Measurement of Apparent Thermal Conductivity of Multilayer Insulation

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Measurement of Apparent Thermal Conductivity of Multilayer Insulation

Major Project Report

Submitted in partial fulfillment of the requirements

For the Degree of

Master of Technology in Mechanical Engineering

(Energy System)

By

Naik Shivang P.

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Declaration

This is to certify that

1. The thesis comprises my original work towards the degree of Master of Technology in Thermal Engineering at Nirma University and has not been submitted elsewhere for a degree or diploma.
2. Due acknowledgement has been made in the text to all other material used.

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Undertaking for Originality of the Work

I, **Naik Shivang P**, Roll. No. **15MMEN01**, give undertaking that the Major Project entitled "**MEASUREMENT OF APPARENT THERMAL CONDUCTIVITY OF MULTI LAYER INSULATION**" submitted by me, towards the partial fulfillment of the requirements for the degree of Master of Technology in **Mechanical Engineering (Energy System)** of Nirma University, Ahmedabad, is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

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This is to certify that the Major Project Report entitled "**MEASUREMENT OF APPARENT THERMAL CONDUCTIVITY OF MULTI LAYER INSULATION**" submitted by **Mr. Naik Shivang P. (15MMEN01)**, towards the partial fulfillment of the requirements for the award of Degree of **Master of Technology in Mechanical Engineering (Energy System)** of Institute of Technology, Nirma University, Ahmadabad is the record of work carried out by him under our supervision and guidance. In our opinion, the submitted work has reached a level required for being accepted for examination. The result embodied in this major project, to the best of our knowledge, has not been submitted to any other University or Institution for award of any degree.

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Abstract

There are many system in which producing and maintaining low temperature is the primary function. These system require cryogenic temperature for the operations. The National Bureau of Standards have chosen to consider the field of cryogenics as the involving temperature below -150°C (126K). Heat leakage is the common problem involving cryogenics applications. Sometimes it is undesirable and should be maintained at minimum level. At low temperature it becomes more difficult to remove given amount of heat and discharge it at ambient temperature. These unwanted heat leakage accounts into economical burden and acts as barrier in cryogenics applications. Therefore the cryogenics 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 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 Fibre glass are coated with Aluminium 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 Fibre glass cloth, R P Tissue, Nylon net etc. For that, A cylindrical boil off calorimeter has been developed and standardized for testing of thermal performance of insulation. It's measurement principle for determining heat flux (Q) and Apparent Thermal Conductivity (KA) of a test specimen at fixed conditions. The heat transferred to the test vessel results in the formation of nitrogen vapour. From the amount of liquid nitrogen boil off rate, the heat transfer rate and subsequently The Apparent Thermal Conductivity of MLI is estimated. The present work is to develop optimum combination of shield and spacer from available materials (Aluminium foil-Fibre glass cloth, Aluminium foil-R P Tissue, Aluminium foil-Nylon net) by experimental investigation of apparent thermal conductivity. The present work also includes the experimental investigation for apparent thermal composite materials from these different combinations of MLI.

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Nomenclature

Layer density	N^{-}
Number of layers	N
Heat flux	Q/A
Cross section area of heads of vessels (m^2)	A
Specific heat of insulation (J/kg.K)	C
Temperature difference across thickness of the insulation (K)	dT
Thickness of insulation specimen (m)	dX
Diameter of vessel (m)	D
Diameter of inner boundary of insulation specimen (m)	di
Diameter of outer boundary of insulation specimen (m)	do
Latent heat of vaporization of LN_2 at atmospheric pressure (kJ/kg)	hfg
Thermal conductivity (mW/mK)	k
External length of test vessel (m)	L
Length of fill line for test vessel (m)	L1
Length of fill line for guard vessel (m)	L2
Length of vent line for test vessel (m)	L3
Length of vent line for guard vessel (m)	L4
Mass of LN2 vaporized per unit time (kg/s)	m
Knudsen number p Internal pressure (N/m^2)	Nkn
Heat rate across insulation (W)	Q
Specific gas constant (J/kg.K)	R
Thickness of vessel (m)	t
Temperature of gas (K)	T
Temperature of cold boundary (K)	Tc
Temperature of hot boundary (K)	Th
Temperature of inner boundary (K)	Ti
Temperature of outer boundary (K)	To
Thermal diffusivity (m^2/s)	α
Density of insulation (kg/m3)	ρ
Mean free path(μm)	λ
Viscosity of gas (kg/m.s)	μ

Chapter 1

Introduction

1.1 Cryogenics

The word cryogenics is the term today is used as synonym for a low temperatures. 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 the field of cryogenics as the involving temperature below -150°C (126K) or -240°F (220°R).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. The range of the field of cryogenics are illustrated on a logarithmic thermometer scale in below figure. [1]

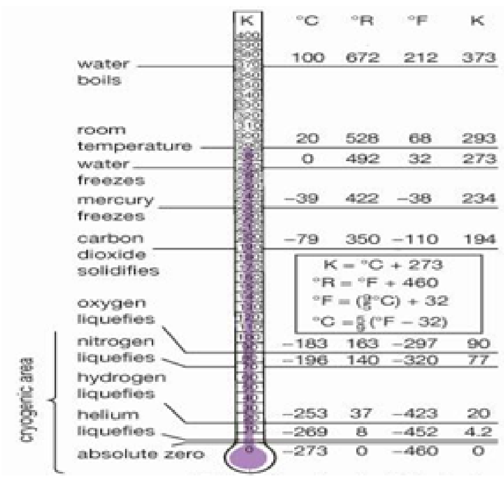

Figure 1.1: Thermometer scale [2]

Storage of cryogen (say, LN2) 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 engineered methods or processes as well as with suitable object materials. Thermal insulation provides a region of insulation in which conduction and convection are reduced and thermal radiation is reflected rather than absorbed by low temperature body.

There are several types of insulation materials that can be used in cryogenics applications,

1. Expanded foam
2. Gas filled powders and fibrous materials
3. Vacuum alone
4. Evacuated powders
5. Opacified powders
6. Multi Layer Insulation

These insulation materials are listed in order of increasing cost and generally in increasing performance. Each insulation to be used for a particular application. In general the performance of thermal insulation is mainly depends on the emittance and temperature of boundary surfaces, it's density, moisture content, the type of pressure and gas contained within it, the thermal shock resistance, the compressive load applied on it.

1.2 Introduction to Multilayer Insulation

Multi Layer Insulation (MLI) was first developed by Petersen of Sweden in 1951. It consists of Alternate Layers of high reflective shields or foils and separated by low thermal conductivity spacers. The high reflecting shields are generally made of Al, Cu or Aluminized Mylar. Aluminium sheet of 6µm thickness is commonly used as low temperature. In order to improve mechanical strength and ease of application, plastic materials like Mylar and Kapton are coated with aluminium.

In general, MLI is a type of high-performance insulators which uses multiple radiation heat-transfer barriers to retard the flow of energy. Individual radiation barriers usually are thin polymer films with vapor-deposited metal on one or both sides because it is impossible to design a blanket that reflects 100 percent of incident radiation. Typically, each reflector will reflect 90 to 99 percent of radiation. The overview of MLI material is illustrated in below fig.

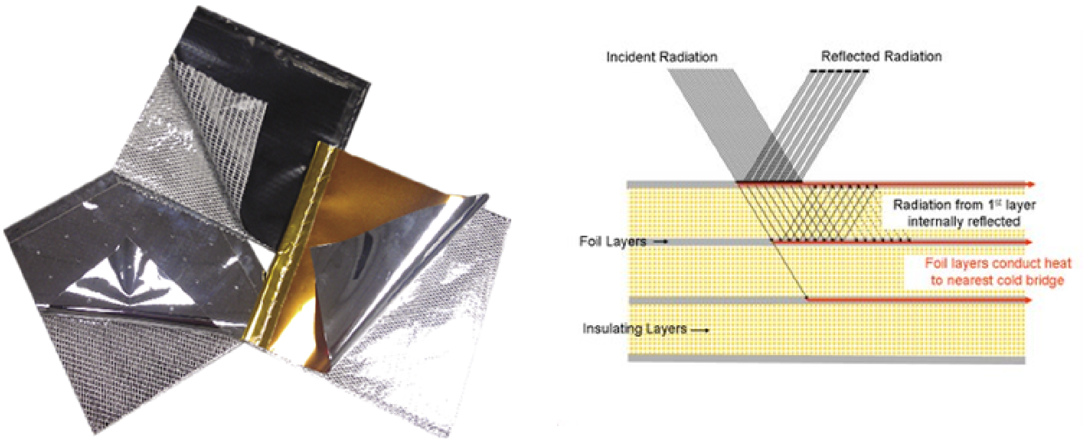

Figure 1.2: MLI Sample [3]

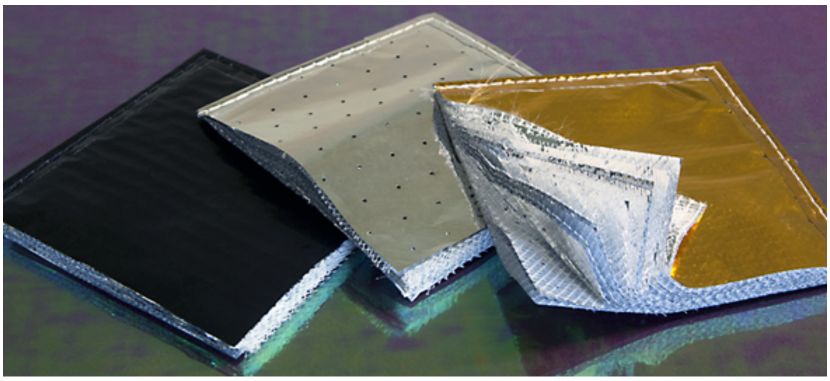

Figure 1.3: MLI Sample [4]

1.2.1 Advantages of Multilayer Insulation

• MLI system can produce "k" values of below 0.1 mw/m-k when properly operating at cold vacuum pressure below about 1×10-4 torr.

• Aluminized thin films offer low emissivity (not greater than 0.35) and excellent radiant barrier performance.

• It saves time by eliminating much of the labor's in installation.

• Cleaner- no messy oils to burn off.

1.2.2 Disadvantages of Multilayer Insulation

• First, there needs to be hard vacuum, below 1× 10-3 torr to be fully effective.

• Maintaining pressures of this range is often a challenge for large systems.
• Tedious installation of Multilayer Insulation , which requires careful attention in order to reduce any
• Thermal linking between layers.

1.3 Modes of heat transfer

Heat transfer is a form of energy movement as a result of temperature difference. There are three modes of heat transfer that must be considered when measurement of Apparent Thermal Conductivity and transportation of thermal energy.

1.3.1 Conduction

Conduction is the energy transfer through a medium by molecular motion. Typically conduction is most important in solid media as there is no induced movement with the exception of lattice vibrations.

Mathematically , the conduction process in one dimensional is described by Fourier's law,

$$Q = K \times A \times \frac{dT}{dX} \tag{1.1}$$

1.3.2 Convection

Convection is a combination of conduction heat transfer advection. It is the transport mechanism through bulk fluid flow.

The mathematical equation to describe convection is known as Newton's law of cooling,

$$Q = h \times A \times (T - T_{\alpha}) \tag{1.2}$$

1.3.3 Radiation

Life would not exist on earth without thermal radiation. Thermal radiation is transferred via electromagnetic spectrum, light, therefore no medium is required to move energy from hot body to cold body. Radiation between two or more bodies depends on a number of factors such as temperature difference of each body, it's view factor, the geometry and emissivity. When a body has an emissivity of unity it is considered a black body whose emitted radiation energy calculated as,

$$Eb(T) = \sigma T^4 \tag{1.3}$$

1.4 Vacuum Technology

1.4.1 Introduction

Vacuum is space that has all matter removed.

The word vacuum comes from Latin roots. It means the empty or void. A perfect vacuum can be defined as a space with no particles of any state (solid, liquid, gas). It is important to note that this definition is only for theoretical understanding .Although in practically, it is impossible to achieve perfect vacuum. Vacuum technology is a important element in cryogenics applications. [13]

1.4.2 Importance of Vacuum in Cryogenics

A person involved in cryogenics is well aware of the importance of vacuum technology in cryogenics systems. One of the most effective cryogenic insulations (multilayer insulation) involves high vacuum together with high reflective shields and separated by low conductivity spacers. A high order of vacuum of 10-5 in a vacuum insulated vessel is required for low heat transfer at cryogenic temperatures. At these low pressures, the gas molecules are so far apart that convection is virtually eliminated. The gas, under this condition, is not treated as a continuous medium. Under this pressure level, molecules strike the side of their channel more often than they strike to each other.

1.4.3 Need of Vacuum in Cryogenics

The net heat leak into cryogenic vessel is,

$$Q_{net} = Q_{solidconduction} + Q_{gasconduction} + Q_{convection} + Q_{radiation} \tag{1.4}$$

From above equation, we can say that heat is transferred or leaked by solid conduction, gas conduction, convection and radiation. Gas conduction and convection are minimized by having vacuum between two surfaces of different temperatures. Therefore, vacuum technology is very important aspects in cryogenic systems.

Vacuum order is typically regarded as follows ;

Table 1.1: Relation of pressure and vacuum [5]

Degree of vacuum	Pressure
Rough vacuum	25 torr < p < 760 torr
Medium vacuum	10-3 torr < p < 25 torr
High order vacuum	10-3 torr < p < 10-6 torr
Very high order vacuum	10-6 torr < p < 10-9 torr
Ultra high order vacuum	Below 10-9 torr

1.5 Methods for measurement of apparet thermal conductivity of Multilayer Insulation

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 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 n 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 has limited application and does not possess the accuracy equal to the other methods.Boil off calorimeter and Electrical input method are the most widely used methods. Indirect methods has limited application and does not possess the accuracy equal to the other methods.

All the above methods are differ only in the way of determination of heat flux through test . Once the heat flux through test specimen is known, the Apparent Thermal Conductivity is calculated using Fourier's following equation ;

$$Q = K \times A \times \frac{dT}{dX} \tag{1.5}$$

1.5.1 Boil off calorimeter

The new cryostats use steady-state liquid nitrogen boil off calorimeter methods to determine Apparent Thermal Conductivity and Heat flux. A cryostat test series begins with a vacuum pumping or gaseous nitrogen purge, as required. A test is defined as the steady-state heat leak rate through the specimen at fixed environmental conditions including a stable warm-boundary temperature (WBT), cold-boundary temperature (CBT) and cold vacuum temperature (CVP). A liquid nitrogen maintains the CBT at approximately 78.36 K. The WBT is maintained at approximately 293 K. Vacuum levels cover the full range from high vacuum (10-4 torr) to soft vacuum (~1 torr) to no vacuum (760 torr). The refrigerant is typically liquid nitrogen but other gases can used as required. The rate of heat transfer (Q) is directly proportional to the liquid nitrogen boil off rate. The flow rate is measured by mass flow meter. The Apparent Thermal Conductivity (k) is determined from Fourier's law for heat conduction. The heat flux is measured by dividing the total heat transfer rate by effective area of heat transfer.

1.5.2 Electrical Input Method

Insulation heat flux is determined from a measurement of the electrical energy, which is dissipated, thermally in a resistive load uniformly distributed over the measuring area of the test specimen. Flat plate or cylindrical geometries may be used for all types of insulation.

The heated surface is located alone at boundary of the specimen while cryogenic fluid is used for the heat sink. So no boil off measurements are made, the cryogen reservoirs are not guarded. A guard heater is used so that one dimensional heat transfer takes place through insulation specimen. The heat input to the heater is taken as the heat through the insulation.

1.5.3 Indirect Method

1.5.3.1 The Flash Method

It measures the increase in temperature at the back surface of the sample when the front side of the sample is irradiated by higher energy pulse from laser or flash lamp. The rise in temperature in line with pattern of propagation of the pulse, thus giving a qualitative and not a quantitative measurement of heat transfer. Composite materials usually furnish erroneous results, more so when translated into conductivity values.

1.5.4 Direct Methods

1.5.4.1 Transient Method

It is used to measure thermal diffusivity. The thermal conductivity is then computed using known or estimated specific heat data and specimen density as follows:

$$\alpha = \frac{k}{\delta} \tag{1.6}$$

$$k = \alpha \times \delta \times c \tag{1.7}$$

1.5.4.2 Comparative Method

The specimen is placed between a heat source and a material of known thermal conductivity placed at the cold boundary. The quantity of heat passing through the specimen and the material of known conductivity is equal.

Since thermal conductivity and geometry of the material placed at the cold boundary are known, heat flow rate through the material is calculated using Fourier conduction equation. The material acts as a heat flow meter.

1.6 Insulation Testing Method

Presently, there are two test methods for the insulation testing like combination of aluminium foil, fiber glass paper, polyester fabric, silica aerogel composite blanket, Nylon net, silica aerogel powder and syntactic foam can be tested by these methods [6]

1.6.1 Cryostat test method

The cryostat apparatus, shown in Figure 1.4 (a), is a sleeved liquid nitrogen boil-off calorimeter that enables direct measurement of the apparent thermal conductivity (k-value) of the insulation system at a vacuum level between 5x10-5 and 760 torr. The cold mass consists of a 10 liter capacity test chamber with 2.5 liter (each) guard chambers on top and bottom over which the instrumented, insulated sleeve is installed. A removable vacuum can allows quick changeover of test articles. The apparatus is supplied with liquid nitrogen, sub cooled to approximately 77.8 K, as depicted in the simplified system schematic of Figure 1.4

The measurable total heat transfer rate is from 0.2 to 20 watts, corresponding to a boil-off flow rate of from 50 to 5000 cubic centimetres per minute of gas at standard temperature and pressure. The vacuum pumping system consists of a combination of turbopumps and mechanical pumps plus a finely metered gaseous nitrogen supply to control pumping speed.Materials are installed around a cylindrical copper sleeve using the custom-built I meter wide wrapping machine as shown in figure 1.5.

Sensors are placed between layers of the insulation to obtain complete temperature-thickness profiles. Temperatures of the cold mass (maintained at near 77.8K), the sleeve (CBT), the insulation outer surface (WBT), and the vacuum can (maintained at near 313 K by thermal shroud) are measured as shown in Figure 1.6The steady-state measurement of insulation performance is made when all temperatures and the boil-off flow are stable. The k-value of the insulation is directly determined from the measured boil-off rate, temperature difference (WBT-CBT), latent heat of vaporization, and geometry of the insulation.

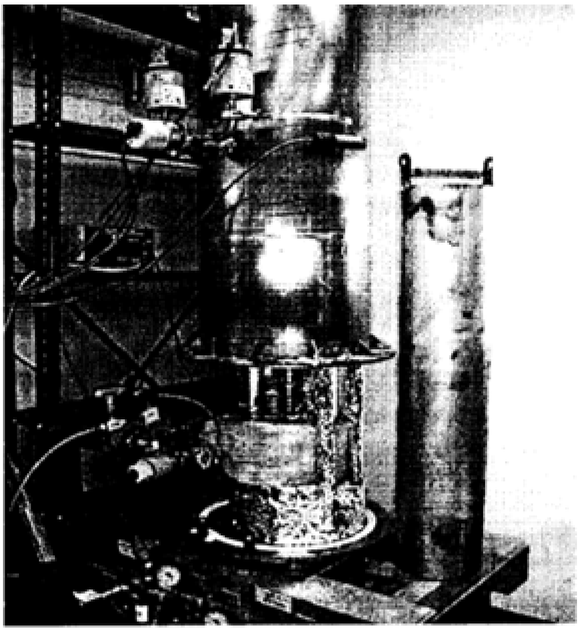

Figure 1.4: Cryostat apparatus[6]

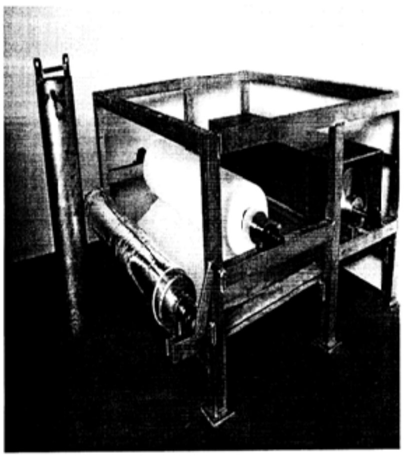

Figure 1.5: MLI wrapping machine & copper sleeve assembly[6]

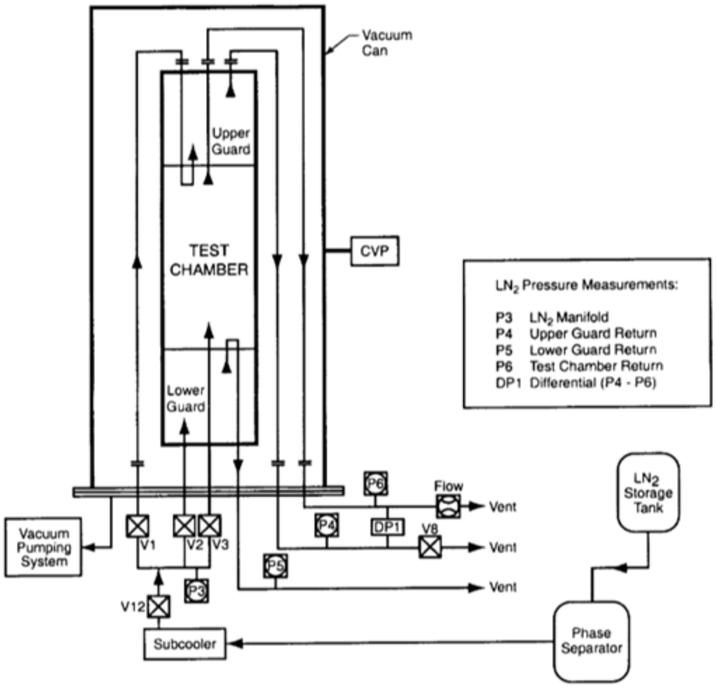

Figure 1.6: Simplified schematic of the cryostat test apparatus indicating key system measurements [6]

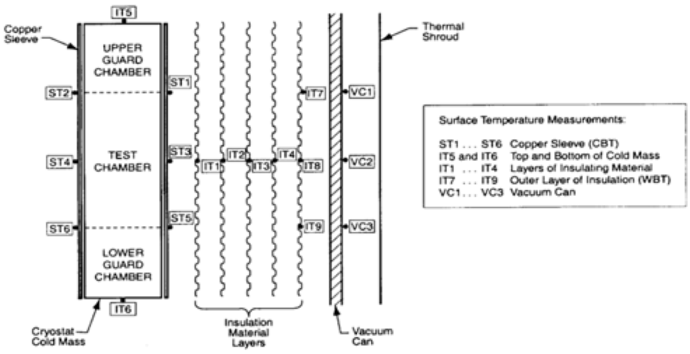

Figure 1.7: Diagram of temperature sensor locations for a typical insulation test configuration[6]

1.6.2 Dewar test method

The Dewar test apparatus provides a means of determining the "real world" performance of aninsulation system with consideration given to the fabrication, quality control, testing and operation of cryogenic tank. This method gives a direct measure of actual system performance as a function of cold vacuum pressure(CVP). A custom built 0.5m wide wrapping machine is used for installing continuously rolled material on the inner vessel. A vacuum pumping stationwith a shut off valve and brake out system with a temperature controller are connected during test preparations. Capacitance monometers are connected to the vacuum port use for measuring vacuum levels from 5×10^{-5} to 100 torr. A transfer standard mass flow meter with a thermal conditioning coil is connected to the dewar. The entire set up is mounted on a precision weight scale for the primary test measurement. The ambient conditions (temperature, barometric pressure and humidity) are also monitored. The weight loss due to the boil off of nitrogen gas is proportional to the total heat leak into the inner vessel.

Chapter 2

Literature Review

2.1 Literature Study

Various literature paper's are conducted for Thermal Performance of Multilayer Insulation.

Some of review's are listed below;

2.1.1 Optimization of Layer Densities for Spacecraft Multilayered Insulation Systems [7]

Numerous tests of various multilayer insulation systems have indicated that there are optimal densities for these systems. However, the only method of calculating this optimal density was by a complex physics based algorithm developed by McIntosh. In the 1970's much data were collected on the performance of these insulation systems with many different variables analyzed. All formulas generated included number of layers and layer density as geometric variables in solving for the heat flux, none of them was in a differentiable form for a single geometric variable. It was recently discovered that by converting the equations from heat flux to thermal conductivity using Fourier's Law, the equations became functions of layer density, temperatures and materials property only. The thickness and number of layers of the blanket were merged into a layer density. These equations were then differentiated with respect to layer density. By setting the first derivative equal to zero and solving for the layer density, the critical layer density was determined. Taking a second derivative showed that the critical layer density is a minimum in the function and thus the optimum density for minimal heat leak, this is confirmed by plotting the original function. This method was checked and validated using test data from the Multipurpose Hydrogen Test bed which was designed using McIntosh's algorithm.

2.1.2 Study on the heat transfer of high vacuum multilayer insulation tank after sudden, catastrophic loss of insulating vacuum[8]

One of the worst accidents that may occur in a high vacuum multilayer insulation (HVMLI) cryogenics tank is a sudden, catastrophic loss of insulating vacuum (SCLIV). There is no doubt that the gases leaking into the insulation jacket have some influence on the heat transfer process of it. However, this issue has not been thoroughly studied so far. In this paper, a test ring was built up and experiments were conducted using a SCLIV cryogenic tank and with nitrogen, helium and air as the working medium respectively. The venting rates of the tank and temperature in the insulation jacket were measured respectively after the three different gases leaking into the jacket. A heat transfer model describing the heat transfer process of a SCLIV tank was also presented. The calculated results using this model were compared against the experimental data. It is found that the heat transfer performance of the HVMLI cryogenic tank after SCLIV is strong relevant to the type of gas leaking into the insulation jacket.

2.1.3 The effective thermal conductivity of insulation materials reinforced with aluminium foil at low temperatures[9]

The effective thermal conductivity (ETC) of multilayer thermal insulation materials was experimentally investigated as a function of temperature (0–25 $^\circ$C). The materials consisted of binary/ternary glass wools or ternary expanded polystyrene foams reinforced with aluminium foil. The experimental measurements were performed using a guarded hot plate with temperature differences of 5, 10 and 15 $^\circ$C. The ETC decrease with reinforcement with aluminium foil at the same temperature or with temperature differences of 5 and 15 $^\circ$C. In addition, it was clearly observed that the ETC decrease sharply with decreased temperature. Consequently, reflective materials may reduce the ETC at low temperatures.

2.1.4 A calorimeter for measurements of multilayer insulation at variable cold temperature[10]

An improved calorimeter cryostat for MLI thermal performance measurements has been designed and put into operation at the TU Dresden.

Based on a liquid helium cooled flow cryostat, it allows the setting of any cold level temperature between approx. 30 K and ambient temperature. Thermal shields and all embracing radiation guards at both ends can be kept at nearly identical temperature and the cooling of the mechanical support cold test surface temperature and the cooling of the mechanical support and radiation shields can be independently controlled.Insulationspecimensarewrappedaroundatestcylinderwithasurfaceof0.9m2. The heat transfer through the MLI is measured by recording the mass flow and the inlet and outlet temperature of the cooling fluid. Measurements both in horizontal and vertical orientation can be performed or compared respectively. Moreover the effect of an additional vacuum degradation as it might occur bydecreasinggettermaterialperformanceinrealsystemsatelevatedtemperatures can be studied by controlled inlet of an elective gas.

2.1.5 Test apparatus utilizing a Gifford-McMahon cryocooler to measure the thermal performance of multilayer insulation[11]

A vertical cylindrical calorimeter for measuring the thermal performance of multilayer insulation (MLI) has been developed. Two concentric oxygen-free high-conductivity copper drums are wrapped with sample MLI blankets, and are cooled using a two stage Gifford-McMahon cryocooler. As the drums are vertically supported, the layer density of the MLI sample is unaffected by gravity. The inner drum is cooled by the 2nd stage of the cooler and is maintained at a temperature of about 6 K. The outer drum is maintained at a temperature of about 65 K by connecting it to the first stage of the cooler. The heat transfer through the blanket is determined by measuring the temperature difference across the stainless steel thermal resistance tube in a heat flow meter placed between the drum and cold finger of the cryo cooler.

2.1.6 Cylindrical boil off calorimeters for testing of thermal insulation systems[12]

Cryostats have been developed and standardized for laboratory testing of thermal insulation systems in a cylindrical configuration. Boil off calorimeter is the measurement principle for determining the effective thermal conductivity (ke) and heat flux (q) of a test specimen at a fixed environmental condition (boundary temperatures, cold vacuum pressure, and residual gas composition). Through its heat of vaporisation, liquid nitrogen serves as the energy meter, but the design is adaptable for various cryogens.

The main instrument, cryostat -100, is thermally guarded and directly measures absolute thermal performance. A cold mass assembly and fall fluid and instrumentation feed through are suspended from a lid of the vacuum canister; and a custom lifting mechanism allows the assembly and specimen to be manipulated easily. Each of three chambers is filled and vented through a single feed through for minimum overall heat leakage. The cold mass design precludes direct, solid-conduction heat transfer (other than through the vessel's outer wall itself) from one liquid volume to another, which is critical for achieving very low heat measurements.

Chapter 3

Experimental Setup

An experimental setup for the investigation of thermal conductivity of different multilayer insulations under evacuation was utilized.

The setup detail are as following:

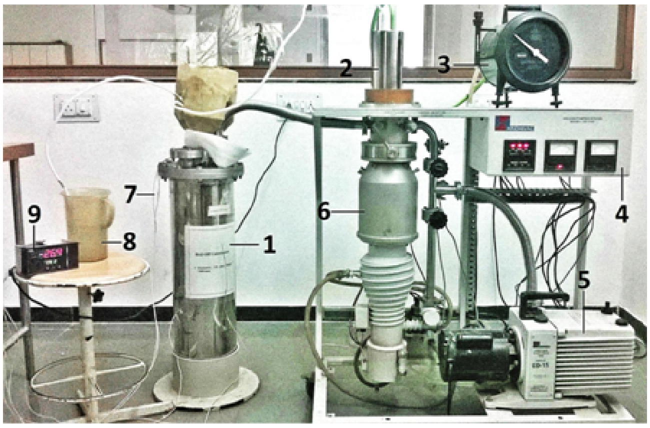

Figure 3.1: Layout of setup[13]

1. Calorimeter	7. Temperature indicator
2. Water saturator	8. Water bubbler
3. Wet gas flow meter	9. Fill line for test vessel
4. High vacuum pumping system	10. Vent line for test vessel
5. RTD pt 100 sensors	11. Fill line for guard vessel
6. Feed through	12. Vent line for guard vessel

3.1 General layout of experimental setup

The layout of the experimental setup for determining the Apparent Thermal Conductivity of Multilayer Insulation is shown in 3.2

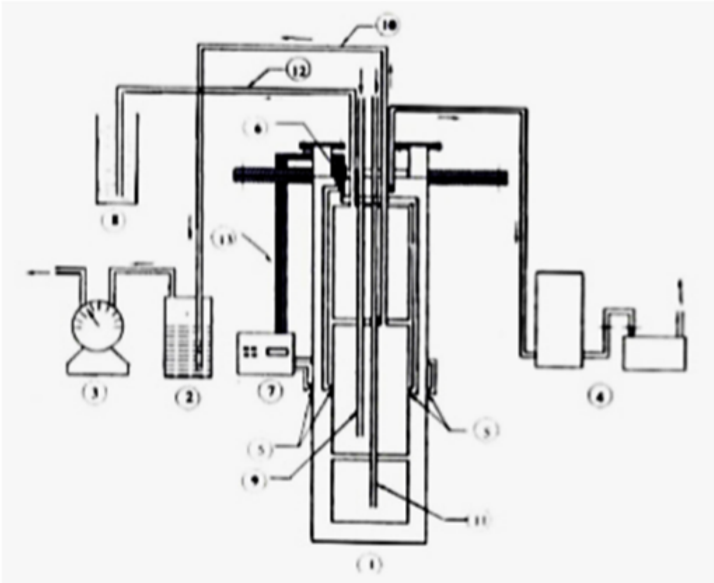

Figure 3.2: Experimental set up

1. Water bubbler	6. Gas flow meter
2. S.S funnel	7. Vacuum pumping system
3. Calorimeter	8. Rotary pump
4. Temperature indicator	9. Diffusion pump
5. Water saturator	10. Temperature sensors

From fig 3.2, 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 and outlet from the flow meter is open to the atmosphere.

The vent line for the nitrogen vapor from the guard vessels is connected to the water bubbler. Nitrogen vapor after having passed through the water column in the water bubbler passes out in the atmosphere. Leads to RTD sensors 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.

3.2 Setup Description

The main components of the experimental set up are follows.

1. LN2 boil off Calorimeter
2. Water saturator
3. High vacuum pumping system
4. Gas flow meter
5. Rotary pump

6. Diffusion pump
7. Temperature sensors
8. Water bubbler
9. Digital temperature indicator

3.2.1 Boil off calorimeter

A double guarded cylinder boil o calorimeter is used as shown in Fig. 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 iswrapped around test vessel for the determination of Apparent Thermal Conductivity. A vacuum of the order of 1×10-4 torr is created in the insulation space through the pump out port.

Figure 3.3: Inner test vessel & Boil off calorimeter

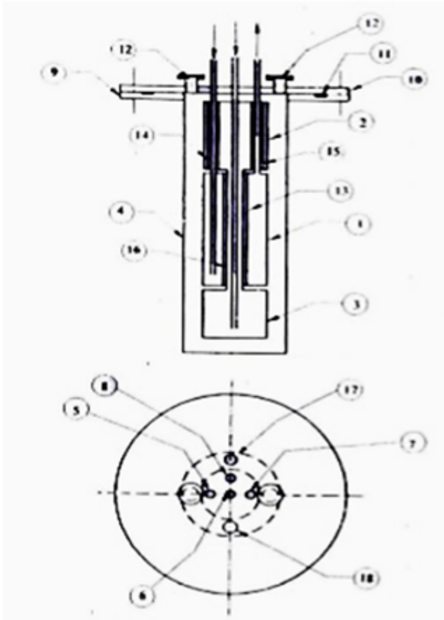

Figure 3.4: Calorimeter[13]

1. Test vessel	10. Cover
2. Upper guard vessel	11. 'O' ring
3. Lower guard vessel	12. Powder filling port
4. Vacuum jacket	13. Tube for isolation of line
5. Fill line for test vessel	14. Tube for isolation of fill line
6. Fill line for guard vessel 1	15. Tube for isolation of vent line
7. Vent line for test vessel	16. Tube connecting guard vessel
8. Vent line for guard vessel	17. Pump out port
9. Flange	18. Feed through

3.2.2 Water saturator

The nitrogen vapor coming out of the calorimeter may be wet. Therefore it is passed through water. Due to heat received from water, the nitrogen vapor becomes dry and gets superheated up to the temperature of water. The vapor then enters in to the gas flow meter. If wet vapor is allowed in to the gas flow meter, the values of flow rate indicated will be erratic.

3.2.3 High vacuum pumping system

Low pressure is obtained with the help of the high vacuum pumping system. The vacuum module consists of a diffusion pump and an oil sealed rotary vane type of pump. The pressure range up to 1×10-4 torr to 1×10-6 torr can be obtained from this system. The high vacuum pumping system is shown in below Fig.

Figure 3.5: High vacuum pumping system

3.2.4 Flow meter

Wet gas meter is used to measure the boil off 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 3.6: Gas flow meter

3.2.5 Temperature sensors

RTD Pt 100 sensors are used to measure boundary temperatures of the insulation. There are four numbers of sensors, two on the inner boundary and the other two on the outer boundary of the insulation.

3.2.6 Temperature indicator

The temperature indicator indicates the boundary temperatures of the insulation as sensed by the sensors.

Figure 3.7: Temperature indicator

3.2.7 Water bubbler

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,

1. Prevent end heat transfer.
2. Prevent condensation of nitrogen vapor from test vessel since the vent line passes through the upper guard vessel filled with LN2 at atmospheric pressure.

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 3.8: Water bubbler

3.3 Specifications of Experiment

3.3.1 Calorimeter

All components that mentioned above are made from SS-304.

3.3.2 High Vacuum Pumping System

HINDHIVAC (MODEL VS 114D).

3.3.2.1 Rotary vacuum pump

Ultimate vacuum 1×10^{-3} mbar. High Molecular Distilled Oil Grade MD-504 is used

3.3.2.2 Diffusion pump

Ultimate vacuum 1×10^{-6} mbar . Dow Coring 704 silicon fluid (100 cc) is used.

3.3.2.3 Pirani gauge

Range 0.5 mbar to 1×10^{-3} mbar.

3.3.2.4 Penning gauge

Range 1 : 1×10^{-3} mbar to 1×10^{-5}mbar. Range 2 : 2×10^{-5} mbar to 1×10^{-6} mbar.

3.3.3 Flow meter

Wet gas type: Flow range 0.5 to 135 lph.

Minimum pressure 500 Pa.

Maximum pressure 3×10-3 Pa.

3.3.4 Temperature sensors

RTD Pt 100.

3.3.5 Temperature indicator

Make F & B Japan Number of channels 16.

3.4 Assembly of test and guard vessels

3.4.1 Test vessel

It is made of SS-304 tube.

Standard tube size of outer diameter 89 mm and thickness 2 mm is used. Ends(Heads) of vessel are also 2 mm thick and welded to shell of the test vessel. Total height of test vessel is 295mm. Capacity of the test vessel to hold LN2 is 1.65 litre.

3.4.2 Guard vessel

To prevent the heat transfer from top and bottom sides of the test vessel, upper and lower guard vessels are used respectively. These vessels are also filled with LN2 and are nearly at same temperatures as end of the test vessel. Thus heat transfer to the test vessel from top and bottom side is cut off.

Guard vessels are also made of the same diameter and thickness as that of the test vessel. The capacity of guard vessels to hold LN2 is 1.94 litre.

The pressure in guard vessel is kept a few mm of Hg higher than that in the test vessel. As a result, saturation temperature of LN2 in guard vessels is maintained a little higher than that in the test vessel. This ensures that condensation of nitrogen vapor does not take place as it passes through the vent line of the test vessel, which passes through the upper guard vessel. However temperature in the guard vessels is not maintained very high to reduce the error due to transfer of heat from guard vessels to the vessel. The pressure in guard vessels is kept 11 to 2 mm of Hg higher than that in the test vessel.

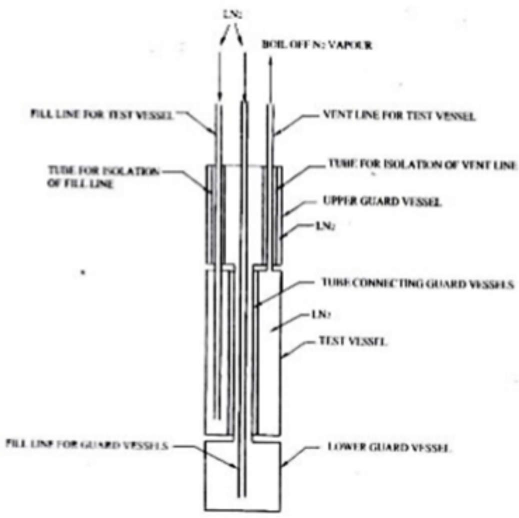

Figure 3.9: Assembly of test and guard vessel[13]

3.4.3 Pump out port

Pump out port is provided on the flange cover of the vacuum jacket to produce vacuum in the jacket. The port connection is made of 25mm diameter , 3mm thick 115 mm high SS – 304 tube. A large diameter connecting tube is used to keep the resistance low. The pump output is welded to the flange cover of the vacuum jacket with one of its ends projecting into the vacuum jacket and the other on top of flange cover. A cap with a 400 wire mesh is screwed to the end inside the vacuum jacket to prevent the powder from being drawn in to the vacuum pumping system. The other end of the pump out connection is provided with a quick coupling KF 25(25 mm).

3.4.4 Instrumentation feed through

Instrumentation feed through is mounted on the flange cover of vacuum jacket for taking the leads of RTD sensors out of the vacuum jacket. There are two RTD sensors having two lead wires for each mounted on the test vessel. Hence a four pin feed through is used.

3.4.5 Fill and vent lines

There is a fill line for each the test vessel and the two guard vessel, for filling LN2 in the test and the guard vessels. Also there is a vent line for each, the test vessel and the two guard vessels. The vent lines are provided in the vessels for the nitrogen vapor to come out. The fill and vent lines are 6.3 mm diameter 0.5 mm thick tubes of SS – 304. The diameter and thickness of these lines is kept at a minimum to reduce the axial heat conducted to the test vessel.

One end of these lines is outside the calorimeter in the atmosphere whereas the other end is connected to the vessels. Thus one end of the lines is at atmospheric temperature and the other end is at LN2 temperature. Very small thickness of fill and vent lines keep the axial heat conduction considerably low. The lengths of the fill and vent lines are decided on the basis of overall dimensions of the calorimeter. The lengths of these tubes are as under ,

- Fill line for test vessel 735 mm
- Vent line for test vessel 460 mm
- Fill line for guard vessel 850 mm
- Vent line for guard vessel 205 mm

3.4.6 Water saturator

It 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.

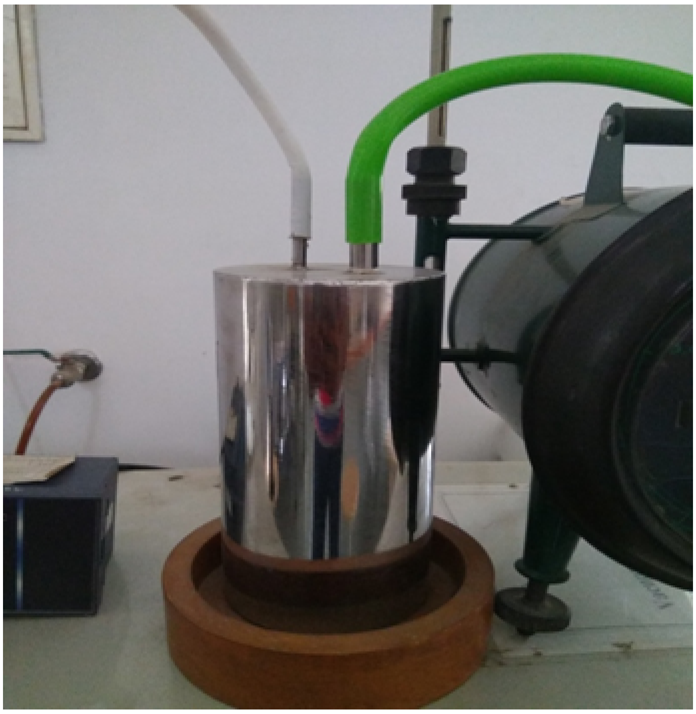

Figure 3.10: Water saturator

3.5 Design aspects of calorimeter

3.5.1 General design considerations

1. The calorimeter should be strong enough to withstand the atmospheric pressure acting on it when vacuum is produced in the insulation space of the calorimeter.

2. The capacity of test and guard vessels to hold LN2 should is sufficient so that the experiment can be performed uninterrupted. Due to the transfer of heat to the test and guard vessels from the surroundings, LN2 in the vessels is vaporized.

3. The boil off rate of LN2 in the test vessel of the calorimeter is used as a measure of heat flux through the insulation specimen and then this flux is used to calculate its apparent thermal conductivity. Thus all the heat reaching the test vessel and causing the boil off of the LN2 in it must pass through the insulation. Any extraneous heat reaching the test vessel should be minimum so as to reduce the error in determine apparent conductivity. Therefore, heat transfer along the length of the calorimeter (end heat transfer) and heat conducted to the test vessel along the fill and vent lines should be minimum.

4. The surface of test vessel forms cold boundary of the insulation specimen, the temperature of the surface of test vessel has to be uniform to reduce the error in deter mine of apparent thermal conductivity.

5. In order to minimize the error, the thickness of the specimen insulation should be uniform in the annular space. If the test vessel and outer vessel (vacuum jacket) are not concentric, thickness of insulation in annular space becomes uneven. Hence the test vessel and outer vessel should be concentrically located.

Chapter 4

Experimental Procedure

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 1×10^{-4} mbar to 4×10^{6} mbar.

4.1 Procedure

4.1.1 Procedure for boil-off calorimeter

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.

4.1.2 Procedure to operate and shut down of the vacuum pumping system

4.1.2.1 Operate the vacuum pumping system

1. Switch on the R.P. by pressing the rotary pump start switch or circuit breaker on the control panel.

2. Open the B.V. slowly keeping R.V. closed and observe the reading in Pirani gauge

by selecting gauge heads 1.

3. As soon as the Pirani gauge shows a vacuum better than 0.05 m bar switch on the D.P. by selecting the D.P. start switch or circuit breaker on the front panel.

4. Make sure that water connection are given to the D.P. cooling line. The D.P. takes about 30 minutes to attain the operating temperature.

5. Close B.V. and slowly open the R.V. Select gauge head 2 in the Pirani gauge to read the rough vacuum.

6. When the vacuum in the collar reaches better than 0.05 m bar close the R.V. and slowly open the B.V. Now the system is ready to test for high vacuum.

7. Open the H.V.V. slowly without applying much force.

8. When vacuum improves better than 0.001 m bar switch on the penning gauge and select the range 1. The pointer will now show the exact vacuum in the collar.

Note : Sometimes the ionisation phenomenon on which the penning gauge works will not begin as soon as it switched on. So keep the gauge on for some time.

The chamber should be perfectly dry and clean. If there is any contamination due to the water vapors and organic vapors released from chamber while evacuating or while doing experiment. It is advisable to protect the system from these contaminates by using proper traps like fore line trap, liquid nitrogen trap, cold trap or high vacuum valve etc. Otherwise performance will deteriorate within no time.

4.1.2.2 Shut down of the vacuum pumping system

It is recommended to leave the chamber under vacuum. This reduce pump down time and leaves the system clean.

1. Switch of the penning gauge

2. Close the H.V.V. slowly without applying much force .

3. Close the R.V. if it is opened.

4. Switch off D.P. heater and keep the R.P. running for about 300 minutes by keeping B.V. open position. Allow the water flow to cool down the D.P.

5. Switch off the Pirani gauge.

6. Close the B.V. and water connection.

7. Switch of the R.P.

4.1.3 Procedure to pour LN_2 in vessels

• LN_2 is poured into Guard and Test vessels with the help of conical flask from top of tubes which are mounted on the calorimeter.

• When LN_2 began coming out of vent line, the vessels are taken to be completely filled.

• When LN_2 is poured into guard and test vessels , interstitial pressure decreased to 1×10^{-6} mbar. Since much a low ultimate pressure is obtained, so no need to fill LN_2 trap of vacuum pumping system.

• We should have highly safety precaution while pouring LN_2.

4.1.4 Procedure for water saturator , flow meter and water bubbler

• Water was filled in the water saturator to the height of 70 mm.

• If the height of water in the water saturator is too small, contact time will be less between the wet nitrogen vapor entering into the water saturator and the water in it and there is a possibility of nitrogen vapor to leave the water saturator and the water in it and there is a possibility of nitrogen vapor to leave the water saturator as a wet vapor only.

• On the other hand if the height of water column is too large unnecessarily more resistance will be introduced to the nitrogen vapor passing though the water saturator and more pressure will be developed in the test vessel.

• Flow meter was filled with distilled water up to the gauge mark on the level indicator and it was level indicator and it was leaved using the levelling screws. The flow rate of nitrogen gas was small. Therefore minimum pressure drop of 50 mm of water was considered across the flow meter. Thus neglecting the pressure drop in connecting tubes, pressure drop across the water saturator and flow meter is 120 mm of water. Therefore 120 mm of water gauge pressure will be developed in the test vessel.

• As discussed earlier pressure in the guard vessels is kept 1 to 2 mm of Hg higher than that test vessel. This pressure is maintained by passing the nitrogen vapor coming out of guard vessels through a column of water in the water bubbler.

• Hence water bubbler was filled with water to the height of 150 mm so that 30 mm of water gauge more pressure would be developed in the guard vessels.

• Vent line of test vessel was connected to the inlet of water saturator using a flexible Teflon tube.

- Outlet of water saturator was connected to the flow meter using a flexible PVC tube.
- Vent of the guard vessels was connected with a flexible teflon tube to the water bubbler.

4.2 Working

- Due to the transfer of heat through multilayer insulation material radially inwards, LN_2 in the test vessel starts vaporizing.
- Steady state was reached in about three hours.
- Temperature indicator was switched on.
- Parameter as follows were measured and recorded in the observation table.
- One revolution of pointer on the dial of the flow meter indicated 0.5 litre of volume flow.
- To measure flow rate of nitrogen gas, time required for 3 litre of gas to flow through the flow meter was measured in seconds using a stop watch.
- Then 3 litre flow of nitrogen gas was divided by the time taken. In this way, volumetric flow rate of the gas in litre per second was obtained.
- Temperature of the nitrogen gas passing through the flow meter was measured using a thermometer mounted on the flow meter.
- There are two sensors mounted for each boundary temperature to be measured. Average of the two temperatures on a boundary is taken as the boundary temperature.
- Boundary temperatures are indicated by the temperature indicator and recorded. Ultimate pressure is indicated by the penning gauge and recorded.

4.3 Planning of insulations for experimental work

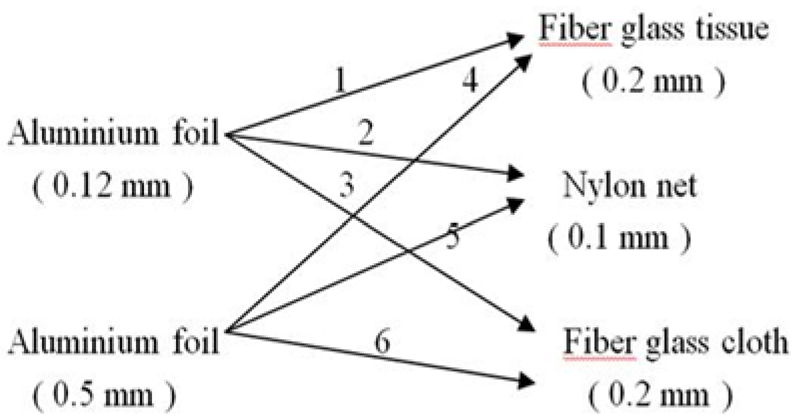

Figure 4.1: Planning of insulations

Above fig shows various combinations of Multilayer insulation to be worked upon it.

STEP 1

To test the thermal conductivity with various insulating materials, different thickness of reflecting shield as well as spacer material combinations to be prepared.

STEP 2

For Reflective shields, high reflectivity and low emissivity insulating material are necessary in MLI. Aluminium foil has reflectivity of 88% and ε is equal to 0.001 to 0.004. Thus Aluminium foil is the optimum choice as reflective shield material.

STEP 3

For spacers, material with low thermal conductivity is necessary in MLI. Such materials can be found in various forms like Nylon net, Tissue paper, Powder, Fabric etc. From above materials suitable for MLI are to be selected. Hence we have selected Nylon net, R P Tissue and Fibre glass cloth as spacer materials for MLI.

STEP 4

Thermal Conductivity of various materials are illustrated in table 4.1

Table 4.1: K value of various insulating materials

Material	Thermal Conductivity, k (W/mK)
Air	0.02
Foam , Polyurethane	0.03
Fibre glass cloth	0.04
Cotton	0.06
Sawdust	0.06
Nylon net	0.25
R P tissue	0.05

STEP 5

Aluminium foil as a reflective shield is the best insulation material as compared to others. The comparison for different material is illustrated in fig 4.2.

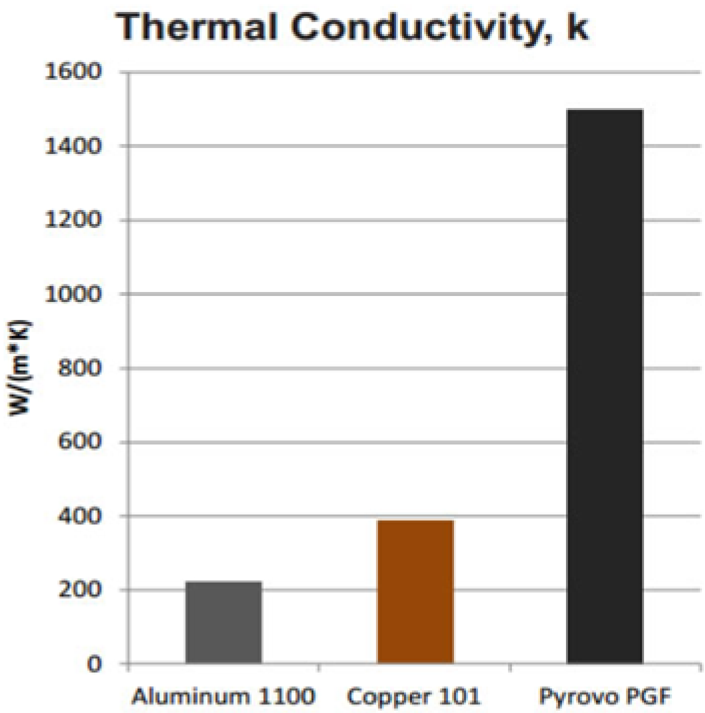

Figure 4.2: Reflective shield Vs Thermal conductivity

Step 6

Layer density is the important aspect for measurement of Apparent Thermal Conductivity of MLI. So optimum layer density has to be maintained for achieving low thermal conductivity.

The equation for optimum layer density is,

$$N_{OPT} = [\frac{C_R \times \varepsilon \times (T_{H^{4.67}} - T_{C^{4.67}}) + C_G \times P \times (T_{H^{0.52}} - T_{C^{0.52}})}{1.63 \times C_S \times (T_H - T_C)}]^{1/2.63}$$

STEP 7

After obtaining optimum layer density for insulations, No of experiments will be conducted for measurement of Apparent thermal conductivity of MLI.

STEP 8

With the results obtained for these insulations, further experiments can be conducted with composite materials which prepared with the combinations of last performing materials.

4.4 Experimental Uncertainty

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%

The details of the calculations performed for determining the uncertainty in the thermal conductivity is shown in Appendix A

Chapter 5

Results and Discussions

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

The experimental investigations are discussed in this chapter.

5.1 Experimental observations

As stated earlier, the experimental results were obtained for the following various combinations of multilayer insulations,

Table 5.1: Combination of MLI with no of layers

Insulation material	Layers
Aluminium foil - R P tissue	13
	24
	33
Aluminium foil - Fibre cloth	13
	24
	33
Aluminium foil - Nylon net	13
	24
	33

The observations recorded for the experiments conducted as per the above planned combinations are presented in Table 4.2

Table 5.2: The experimental results for apparent thermal conductivity

Materials	N	Time for volume flow (s)	Q	$\triangle T$	K (m W/mK)
Al foil - R P 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 - Fibre cloth	13	492	0.0123	201.5	0.029
	24	510	0.0085	205.3	0.018
	33	621	0.0044	205.3	0.007
Al foil - Nylon net	13	105	0.043	202.5	0.099
	24	110	0.030	203.6	0.069
	33	113	0.025	203.2	0.017

5.2 Calculation of apparent thermal conductivity

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

$$Q = \frac{2 \times \pi \times L \times k \times (Th - Tc))}{(ln\frac{d_0}{d_i})} \tag{5.1}$$

$$k = \frac{Q \times ln(\frac{do}{di})}{2 \times \pi \times L \times (Th - Tc)} \tag{5.2}$$

A sample calculation for the thermal conductivity is shown below,
Given:
do = 0.213,
di = 0.089,
Q = 0.023 W,
L = 0.295 m,
Th −Tc = 205.3 K

$$0.023 = \frac{2 \times \pi \times 0.295 \times k \times 205.3}{ln\frac{0.0213}{0.089}} \tag{5.3}$$

$$k = 5.3 * 10^{-5} W/mK$$

$$k = 0.053 mW/mK$$

Chapter 6

Theoretical Analysis

6.1 Optimization of Layer Density

The apparent thermal conductivity of MLI can be reduced by increasing the layer density up to a certain point. If the insulation is compressed too tightly, the solid conductance increases faster than N \X, So the insulation conductivity also increases. The variation of the apparent thermal conductivity with the layer density for a typical MLI is shown in 4.1

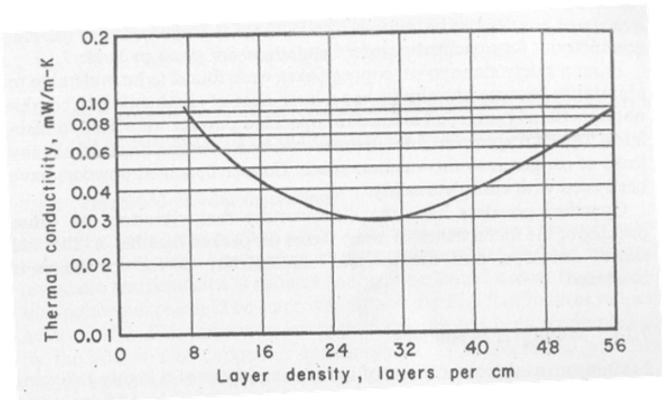

Figure 6.1: Layer density vs. Thermal Conductivity [14]

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.The following conclusions are drawn based on study of multi layer insulations,

6.2 Calculations For Optimum Layer Density of Multilayer Insulation

MATERIALS

1. Aluminium foil & Fiber glass cloth
2. Aluminium foil & R P Tissue
3. Aluminium foil & Nylon net

$$N_{OPT} = [\frac{C_R \times \varepsilon \times (T_{H^{4.67}} - T_{C^{4.67}}) + C_G \times P \times (T_{H^{0.52}} - T_{C^{0.52}})}{1.63 \times C_S \times (T_H - T_C)}]^{1/2.63} \tag{6.1}$$

Now take the values of

E	0.002
C_S	8.95×10^{-8}
C_R	5.39×10^{-10}
C_G	1
P	10^{-6} torr

ε = Emissivity of Aluminium foil
C_S = Coefficient of solid conduction
C_R= Coefficient of radiation
C_G = Coefficient of gas conduction

$$N_{OPT} = [\frac{C_R \times \varepsilon \times (T_{H^{4.67}} - T_{C^{4.67}}) + C_G \times P \times (T_{H^{0.52}} - T_{C^{0.52}})}{1.63 \times C_S \times (T_H - T_C)}]^{1/2.63}$$

$$N_{OPT} = [\frac{5.39 \times 10^{-10} \times 0.002 \times (298^{4.67} - 77.36^{4.67}) + 10^{-6} \times (298^{0.52} - 77.36^{0.52})}{1.63 \times 8.95 \times 10^{-8}(298 - 77.36)}]^{1/2.63}$$

$$N_{OPT} = 35.58/cm$$

6.3 Theoretical Calculation for Measurement of Apparent Thermal Conductivity of Multilayer Insulation

For a well evacuated MLI, heat is transmitted primarily by radiation and solid conduction through the spacer material. For this situation the apparent thermal conductivity of MLI can be calculated by,

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

Where,
K_A= Apparent thermal conductivity
N/x = Layer density

Where, N = No of layers X = Thickness
h_c = Solid conductance
σ = Stefan-Boltzmann constant
σ = 5.67 × 10-8 W \ m^2k^4
e = effective emissivity of the shield material
T_h , T_c = Boundary temperatures of the insulation

6.3.1 MATERIAL 1 (Aluminium foil- fibre glass tissue)

We consider,

T_h= 298 K
T_c= 77.36 K
e = 0.002
h_c= 0.05
K_A = (N/x)$^{-1}$ [h_c + σ × (T_h^2 + T_c^2) × (T_h + T_c) / (2- e)]
K_A = (35.58)$^{-1}$ [0.05 + 5.67 ×10^{-8} × 0.002 × (298 + 77.36) × (298 + 77.36) / (2 - 0.002)]
K_A= 0.00076 W / m-K
K_A= 0.76 mW / m-K

6.3.2 MATERIAL 2 (Aluminium foil - Nylon net)

We consider,

T_h= 298 K
T_c= 77.36 K
e = 0.002
h_c= 0.05
K_A = (N/x)$^{-1}$ [h_c + σ × (T_h^2 + T_c^2) × (T_h + T_c) / (2- e)]
K_A = (35.58)$^{-1}$ [0.25 + 5.67 ×10^{-8} × 0.002 × (298 + 77.36) × (298 + 77.36) / (2 - 0.002)]
K_A= 0.000357 W / m-K
K_A= 0.357 mW / m-K

6.3.3 MATERIAL 3 (Aluminium foil - fibre glass cloth)

We consider,

$T_h = 298$ K

$T_c = 77.36$ K

e = 0.002

$h_c = 0.05$

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

$K_A = (35.58)^{-1} [0.25 + 5.67 \times 10^{-8} \times 0.002 \times (298 + 77.36) \times (298 + 77.36) / (2 - 0.002)]$

$K_A = 0.00061$ W / m-K

$K_A = 0.61$ mW / m-K

6.3.4 Calculated Apparent thermal conductivity for different combinations of Multilayer Insulation from Theoretical Approach

Table 6.1: Theoretical Calculation

Material Combination	No of Layers	Thermal Conductivity, K (m W/m K)
Al foil- RP Tissue	13	0.64
	24	0.35
	33	0.25
Al foil-Fibre cloth	13	0.98
	24	0.53
	33	0.38
Al foil-Nylon net	13	3.57
	24	2.85
	33	2.12

6.4 Graphical Representation

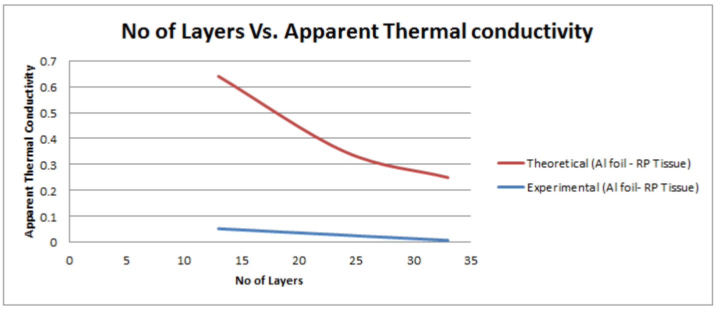

Figure 6.2: No of Layers Vs. Apparent Thermal conductivity

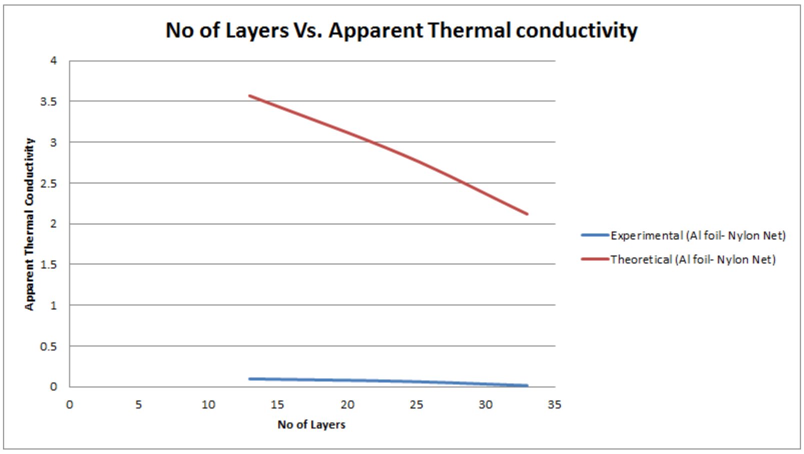

Figure 6.3: No of Layers Vs. Apparent Thermal conductivity

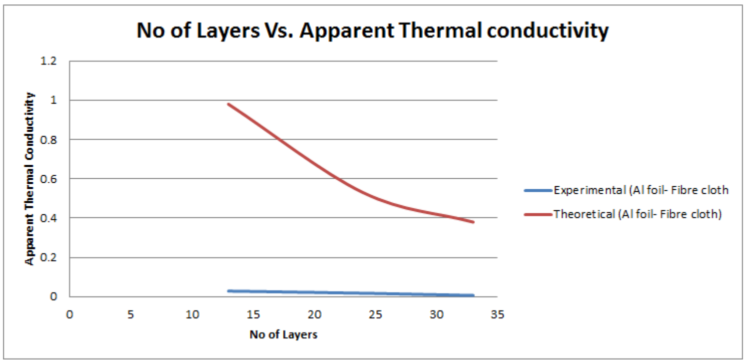

Figure 6.4: No of Layers Vs. Apparent Thermal conductivity

6.5 Comparison between experimental and theoretical evaluation

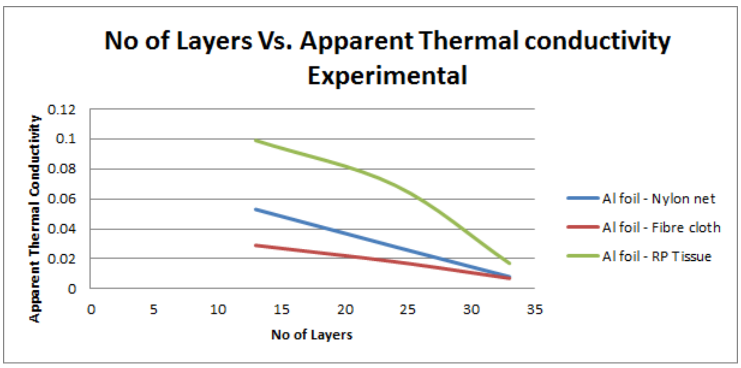

Figure 6.5: No of Layers Vs. Apparent Thermal conductivity

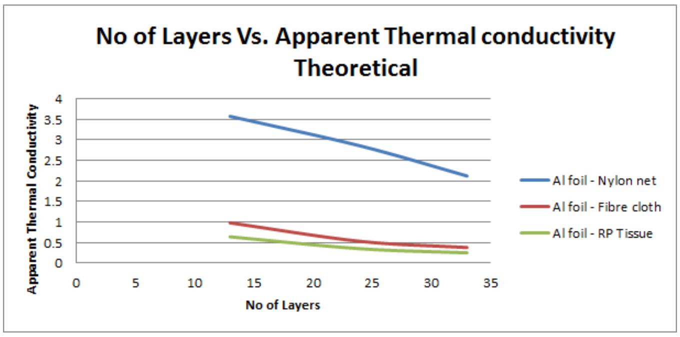

Figure 6.6: No of Layers Vs. Apparent Thermal conductivity

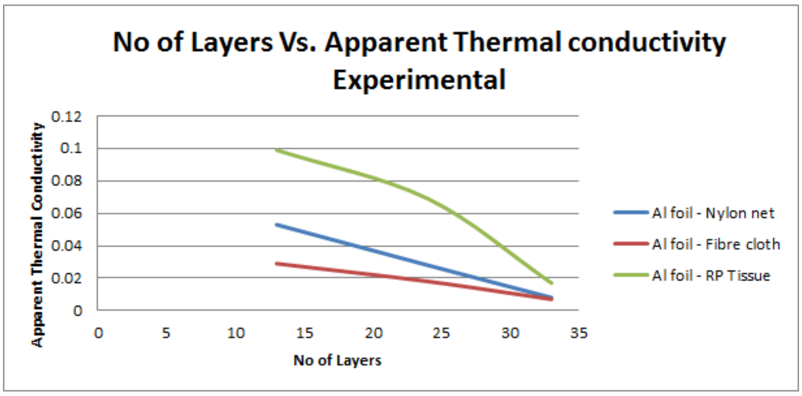

Figure 6.7: No of Layers Vs. Apparent Thermal conductivity

Chapter 7

Conclusion & Future Work

7.1 Conclusion

The following conclusions are drawn based on study of multi layer insulations,

- 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.

- Aluminium 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 & Fibre cloth has lower k value among other insulating materials.

7.2 Future work

Following are the scopes of future work derived through the conclusion of the project:

1. Analytical study of various composite MLI materials for the optimization of Apparent thermal conductivity.

2. Development of MLI with composite materials from the generated results to improve the insulation performance.

3. Validation of theoretical results with practical testing under laboratory conditions.

4. Analytical study of various composite MLI materials for the optimization of Apparent thermal conductivity.

5. Development of MLI with composite materials from the generated results to improve the insulation performance.

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Appendix A Uncertainty Analysis

While performing the experiments, the end result of an investigation is not measured directly due to the fact that the instruments used for measuring data may have some errors in it. So there is a need for performing an uncertainty analysis. The end result, and the uncertainty in it, are a product of the direct measurement of other parameters and, in most cases, assumed values of material properties or other physical "constants". The uncertainties of the experimental apparatus used in this experiment are specified by the apparatus suppliers:

- The temperature sensor (RTD pt 100) for measuring temperature of test vessel and ambient temperature has an uncertainty of $\pm 1\%$.
- The gas flow meter for measuring boil-off rate LN2 has uncertainty of $\pm 0.6\%$.
- The vernier calliper for measuring outer and inner diameter of cylinder of boil-off calorimeter has an uncertainty of $\pm 0.0002\%$.
- The measuring tape for measuring height of the outer cylinder has an uncertainty of 0.01%.

A.1 Calculation

Consider calculation of the apparent thermal conductivity from,

$$k = \frac{Q \times ln \times (do/di)}{2 \times \pi \times L \times \Delta T} \tag{7.1}$$

The result k is a given function of independent variables Q, do, di, L , $\triangle$T.

Thus,

$$k = k(Q, do, di, L, \triangle T) \tag{7.2}$$

Let wk be the uncertainty in the result and wQ, wL, wdo, wdi, w$\triangle$T be the uncertainties in the independent variables. If the uncertainties in the independent variables are all given with same odds, then the uncertainty in the result having these odds will be given by,

$$w_k = [(\frac{dk}{dQ} \times w_Q)^2 + (\frac{dk}{dL} \times w_L)^2 + (\frac{dk}{d\Delta T} \times w_{\Delta T})^2 + (\frac{dk}{dd_o} \times wd_o)^2 + ((\frac{dk}{dd_i} \times wd_i)^2]^{1/2} \tag{7.3}$$

The uncertainty in this value is calculated by applying (14) the various terms are,

$$\frac{dk}{dQ} = [\frac{Q \times \ell n(do/di)}{2 \times \pi \times \Delta T}] \tag{7.4}$$

$$\frac{dk}{dL} = -[\frac{Q \times \ell n(do/di)}{2 \times \pi \times \Delta T \times L^2}] \tag{7.5}$$

$$\frac{dk}{d\Delta T} = -[\frac{Q \times \ell n(do/di)}{2 \times \pi \times \Delta T^2 \times L}] \tag{7.6}$$

$$\frac{dk}{dd_o} = [\frac{Q}{2 \times \pi \times \Delta T \times L \times do}] \tag{7.7}$$

$$\frac{dk}{dd_i} = -[\frac{Q}{2 \times \pi \times L \times \Delta T \times d_o \times d_i}] \tag{7.8}$$

The uncertainty in the apparent conductivity may now be calculated by assembling these derivatives in accordance with (14). Designating this assembly as (15), (16), (17), (18) & (19) and then dividing by (12) gives,

$$\frac{w_k}{k} = [(\frac{w_Q}{Q})^2 + (\frac{w_L}{L})^2 + (\frac{w_{\triangle T}}{\triangle T})^2 + (\frac{w_{do}}{d_o \times \ell n(do/di)})^2 + (\frac{w_{di}}{d_o \times d_i \times \ell n(do/di)})^2]^{1/2} \quad (7.9)$$

Inserting the appropriate numerical values gives,

$$\frac{w_k}{k} = [(\frac{0.006}{0.053})^2 + (\frac{0.001}{0.295})^2 + (\frac{0.01}{215.8})^2 + (\frac{0.002}{0.1859})^2 + (\frac{0.002}{0.01654})^2]^{1/2} \quad (7.10)$$

$$\frac{w_k}{k} = 0.11\% \quad (7.11)$$

Therefore, the uncertainty in the apparent thermal conductivity for the present experimental study is 0.11 %