maximum Heat Transfer*

---

1. INTRODUCTION

Cryogenics is fundamentally about energy, and thermal insulation is about energy conservation. The technological developments of this century have led to insulation systems that have approached the ultimate limit of performance. More technologies and markets forecast for rapid expansion into the 21st century will require, in many cases, not super insulations but more efficient systems for a wide variety of cryogenic applications. Although bulk storage and delivery of cryogens such as liquid nitrogen, argon, oxygen, hydrogen, and helium are routinely accomplished, cryogenics is still considered a specialty. As ice usage was a specialty in the 19th century (not becoming commonplace until the 20th century), goal is to make cryogen usage commonplace in the early 21st century. To make liquid nitrogen "flow like water," superior methods of thermal insulation are needed. The development of efficient, robust cryogenic insulation systems that operate at a soft-vacuum level is the focus and the corresponding research.

Storage of a cryogen (say, LN2) is difficult, as there is a continuous boil off due to heat in leaks. Vessels cannot be sealed as boil off generates huge volumes of vapor, resulting in large pressure rise so this may lead to bursting. For example, vapor to liquid volume ratio for a general cryogen is 175 (1600 for water). To avoid the pressure rise, the need of insulation is vital. Insulation or a combination of insulations minimizes all these modes of heat transfer. Consider a LN2 container as shown in the figure 1. The inner vessel is housed inside an outer vessel and these vessels are separated by some form of insulation. Also, the inner vessel is supported using lateral beams as shown. The liquid boils off continuously due to the various modes of heat transfer.

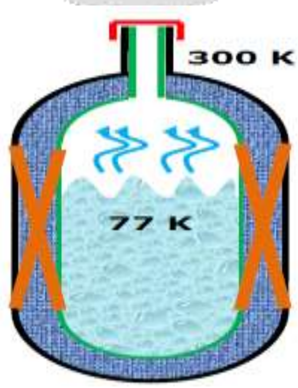

Figure 1: Cyogenic Insultion

1.1 Problem Formulation
The paper focuses on two phases:
Phase 1:
- Selection of design, dimensions and materials for LN_2 tank
  - Specification of LN_2 tank components
  - Specification of MLI material
- Experimental set up of LN_2 tank
  - Specification of vacuum pump
  - Specification of vacuum gauge
  - Specification of pressure gauge
  - Specification of liquid nitrogen (LN2)

Phase 2:
- Methodology of experimental set up
  - Analytical method
  - Experimental method

2. SPECIFICATION OF LN_2 TANK COMPONENT

2.1 Outer cylinder

- Material – Stainless steel (304 – 18% chromium, 8% nickel)
- Thermal conductivity – 17 W/mK
- Outer diameter – 220 mm
- Inner diameter – 210 mm
- Length – 450 mm
- PCD – 247 mm
- Dead flange diameter – 260 mm

Figure 2: (a) Outer Cylinder and (b) Inner Cylinder

2.2 Inner cylinder
- Material – Stainless steel (304 – 18% chromium, 8% nickel)
- Thermal conductivity – 17 W/mK
- Outer diameter – 120 mm
- Inner diameter – 110 mm
- Length – 320 mm
- PCD – 247 mm
- Dead flange diameter – 260 mm

2.3 Dead flange

- Material – Stainless steel (304 – 18% chromium, 8% nickel)
- Thermal conductivity – 17 W/mK
- Diameter – 260 mm
- Thickness – 10 mm
- PCD – 247 mm
- Vent hole diameter – 1mm

2.4 Gasket – 1

- Material – PTFE (polytetrafluroethylene)
- Diameter – 260 mm
- Thickness – 2 mm
- PCD – 247 mm
- Vent hole diameter – 1 mm

2.5 Gasket – 2

- Material – PTFE (polytetrafluroethylene)
- Outer diameter – 260 mm
- Inner diameter – 160 mm
- Thickness – 2 mm
- PCD – 247 mm

Material	Thermal Conductivity (W/mK)	Width (mm)	Thickness (mm)
Aerogel blanket	0.019	320	0.5
Polyurethane foam	0.033	320	0.5
Polyimide foam	0.043	320	0.5
Aluminum foil	235	320	0.006
Fiber glass	0.043	320	0.15

2.6 Specification of Vacuum Pump

This pump is designed to work non-stop without any problem, for a long period of time. This is direct drive, single stage, oil sealed, rotary high vacuum pumps wherein, state of the art technique has been adopted to ensure proper alignment and the fine setting of each & every component used, and remain ever undisturbed. The main components of the pump are made out of the selected superior quality raw materials, which mainly consist of specially treated cast iron and steel. The pump is coupled directly to the motor shaft without using any additional coupling which not only makes it compact, but also ensures its powerful positive drive sufficiently noiseless.

2.7 Specification of Vacuum Gauge

This vacuum manometer is a dial instrument with double scale Its measurement range is 0 to 760 mm of Hg or 0 to 30 in of Hg. Metal outer case, well protect the inner accessories mini size, convenient to carry material stainless steel diameter.

2.8 Specification of Pressure Gauge

This manometer is a dial instrument with single scale. Its measurement range is 0 to 3 psi. It’s broad applications - water, oil, air and more Metal outer case, well protect the inner accessories super mini size, portable and convenient to carry.

Figure 3: Experimental Setup of LN_2 Tank

Table 1: Transient heat transfer data for different time interval

Sr.No.	Time (min)	Time (sec.)	Biot Number (B_i)	Fourier number (F_o)	$Q_{Transient}$ (kW)
1	10	600	0.1617	3.1810	-1.927
2	20	1200	0.1617	6.3620	-1.539
3	30	1800	0.1617	9.5431	-1.256
4	40	2400	0.1617	12.7241	-1.044
5	50	3000	0.1617	15.9051	-0.885
6	60	3600	0.1617	19.0862	-0.762

Note: Here negative sign shows that heat is rejected from the system

Table 2: Properties of MLI

Sr. No.	**Combination of MLI**	**Equivalent thermal conductivity k_e in (W/m-K)**	**Critical thickness r_c in (mm)**	**No. Layers**	**Total insulation thickness in (mm)**	**Radius of insulation r_e in (m)**
1	Aerogel blanket + Aluminum foil + Fiber glass	0.01317	1.317	2	1.312	0.061312
2	Polyurethane foam + Aluminum foil + Fiber glass	0.01866	1.866	3	1.968	0.061968
3	Polyimide foam + Aluminum foil + Fiber glass	0.02149	2.149	3	1.968	0.061968

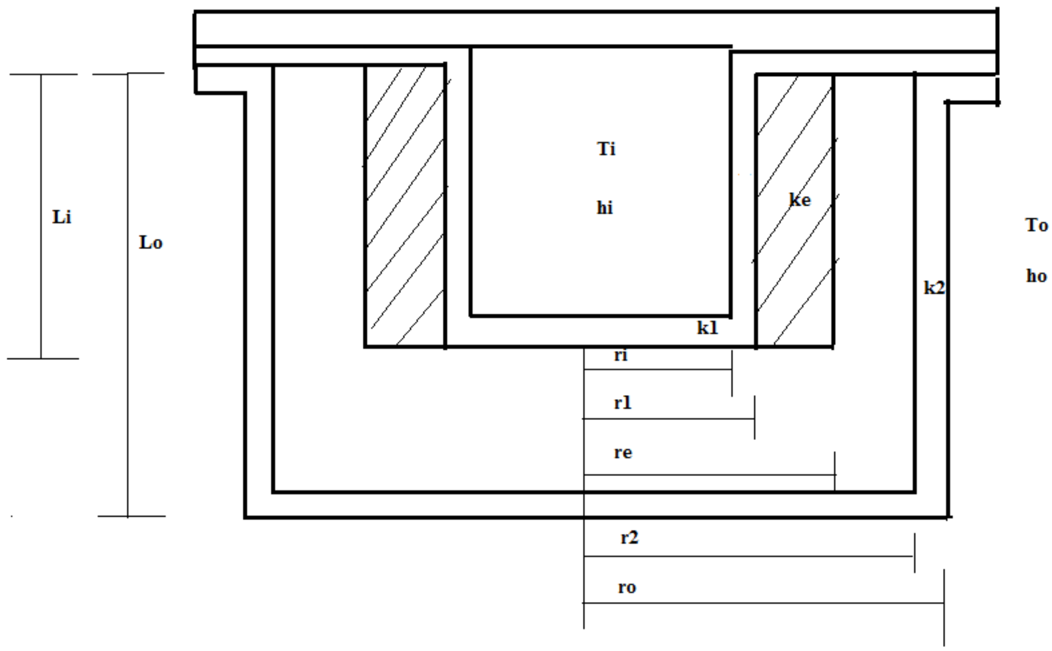

Figure 4: Cross section of LN_2 tank

Table 3: Value for heat transfer for different combination of MLI

Sr. No.	Combination of MLI	Number of layers (n)	Total thickness (t) in meter	Solid conduction in W/m^2-K	k_A in W/m-K	r_e in meter	Q_{MLI} in kW
1	Aerogel blanket + Aluminum foil + Fiber glass	2	0.001312	h_c = 32.77 h_1 = 14.48	0.031	0.061312	0.642
2	Polyurethane foam + Aluminum foil + Fiber glass	3	0.001968	h_c = 21.84 h_2 = 16.76	0.025	0.061968	0.347
3	Polyimide foam + Aluminum foil + Fiber glass	3	0.001968	h_c = 21.84 h_3 = 21.84	0.028	0.061968	0.388

Table 4: Total heat transfer for MLI combination 1

Sr. No.	Time (min)	$Q_{Transient}$ (kW)	Q_{MLI} (kW)	Q_{Total} (kW)
1	10	1.927	0.642	2.569
2	20	1.539	0.642	2.181
3	30	1.256	0.642	1.898
4	40	1.044	0.642	1.686
5	50	0.885	0.642	1.527
6	60	0.762	0.642	1.404

Table 5: Total heat transfer for MLI combination 2

Sr. No.	Time (min)	$Q_{Transient}$ (kW)	Q_{MLI} (kW)	Q_{Total} (kW)
1	10	1.927	0.347	2.274
2	20	1.539	0.347	1.886
3	30	1.256	0.347	1.603
4	40	1.044	0.347	1.391
5	50	0.885	0.347	1.232
6	60	0.762	0.347	1.109

Table 6: Total heat transfer for MLI combination 3

Sr. No.	Time (min)	$Q_{Transient}$ (kW)	Q_{MLI} (kW)	Q_{Total} (kW)
1	10	1.927	0.388	2.315
2	20	1.539	0.388	1.927
3	30	1.256	0.388	1.644
4	40	1.044	0.388	1.432
5	50	0.885	0.388	1.273
6	60	0.762	0.388	1.150

Table 7: Combination 1: (Aerogel blanket + Aluminum foil + Fiber glass)

Reading No.	Time in (min)	Inner Tank Pressure Difference (ΔP) in (psi)	Inner Tank Pressure Difference (ΔP) in (N/mm^2)	Length of LN_2 in (mm)	Difference of length of LN_2 in (mm)	Heat transfer rate in (kW)
1	10	0.350	2413.1625	304.4431	15.5569	0.9463
2	20	0.320	2206.3200	278.3480	26.0951	1.5873
3	30	0.310	2137.3725	269.6496	8.6984	0.5291
4	40	0.300	2068.4250	260.9512	8.6984	0.5291
5	50	0.295	2033.9512	256.6020	4.3492	0.2645
6	60	0.295	2033.9512	256.6020	0	0

Table 8: Combination 2: (Polyimide foam + Aluminum foil + Fiber glass)

Reading No.	Time in (min)	Inner Tank Pressure Difference (ΔP) in (psi)	Inner Tank Pressure Difference (ΔP) in (N/mm^2)	Length of LN_2 in (mm)	Difference of length of LN_2 in (mm)	Heat transfer rate in (kW)
1	10	0.355	2447.6362	308.7923	11.2071	0.6817
2	20	0.340	2344.2150	295.7447	13.0476	0.7936
3	30	0.330	2275.2675	287.0463	8.6984	0.5291
4	40	0.325	2240.7937	282.6971	4.3492	0.2645
5	50	0.320	2206.3200	278.8348	3.8623	0.2349
6	60	0.320	2206.3200	278.8348	0	0

Table 9: Combination 3: (Polyurethane foam + Aluminum foil + Fiber glass)

Reading No.	Time in (min)	Inner Tank Pressure Difference (ΔP) in (psi)	Inner Tank Pressure Difference (ΔP) in (N/mm^2)	Length of LN_2 in (mm)	Difference of length of LN_2 in (mm)	Heat transfer rate in (kW)
1	10	0.352	2426.9520	306.1828	13.8172	0.8405
2	20	0.335	2309.7412	291.3955	14.7873	0.8995
3	30	0.325	2240.7937	282.6971	8.6984	0.5291
4	40	0.310	2137.3725	269.6496	13.0475	0.7936
5	50	0.300	2068.4250	260.9512	8.6984	0.5291
6	60	0.300	2068.4250	260.9512	0	0

3. RESULTS

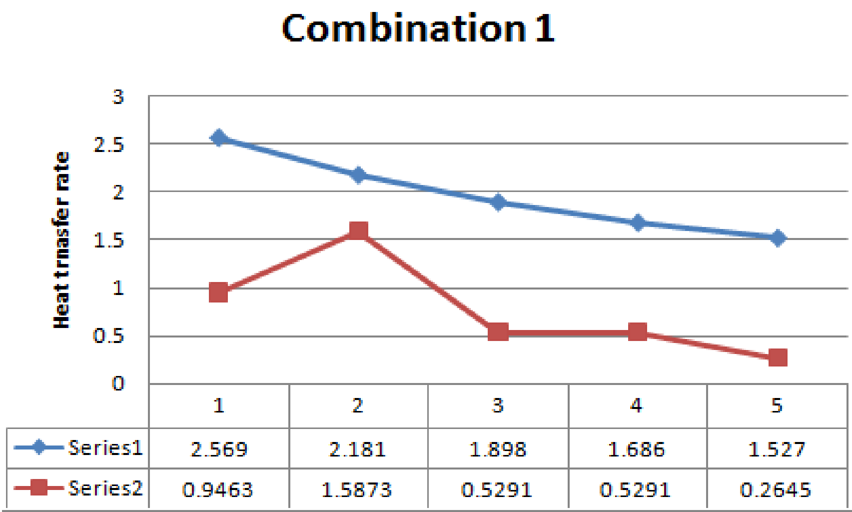

Figure 5: Comparison of analytical & experimental heat transfer rate with graphical representation for combination 1

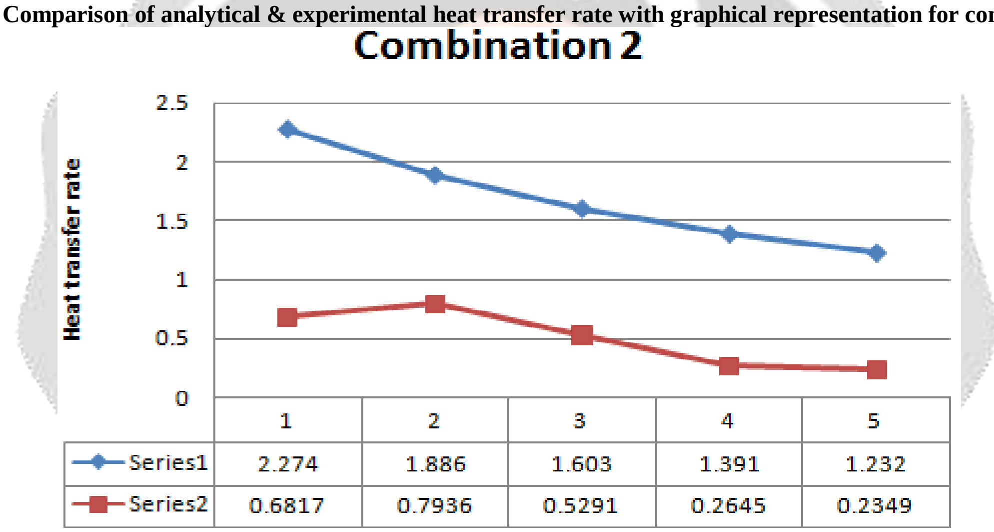

Figure 6: Comparison of analytical & experimental heat transfer rate with graphical representation for combination 2

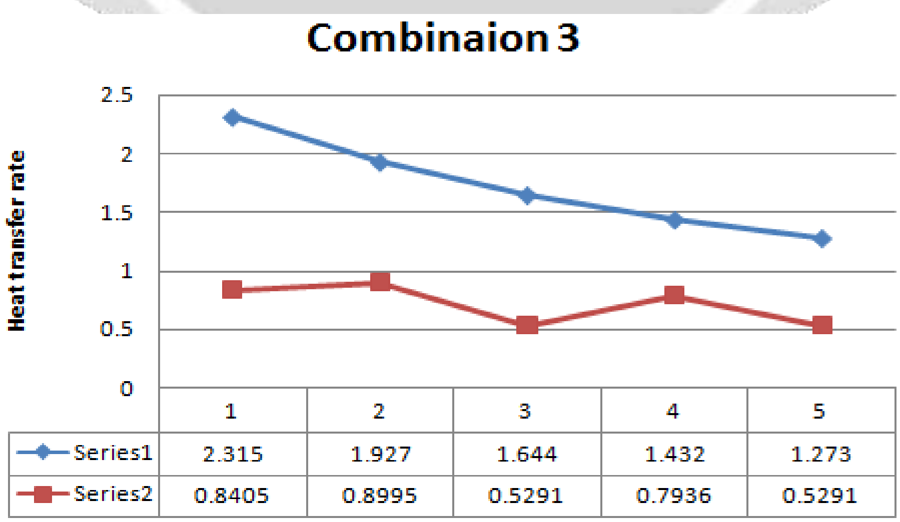

Figure 7: Comparison of analytical & experimental heat transfer rate with graphical representation for combination 3

4. CONCLUSION

From the analytical and experimental methodology the heat transfer rate is defined for each combination of MLI. Then that heat transfer rate value compared between analytical and experimentally for each combination of MLI and represent on graph so the conclusion is that the net heat transfer rate is less in combination 2 (Polyimide foam + Aluminum foil + Fiber glass). So, the best choice of MLI is combination 2 among the 3 combinations of MLI.

5. REFERENCES

[1]. S. T. Stoy, "CRYOGENIC INSULATION DEVELOPMENT ." Business Media New York 1960.
[2]. S. D. AUGUSTYNOWICZ, J. E. FESMIRE, and J. P. WIKSTROM, "CRYOGENIC INSULATION SYSTEMS." 20th International Congress of Refrigeration, IIR/IIF, Sydney, 1999.
[3]. S.D. Augustynowicz and J. E. Fesmire, "CRYOGENIC INSULATION SYSTEMFOR SOFT VACUUM." Kluwer Academtc I Plenum Publishers, 2000.
[4]. G.F. Xie, X.D. Li, R.S. Wang, "Study on the heat transfer of high-vacuum-multilayer-insulation tank after sudden, catastrophic loss of insulating vacuum." Cryogenics 50, 2010. P. 682–687.
[5]. J.E. Fesmire , B.E. Coffman , B.J. Meneghelli , K.W. Heckle, "Spray-on foam insulations for launch vehicle cryogenic tanks." Cryogenics 52, 2012. p. 251–261.
[6]. S. Dye, A. Kopelove , G.L. Mills, "Novel load responsive multilayer insulation with high in-atmosphere and on-orbit thermal performance." Cryogenics 52, 2012. p. 243–247.
[7]. Takeshi Miyakita, Ryuta Hatakenaka, Hiroyuki Sugita, Masanori Saitoh, Tomoyuki Hirai, "Development of a new multi-layer insulation blanket with non-interlayer-contact spacer for space cryogenic mission." Cryogenics, 2014.
[8]. S.A. Dye, P.N. Tyler, G.L. Mills, A.B. Kopelove, "Wrapped multilayer insulation design and testing." Cryogenics 64, 2014. p. 100–104.
[9]. T.C. Nast, D.J. Frank, J. Feller, "Multilayer insulation considerations for large propellant tanks." Cryogenics, 2014.
[10]. J.E. Fesmire, "Layered composite thermal insulation system for nonvacuum cryogenic applications." Cryogenics, 2015.
[11]. B. Wang, Y.H. Huang, P. Li, P.J. Sun, Z.C. Chen, J.Y. Wu, "Optimization of variable density multilayer insulation for cryogenic application and experimental validation." Cryogenics 80, 2016. p. 154–163.
[12]. Zhan Liu, Yanzhong Li, Fushou Xie , Ke Zhou, "Thermal performance of foam/MLI for cryogenic liquid hydrogen tank during the ascent and on orbit period." Applied Thermal Engineering 98,2016. p. 430–439.
[13]. G. Cunnington, C. Tien, A study of heat transfer processes in multilayer insulation, AIAA Prog. Astronaut. Aeronaut. 23 (1970).
[14]. S.D. Augustynowicz, J.E. Fesmire, and J.P. Wikstrom, Cryogenic insulation systems, 20th International Refrigeration Congress, Sydney, 1999.
[15]. M.G. Kaganer, "Thermal Insulation in Cryogenic Engineering," Israel Program for Scientific Translations, Jerusalem, 1969.
[16]. Jacob S, Kasthurirengan S, Karunanithi R. Investigations into the thermal performance of multilayer insulation (300–77 K), Part II: thermal analysis. Cryogenics 1992;32(12):1147–53.
[17]. Demko JA, Duckworth RC, Roden M, Gouge M. Testing of vacuum insulated flexible line with flowing liquid nitrogen during the loss of insulating vacuum. Adv Cryogenic Eng 2008;53:160–7.
[18]. Leslie Buchanan, Steve Buerger. MLI Layup Optimization Test. In: Proceedings of space thermal control workshop; 2010.
[19]. Kawasaki H, Okazaki S, Sugita H, Murakami M. Temperature dependence of thermal performance in space using multilayer insulation. AIAA-2012-3407; 2012.
[20]. R.L. Rusby, M. Kempson, " CRYOGENIC TEMPERATURE MEASUREMENT." 1996 (35), 338-343.
[21]. J.S. Johnston, "THE MEASUREMENT OF LOW TEMPERATURE." Cryogenics July 1984.
[22]. H. Yoshiki, "SIMPLE THERMO-LEVEL METER FOR HE1 AND HE2 BY A DYNAMIC METHOD." July,1984.
[23]. Z.X. Wu, H. Zhang, H.H. Yang, X.X. Chu, L.F. Li, "NOVEL RADIATION-RESISTANCE GLASS FIBER/EPOXY COMPOSITE FOR CRYOGENIC INSULATION SYSTEM." June, 2010.
[24]. P.J. Sun, J.Y. Wu, P. Zhang, L. Xu, M.L. Jiang, "EXPERIMENTAL STUDY OF THE INFLUENCES OF DEGRADED VACUUM ON MULTILAYER INSULATION BLANKET." 2009.
[25]. Celso de Araujo Duarte, "A THERMOCOUPLE VACUUM GAUGE FOR LOW VACUUM MEASUREMENT ." February 2011.
[26]. Mata Amritanandamayi Devi, Ganesha Udupa, Pramod Sreedharan, "ANTI-BOURDON TUBE PRESSURE GAUGE ." January 2017.
[27]. Ho-Myung Chang, Ki Nam Ryu, Hyung Suk Yang, "CRYOGENIC DESIGN OF LIQUID NITROGEN CIRCULATION SYSTEM FOR LONG-LENGTH HTS CABLES WITH ALTITUDE VARIATION ." February 2017.
[28]. Er. R. K. Rajput. "Heat and Mass Transfer " 6th Edn; S. Chand & Company Pvt. Ltd., New Delhi, 2016.
[29]. Gilmore DG. Spacecraft thermal control handbook. California: Aerospace Press; 2002.