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EXPERIMENTAL INVESTIGATION ON PERFORMANCE OF LOW TEMPERATURE MULTILAYER INSULATION

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ABSTRACT

Heat leakage is a common problem involving cryogenics applications. Sometimes it is undesirable and should be maintained at the minimum level. At low temperature, it becomes more difficult to remove a given amount of heat and discharge it at ambient temperature. These unwanted heat leakage accounts into an economic burden and acts as a barrier in cryogenic applications. Therefore the cryogenic vessels and transfer lines are insulated with different types of Multi-Layer Insulations (MLI) which are very effective. MLI consists of alternate layers of high reflective shields or foils and separated by low thermal conductivity spacers. One of the most effective cryogenics insulations (MLI) involves a high vacuum. It is known that in high vacuum radiation plays a major role because gas conduction and convection are negligible. In order to improve mechanical strength and ease of application, Plastic materials like Mylar and Fiberglass are coated with Aluminum foil. The spacers for MLI are made of high resistive material. For the estimation of heat transfer, Apparent Thermal Conductivity must be known. Due to unpredictable changes in parameters such as uniform contact pressure and interstitial pressure, accurate theoretical performance of MLI is very difficult. Thus an experimental investigation has been carried out on a few indigenous MLI materials like Fiberglass cloth, R P Tissue, Nylon net etc. For that, a cylindrical boil off calorimeter has been developed and standardized for testing of the thermal performance of insulation. Its measurement principle for determining heat flux (Q) and Apparent Thermal Conductivity (K_A) of a test specimen at fixed conditions. The present work is to develop optimum combination of shield and spacer from available materials (Aluminum foil- Fiberglass cloth, Aluminum foil-R P Tissue, Aluminum foil- Nylon net) by experimental investigation of apparent thermal conductivity.

Keywords: cryogenics, insulation, multilayer insulation (MLI), boil off calorimeter.

INTRODUCTION

The word cryogenics is the term today is used as synonym for a low temperature. The point on the temperature scale at which refrigeration in the ordinary sense of the term ends and cryogenics begins is not sharply defined. The National Bureau of Standards have chosen to consider [1] the field of cryogenics as the involving temperature below -150°C (126 K) or -240°F (220°R) [2]. This is a logical dividing line, because the normal boiling points of so called permanent gases, such as hydrogen, neon, oxygen, nitrogen, helium and air, lie below -150°C, While the Freon refrigerants, ammonia, hydrogen sulfide and other conventional refrigerants all boil at temperature above -150°C. Storage of cryogen (say, LN_2) is difficult, as there is continuous boil off due to heat in leaks. From food industry, transportation, medical applications to the space shuttle, cryogenics liquids must be stored or transferred from one point to another. To minimize the heat leaks into storage lines and storage tanks, high performance materials are needed to provide high level of thermal insulation. Heat transfer is the heart of life as we know it. The removal of heat is just as good as important in the operation of air conditioners that keep many offices cool as well as refrigerators & freezers that preserve food for a long duration. But heart of heat transfer is insulation because many operations depend on the transfer of thermal energy.

Basically thermal insulation is the transfer of heat energy between objects of differing temperature. It can be achieved with suitable engineering methods [3] or processes as well as with suitable object materials. Thermal insulation provides a region of insulation in which conduction and convection are reduced [4] and thermal radiation is reflected rather than absorbed by low temperature body.

Thermal conductivity test methods are:

a) Boil off calorimeter

b) Electrical input method

c) Indirect methods

The boundary temperature of some thickness the insulation can be fixed, heat transferred through it can be measured and then apparent thermal conductivity computed using Fourier conduction equation [5]as if the heat transfer mechanism is the only conduction through the insulation. The arithmetic mean of the boundary temperatures is then assumed as the temperature for which the conductivity was found. The apparent thermal conductivity of insulation can thus be used as convenient indices to compare different insulation of same thickness and extrapolation / interpolation are made in order to design equipment using different thickness of the same insulation. Boil-off calorimeter and Electrical input method are the most widely used methods. Indirect methods have limited application and do not possess the accuracy equal to the other methods. Boil off calorimeter and Electrical input method is the most widely used

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methods. Indirect methods have limited application and do not possess the accuracy equal to the other methods.

EXPERIMENTAL SETUP

An Experimental setup as shown in Figure-1 for [6] the investigation of apparent thermal conductivity of different multilayer insulations under evacuation was utilized. The setup details are as follows with corresponding components shown in Table-1.

Figure-1. Experimental set up

A double guarded cylinder boil off calorimeter is used as shown in Figure-2. The calorimeter consists of a test vessel, two guard vessels and outer vessel also called an outer vacuum jacket. There are two filling ports and one pump out port provided on the top cover flange of outer vessel. A feed through is fitted in the cover for taking the RTD leads out from the annular space. Test and guard vessels have fill lines to filled liquid nitrogen and vent lines for the removing nitrogen vapor out. Multilayer insulation is wrapped around test vessel for the determination of 10^{-4} torr is created in the insulation space through the pump out port.

Figure-2. Inner test vessel & Boil off calorimeter.

Low pressure is obtained with the help of the high vacuum pumping system. The vacuum module [7] consists of a diffusion pump and an oil sealed rotary vane type of pump. The pressure range up to 10^{-4} torr to 10^{-6} torr can be obtained from this system. The high vacuum pumping system is shown in below Figure-3.

Figure-3. High vacuum pumping system.

Wet gas meter is used to measure the boil o rate of LN2 in the calorimeter. The flow meter consists of a cylindrical drum, which rotates about a horizontal axis inside a casing approximately half filled with water. As the gas passes through the flow meter, the drum in it is caused to rotate by the successive filling of chambers with the gas. Revolutions of the drum are counted for a definite time period, so that the volume flow rate can be determined.

Figure-4. Gas flow meter.

RTD Pt 100 sensors are used to measure boundary temperatures of the insulation as shown in Figure-5. There are four numbers of sensors, two on the inner boundary and the other two on the outer boundary of the insulation. The temperature [8] indicator indicates the boundary temperatures of the insulation as sensed by the sensors.

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Figure-5. Temperature indicator.

Nitrogen vapor coming out of the test vessel passes through the water saturator and then flow meter. Water saturator and flow meter offer resistance to the flow of nitrogen vapor. Hence static pressure gets built in the test vessel. Therefore the pressure in the test vessel will be little higher than the atmospheric pressure. At this higher pressure, saturation temperature of LN2 will also be higher than the normal boiling point. Therefore, the guard vessels should also be at the same temperature as that of the test vessel in order to,

a) Prevent end heat transfer.

b) Prevent condensation of nitrogen vapor from test vessel since the vent line passes through the upper guard vessel filled with LN2 at atmospheric pressure.

Figure-6. Water bubbler.

For this reason pressure in the guard vessel is required to be increased. This is done by passing the nitrogen vapor coming out of the guard vessels through a column of water provided by the water bubbler.

Figure-7. Water saturator.

Water saturator is a closed cylindrical vessel with two tubes at top. One tube is for inlet of wet nitrogen vapor coming from the test vessel of calorimeter and other is outlet for superheated nitrogen vapor. The outlet tube is connected to the flow meter. The vessel is filled with water. As the wet nitrogen vapor through it, the nitrogen vapor is superheated.

EXPERIMENTAL OBSERVATIONS

The apparent thermal conductivity of multilayer insulation is determined under vacuum. The Apparent thermal conductivity is evaluated at boundary temperatures of LN2 and atmosphere and the interstitial gas pressure of 10^{-4} mbar to 10^{-6} mbar.

Before the calorimeter was assembled, all the vessels, flanges, 'O' rings and 'O' ring grooves were wiped gently with a clean lint free cloth to remove any moisture or dust particles adhering to them. Silicon grease was applied to the 'O' rings. Quantity of vacuum grease used was sufficient only to give the elastomer ('O' ring material) sheen. Excessive use of grease is avoided. 'O' ring was placed in the groove in the flange of vacuum jacket. The cover of vacuum jacket with the assembly of test and guard vessels suspending from it, was placed in position on the flange of vacuum jacket and it was bolted, while bolting uniform pressure is used and care is taken that the 'O' ring is not compressed very much. Multilayer insulation is wrapped around test vessel and it is enclosed by vacuum jacket. Pump out port was connected to the high vacuum pumping system using steel flexible hose pipe, KF 25 couplings was used for the connection.

The experimental results were obtained for the following various combinations of multilayer insulations as shown in Table-1.

Table-1. Combination of MLI with no. of layers.

Insulation materials	No of layers
Aluminum foil - R P Tissue	13
	24
	33
Aluminum foil - Fiber cloth	13
	24
	33
Aluminium foil - Nylon net	13
	24
	33

As shown in Figure-7, the vent line for the nitrogen vapor from the test vessel is connected to the water saturator. The outlet of the vapor from the water saturator is connected to the flow meter a shown in Figure-4 and outlet from the flow meter is open to the atmosphere.

Table-2. Components of experimental setup.

1. Calorimeter	6. Diffusion pump
2. Water saturator	7. RTD sensors
3. Gas flow meter	8. Water bubbler
4. Vacuum pumping system	9. Temperature indicator
5. Rotary pump	

The vent line for the nitrogen vapor from the guard vessels is connected to the water bubbler as shown in Figure-6. Nitrogen vapor after having passed through the water column in the water bubbler passes out in the atmosphere. Leads to RTD sensors [9] are taken out from the calorimeter through a feed through. A flexible hose pipe (size 25mm) connects the calorimeter to the vacuum system. A quick coupling (size 25 mm) is used for the connection.

EXPERIMENTAL CALCULATIONS

The apparent thermal conductivity can be calculated by using Fourier rate equation for the conduction heat transfer [10] using the heat transfer rate through multilayer insulation For a cylindrical geometry,

$$Q = \frac{2 \times \pi \times L \times k \times (Th - Tc))}{(ln\frac{do}{d_i})}$$

$$k = \frac{Q \times ln(\frac{do}{di})}{2 \times \pi \times L \times (Th - Tc)}$$

THEORETICAL CALCULATION

One of the problems associated with the MLI is the effective evacuation of residual gas from the space within the insulation layer. Small vent holes have been used in the foil layers to allow more effective removal of the trapped gas. For a well evacuated MLI, heat is transmitted primarily by radiation and solid conduction [11] through the spacer material. For this situation the apparent thermal conductivity of MLI can be calculated by:

$$K_A = (N/x)^{-1}[h_c + \sigma(T_h^2 + T_c^2)(T_h + T_c)/(2-e)]$$

RESULTS ANS DISCUSSIONS

Under vacuum condition heat transferred by radiation plays a major role. So to minimize the radiation effect, Aluminum foil as a reflective shield is added to the insulation for optimizing apparent thermal conductivity of MLI.

Table-3. The experimental results for apparent thermal conductivity.

Materials	N	Time (s)	Q (W)	ΔT s(K)	K (mW/mK)
Al foil - RP Tissue	13	300	0.023	205.3	0.053
	24	430	0.013	209.1	0.028
	33	320	0.008	201.5	0.008
Al foil - fiber cloth	13	492	0.012	201.5	0.029
	24	510	0.008	205.3	0.018
	33	621	0.004	205.3	0.007
Al foil - Nylon net	13	105	0.04	202.5	0.099
	24	110	0.03	203.6	0.069
	33	113	0.02	203.2	0.017

The apparent thermal conductivity of MLI can be reduced by increasing the layer density up to a certain point as shown in Table-3. If the insulation is compressed too tightly, the solid conductance increases faster than N

/X, so the insulation conductivity also increases as shown in Table-4.

Table-4. Theoretical calculation.

Material combinations	No of layers (N)	Thermal conductivity, k(mW / m K)
Al foil - R P Tissue	13	0.64
	24	0.35
	33	0.25
Al foil - Fiber cloth	13	0.98
	24	0.53
	33	0.38
Al foil - Nylon net	13	3.57
	24	2.85
	33	2.12

COMPARISION BETWEEN EXPERIMENTAL AND THEORITICAL EVALUATION

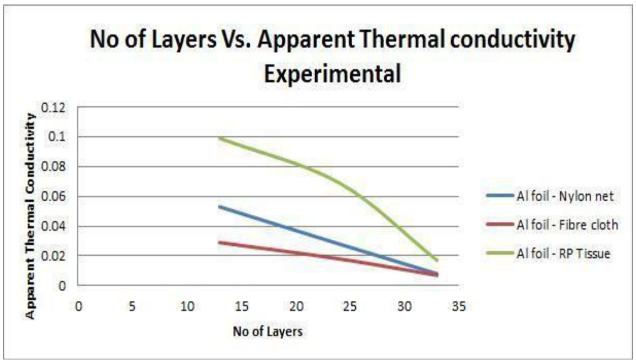

Figure-8. Layers Vs Thermal conductivity [Experimental].

One of the problems associated with the MLI is the effective evacuation of residual gas from the space within the insulation layer. Small vent holes have been used in the foil layers to allow more effective removal of the trapped gas.

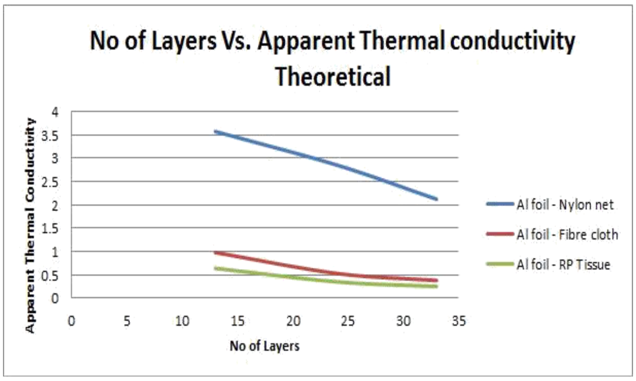

Figure-9. Layers Vs Thermal conductivity [Theoretical].

UNCERTAINTY ANALYSIS

The expected uncertainties in experimentation are as follows: Temperature: ±0.01° C
Dimensions: ±0.01 mm
Heat transfer: ±0.006 W Thermal conductivity: ±0.010%

CONCLUSIONS

The heat leakage is directly proportional to the layer density of insulation materials and inversely proportional to number of layers. So the apparent thermal conductivity of MLI can be reduced by increasing the layer density up to a certain point. Aluminum foil has a reflectivity of 88% and it is available easily in market. So, it is the best reflective shield for MLI. Wrapping of MLI is an important consideration for an experimental work. If the insulation is compressed too tightly, the solid conductance increases faster than layer density so, the insulation conductivity also increases. From experimental results, we can conclude that Al foil & Fiber cloth has lower k value among other insulating materials.

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