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PERFORMANCE EVALUATION OF COMPOUND MULTILAYER INSULATION (77K-300K)

performancer of multilayer insulater for finiding thermal conductivity

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Abstract - *Multilayer insulation (MLI) using alternate layers of shield and spacer. In high vacuum MLI is the most effective Cryogenic Insulation. The Investigations are centered on the influence of the number of layers and layer density, with the cold boundary at the same temperature as liquid nitrogen. The paper Presented theoretical and experimental investigation of the heat transfer of different MLI with different vacuum chamber pressure. Liquid nitrogen boil of rate method is used to measure the heat transfer rate. The apparent thermal conductivity were calculated over a wide range of temperature (77k-300k) and pressure (10^{-6} mbar – 10^{3}mbar). The thermal performance of compound and Composite MLI is investigated. The temperature profile and heat transfer through the MLI were obtained as a function of level of vacuum and vice versa.*

Keywords- *Insulation, vacuum, Liquid nitrogen, pressure; Multilayer*

"I. INTRODUCTION"

Multilayer insulation have been the subject of great interest and importance to thermal engineers and the early development of heat transfer technologies, which called "Super Insulation Material"(MLI) blankets are extensively used in space vehicle and Cryogenic Dewar as light weight thermal protection system because of the virtues of good insulation characteristics and little pollution[1]. Multi layer Insulation is the most effective cryogenic insulation currently available. In general a large number of highly reflecting shields interposed by thermal spacers are placed in a high vacuum environment to form the MLI. Multilayer insulation developments of insulating systems where the heat transfer mechanism of gas conduction, solid conduction and radiation have been reduced to minimum. Radiation is minimized by using many layers of highly reflecting metal foil, solid conduct is minimized by using a low conductivity fibrous material or by crinkling the shield material to allow contact at only a few points. Gaseous conduction is minimized by reducing the residual gas pressure [2].
The modes of heat transfer are also dependent on a variety of parameters such as insulation density, number of layers, contact pressure, out gassing characteristics, gas pressure distribution within the insulation cold and warm boundary temperatures. The present work involves the development of a set up for evaluation of the performance of compound MLI and composite MLI and subsequence investigations on MLI. The investigations here intended to [3]. 1. Compare a few indigenous MLI materials. 2 Study the influence of number of layers and layer density on the performance of MLI. 3.Study the vacuum chamber pressure. 4.Temperature profile of the MLI as a function of chamber pressure. 5.Compare the experimental results with theoretical and each other.

"II. THEORETICAL FORMULATION"

There are three simultations modes of heat transfer within the blanket, thermal radiation between shields and solid conduction through the separator materials and gases conduction [2].

A THERMAL RADIATION

The heat transport due to radiation between two surfaces at different temperatures can be reduced significantly by interposing thermal isolated radiation shields. The radiation heat transfer rate between two surfaces is given by Stefan- Boltzmann equation [2].

$$q_{radiation} = \sigma A_1 E(T_h{}^4 - T_c{}^4)$$

Where σ is steafan- Boltzmann constant (5.67 x 10^{-8} W/m^2-k^4) , A_1 is outer surface area in inner vessel. T_h and T_c hot and cold boundary temperature (K), E is emissivity factor. A_2 inner surface area of outer vessel.e_1 & e_2 is emissivity of inner and outer vessel material at 77 K and 300K.

B GAS CONDUCTION

Corruccini[4]developed the following equation for gas conduction.

$$q_{gasconduction} = GPA_1F_a(T_h - T_c) \quad (2)$$

$$\text{Where } G = \frac{\gamma+1}{\gamma-1}\left[\frac{g_c R}{8\pi T}\right] \quad (2a)$$

P absolute pressure in pa.F_a is accommodation coefficient factor.

$$\frac{1}{Fa} = \frac{1}{a1} + \frac{A1}{A2}\left[\frac{1}{a_2} + 1\right] \quad (2b)$$

a_1 and a_2 are accommodation coefficient of surfaces.

C SOLID CONDUCTION

Conduction through the solid is expressed as [5]

$$q_{solidconduction} = h_c A_1 (T_h - T_c) \quad (3)$$

Where h_c is solid conduction of spacer material. Cunningham (1984) has obtained an

$$h_c = C_s (N/\Delta x)^{2.56} (T_h + T_c) \quad (3a)$$

Where C_s is emperical correlation for the solid conductance ($C_s = 3.40 \times 10^{-13}$ W-m$^{0.56}$/ K^2)

D TOTAL HEAT TRANSFER

$$q_{total} = q_{radiation} + q_{gasconduction} + q_{solidconduction} \quad (4)$$

E THEORETICAL TEMPERATURE DISTRIBUTION

The theoretical temperature distribution for radiation shields separated by a vacuum between parallel walls at 300 k and 76 K 6].

$$T_i = \left[T_2^{\ 4} - \frac{i}{n+1}(T_2^{\ 4} - T_1^{\ 4})^{1/4}\right] \quad (5)$$

Where T_i is the temperature of the ith shield and i is the number of the ith shield counting from the warm wall. n is the total number of shields in the system.

F Variation of Thermal Conductivity of MLI with Layer Density

Cunningham has obtained an empirical correlation for the solid conductance for a MLI consisting of double - aluminized Mylar shields and a two layer thickness of silk net between the shields in 1984[5].

$$h_c = C_s (N/\Delta x)^{2.56} (T_h + T_c) \quad (6)$$

Where $C_s = 2.24 \times 10^{-8}$ W-cm$^{2.56}$ / m^2 - K^2 = 3.40×10^{-13} W-m$^{0.56}$/K^2

If the number of layers per unit thickness is increased, generally the radiant heat transfer is reduced, and the apparent thermal conductivity of the MLI may be reduced up to a certain point. If the insulation is compressed too tightly, solid conduction begins to increase to more than offset the decrease in radiant heat transfer, and the apparent thermal conductivity is increased with further increase in the layer density. This effect is illustrated in Fig.1and table 1 for a typical MLI [2,5].

$$k_t = \frac{1}{\left(\frac{N}{\Delta x}\right)}\left[\frac{h_c + \sigma e (T_H^2 + T_C^2)(T_H + T_C)}{(2-e)}\right] \quad (7)$$

Where $\sigma = 5.67 \times 10^{-8}$ w/m^2 - K^4,
e = radiation shield emissivity
e = 0.02 for aluminum foil
e = 0.0413 for double aluminized Mylar

"III. CYLINDRICAL CALORIMETER WAS DESIGN AND DEVELOPED FOR EXPERIMENTAL WORK."

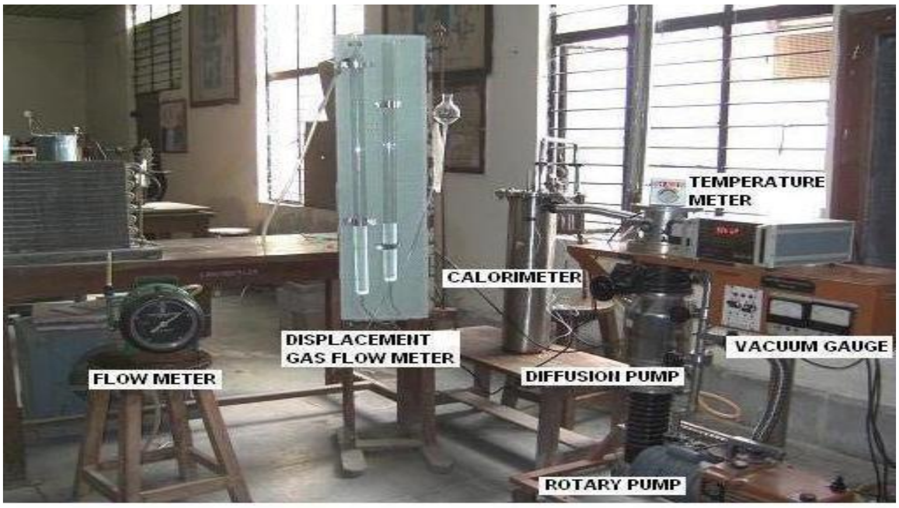


Figure 1 Overall views of experimental set-up

A number of different methods as well as different designs & apparatus are available for the measurement of Apparent thermal conductivity of MLI. Considering this method [7] the cylindrical a calorimeter and the boil off measurement method are preferable from the point of view of simplicity and accuracy. As mentioned by Kagner [8] Main advantage of this arrangement is that the sample can be held with maximum surface area and minimum edge area. The boil of measurement method is more accurate from the power input method Hence, the boil off measurement method and cylindrical apparatus were selected for the present work.

A APPARATUS

The calorimeter consists of a measuring vessel, two guard vessel and vacuum chamber as shown in fig-1.

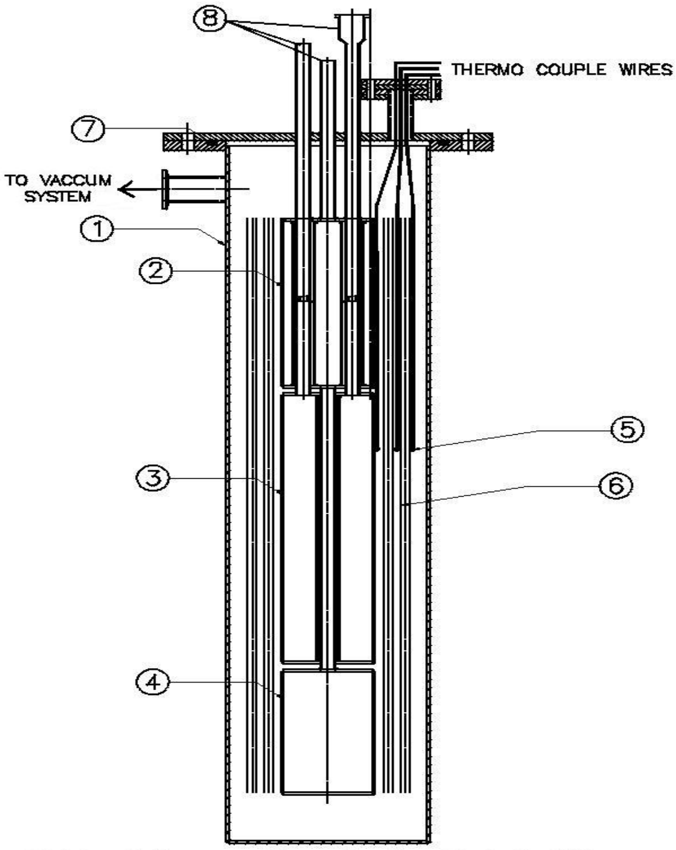


Figure 2 Calorimeter for Measurement of Apparent Mean Thermal Conductivity of MLI
1. Vaccum Chamber ; 2. Upper Guard Vessel ; 3. Test Vessel ; 4. Lower Guard Vessel
5. Thermo Couple ; 6. MLI Sample ; 7. 'O' Rings ; 8. Filling & Vent Tubes

Figure 2. Cylindrical Calorimeter

The test and guard chambers are 76mm in diameter hollow cylinder that form a mandrel for warping the insulation. These chamber are filled with Cryogenic fluid and from the cold boundary during the tests. The thermocouples used to measure the temperature distribution are suggested in the figure. The test chamber is vented through a wet test meter and fundamental water displacement method. The constant temperature bath is used to maintain the boil-off rate measurement. The vapors are in superheated state [3]. The rate of evaporation is directly proportion to the rate of heat transport through the sample. The guard chambers are vented through a column of water in order to make the guard chamber temperature slightly higher than the test chamber temperature. This avoids condensation of the test chamber vent gas as is passes through the guard [9]. The apparent thermal conductivity(K_{atc}) for this experimental arrange is given by [1], [9].

$$K_{atc} = \frac{q_t \ln(r_o / r_i)}{2\pi L T_h - T_c)} \qquad (8)$$

$$q_t = m h_{fg} \qquad (8a)$$

$$m = \rho V \qquad (8b)$$

Where q_t is the rate of heat transport to the test chamber, L is the length of the test chamber and r_o and r_i are inside and outside radius of the specimen, T_h & T_c is hot and cold surface temperature respectively. m is mass flow rate of Boil of gas, h_{fg} is latent heat of liquid nitrogen, V is volume flow rate, ρ is density of boil off gas.

B VACUUM SYSTEM

The vacuum chamber is evacuated using a vacuum system consisting of a two stage rotary vacuum pump, to develop a vacuum up to 10^{-3} mbar and to function as a back up pump. The diffusion pump start to operate when the vacuum is better that 10^{-2} m bar and measure the level of vacuum upto 10^{-6} mbar.

C INSTRUMENTATION

The experiment involves the measurement of boil-off rate, temperature and vacuum chamber pressure.

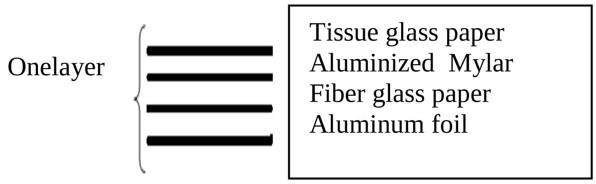
"Boil of rate" The boil-off rate of liquid nitrogen from the measuring vessel is very small relative to the level normally required. Fundamental water displacement method used to measure volume flow rate in high vacuum,10^{-6} mbar to 10^{-4} mbar. 0.5 Lit/revolution capacity, positive displacement wet gas flow meter used to measure the volume flow rate in low vacuum, 10^{-3} mbar to 10^{3} mbar.

"Vacuum pressure" The chamber pressure is measured using a pirani gauge (up to 10^{-3} mbar) and a penning gauge (below 10^{-3} and upto 10^{-6} mbar).

"Temperature" To measure the temperature distribution through the MLI thickness and to study its cool-down history. Digital temperature indicator and copper - constantan thermocouples are located at selected positions.

"IV. PREPARATION OF MLI"

The material for shields and spacers are provided indigenously. For test 1, shield of Aluminum foil (30µm) and spacer of fiber glass paper (125µm) with layer density of 15 layers/cm, and insulation thickness is 10 mm. For test 2 shield of double Aluminized Mylar (12µm) and spacer of Tissu fiber glass paper (125µm) with layer density of 20 layers/cm and insulation thickness is 10 mm. In literature test-1 and test-2 are developed and tested for low temperature insulation applications. More over these two sets of material can be used for compounding as well as composite type MLI. Here in test-3, We have compounded the material like Aluminum foil and fiber glass paper of 10 mm insulation thickness with layer density of 15 layer/cm and 10 mm insulation thickness of double aluminized Mylar and Tissu fiber glass paper with layer density of 20 layer/cm. Total Number of layers are 35 are wrapped on the test and guard chambers of the calorimeter respectively. In test-4, for composite material, first we have layered the all above materials as below.



Whole blanket of composite material is wrapped on the test and guard chambers of calorimeter with layer density is 10 layers/cm. with insulation thickness is 20 mm. The specification of our samples is shown in table-2.

Table 1 specification of material used to fabricate and test samples.

Test No.	MLI Sample	Layer density layers /cm	Total Number of layers	Sample thickness (cm)
1.	Alu.foil (30µm) +fiber glass paper (125 µm)	15	15	1
2.	Double Aluminized Mylar (12µm) +Tissu fiber glass paper (125 µm.)	20	20	1.2

"V. OBSERVATION"

The theoretical and experimental Apparent thermal conductivity of different MLI test is shown in table 3 and table 4 as function of vacuum chamber pressures.

Table 2 Theoritical Comparison of Apparent Thermal Conductivity of different MLI test (T_h-300-305K T_c-77 to 90K).

Chamber Pressure (mbar)	Apparent Thermal Conductivity (mW/m-K)			
	Test 1	Test 2		
10^{-6}	0.181	0.363		
10^{-5}	0.190	0.372		
10^{-4}	0.279	0.461		
10^{-3}	1.172	1.354		
10^{-2}	10.09	10.28		

Table 3 Experiment Comparison of Apparent Thermal Conductivity of different MLI test. T_h-300-305K T_c-77 to 80K

Chamber Pressure (mbar)	Apparent Thermal Conductivity (mW/m-K)-			
	Test 1	Test 2		
10^{-6}	0.182	0.368		
10^{-5}	0.196	0.378		
10^{-4}	0.287	0.477		
10^{-3}	3.56	5.95		
10^{-2}	7.09	9.23		

According to Table 3 and 4, the experimental results agree very well with the values of apparent thermal conductivity derived from the theoretical analysis in high vacuum (less than 10^{-2} mbar) but the difference becomes larger at low vacuum due to inadequate gas conduction models and insufficient data on the gas pressure between the MIL layers.

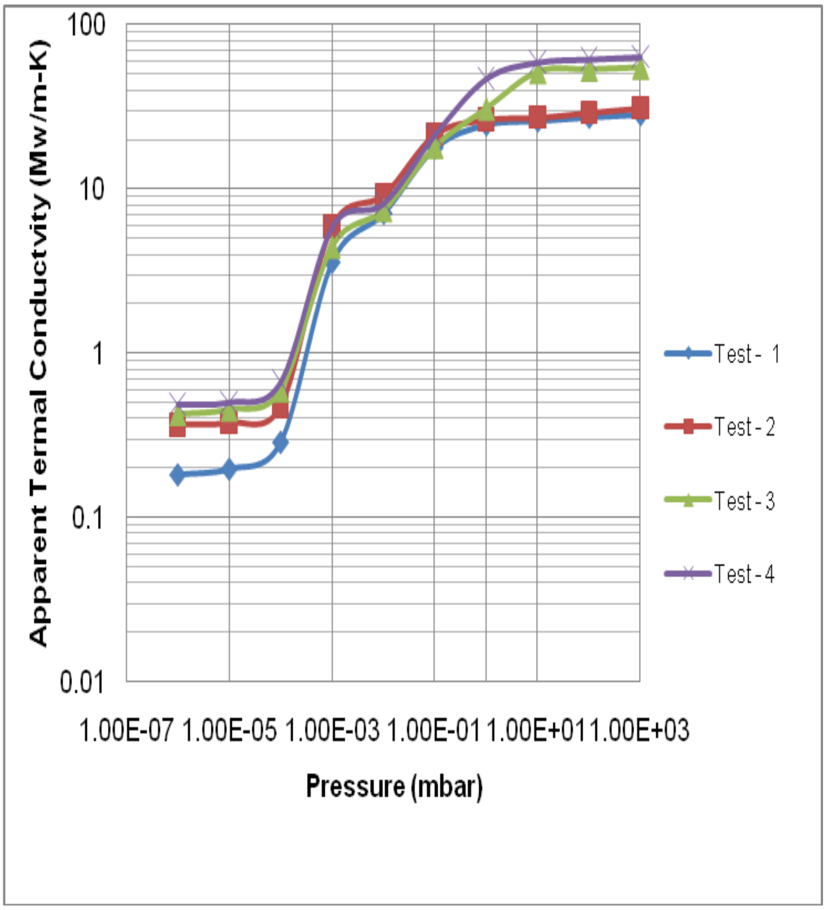


Figure 3. Variation of apparent thermal Conductivity with vacuum chamber pressure.

As per figure 4 the apparent thermal conductivity increases with increases in vacuum chamber pressures and increase in number of layers for a given layer density.As per table 4 and figure 4, the comparison of MLI samples in test-1 and 2, the apparent theramal conductvity of double aluminized Mylar is about two times more than aluminum foil. Thus the aluminum foil is better radiation shield than the double aluminized Mylar.The comparison between test 3 and 4, the apperant thermal conuctivity of compound MLI is less than composite MLI.Thus the compound MLI is better than composite MLI.

"VI. CONCLUSIONS"

Based on the theoretical and experimental investigations the following conclusions are drawn**:**

(1)As per Table 1 and figure 1, as non homogeneous material, the variation of layer density and change in emissivity, correspondingly the thermal conductivity and optimum layer density are also changed**.** Optimum layer density of aluminum foil is 15 layers/cm and doble aluminized Mylar is 20 layers/cm.

(2)As per table 3,4 and figure 4 ,the Aluminum foil and fiber glass paper is the best combination among the various combination.

(3) Apparent thermal conductivity of MLI and heat transfer through the MLI increases with increases in vacuum chamber pressure and increases in number of layers for a given layer density.

(4)As per figure 5(a) to 5(d), with increases in vacuum chamber pressure the temperature profile of the MLI changes from parabolic to linear from indicating an increase in the conductive heat transfer component.

(5)For the same number of layers, the temperature of any specific layer decreases with increases in vacuum chamber pressure and vice versa.

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