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Development Of An Experimental Setup For Emissivity Measurement At Cryogenic Temperatures

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***Abstract*— Emisssivity is a prime most important factor that has to be known to calculate heat loads on the surfaces. The emissivity of the surface depends on the temperature of the surface. Due to the scarce of emissivity data at low temperatures, a calorimetry based experimental setup for emissivity measurement at cryogenic temperatures has been designed and fabricated. In this method the conduction and convection modes of heat transfer are reduced to the maximum extend by proper design and by maintaining high vacuum levels respectively. The setup allows measurement of emissivity of wide variety of metallic and non-metallic tapes and paints and components down to 90 K. The experimentally obtained total hemispherical emissivities with the available literature values of different samples, namely stainless steel, copper, aluminum tape, copper tape, kapton tape, aluminized Mylar and black paint are presented here.**

***Key words* – Emissivity, Calorimetric method, Cryostat.**

I. INTRODUCTION

The emissivity of a surface is its effectiveness in emitting energy. Thermal radiation is electromagnetic radiation and it may include both visible radiation and infrared radiation. Emissivity is the ratio of the thermal radiation emitted by a surface to the radiation emitted by an ideal black surface at the same temperature, by Stefan Bolzmann law. This ratio can vary from 0 to 1. Fusion is the most promising technology for energy production in the future. The reaction of deuterium with tritium to produce helium and neutrons along with the release of energy is possible only when they are confined in a magnetic field environment using a Tokamak. Good vacuum and good surface conditions are essential for the better performance of a Tokamak, whose base pressures are in the range of 10^{-8} mbar during fuel input. To obtain such vacuum levels one needs to use ultra-high vacuum (UHV) pumping systems. Considering the several aspects such as quantitative recovery of hydrogen isotopes, operation in harsh environment of magnetic and electric fields, need for very high pumping speeds, etc., cryosorption pump operating at 4.5 K is the only possible pump that can be used

Cryopump is an entrapment vacuum pump that retains the gas molecules by sorption and or condensation on their internal surfaces at low temperatures. This pumping effect is caused by the interaction between the gas particles and the cold surface of the cryopump. Thus a typical cryopump will consist of a metallic surface such as a panel (copper or stainless steel), on the surface of which activated carbon is adhered using a suitable adhesive. For the best performance of the cryopump, one should ensure that the activated carbon is at the lowest possible temperature with the heat load from the surroundings minimized. By the careful design of a cryopump, the solid conduction heat load can be reduced considerably. The gas conduction heat load will be quite less, since the operational pressure levels of the pump will be quite low. However, the radiative heat loads from the surrounding can be quite significant depending on the emissivity of these surfaces. For the performance improvement of the cryopump, one should ensure that the surfaces of various components /parts of the cryopump are carefully prepared to have reduced emissivity. To minimize the radiation heat influx the emissivity of the internal pump surface has to be reduced. By very clean electropolishing, emissivities of the order of 0.01 are obtained. Cooled radiation shield installed around the cryopanel for adsorbing the entering stray radiation from the radiation source i.e. vacuum chamber is made optically dense and is blackened to have an emissivity of 0.9 or higher.

The emissivity measurement methods are usually divided into three basic groups, the radiometric, heat flux and calorimetric methods. Radiometric methods measure emitted and/or reflected electromagnetic radiation with a sensitive bolometer as a receiver and alternatively include spectral and directional measurements. In the heat flux method, heat emitted by the surface passes through a heat flux sensor and is measured directly. Knowing the heat flux passing through, the total hemispherical emissivity of the surface can be calculated using the Stefan-Boltzmann law of radiation. On the other hand, calorimetric methods detect the heat which is lost or gained by the sample and measure solely total values of emissivity or absorptivity. The calorimetric method is again classified as steady state method and transient method. Calorimetric techniques are commonly used due to their simplicity and accuracy. For the steady-state calorimetric measurement method, the radiation heat flux from the sample to the environment is measured once the sample reaches the desired steady-state temperature. Knowledge about the low-temperature emissivity of materials and coatings can be essential to the design of fusion cryoplants and in the thermal modelling for space satellite missions. The emittance of thermal shields, light baffles, and other components at operational temperatures cannot often be predicted from room temperature data, but for computing radiative loads and infrared background radiation this cryogenic data are often required. However, scarce information is available about the emissivity values at cryogenic temperatures.This knowledge of emissivity values are required for proper design of components of cryogenic systems like cryopump and cryostat so that the amount of radiation heat transfer is reduced. There is a lack of emissivity data at lower temperatures. The objective of this work was to design and develop a calorimetry based experimental setup for measuring total hemispherical emissivity of samples or coatings at cryogenic temperature, using liquid nitrogen and compare them with the available literature values.

[2]Duckworth R.C. et Al. developed a calorimetric based experimental setup for measuring the emissivity of silver coated copper in the temperature range of 25 K to 35 K [2]. [3]Giulietti D et Al. developed an experimental setup and studied emissivity and absorptivity of high-purity metals like copper, aluminium and tantalum samples in the temperature range of 300 K – 77 K [3]. [4]Giulietti D et Al. developed an apparatus using a calorimetric technique to measure the total hemispherical emissivity of opaque solid materials at various temperature ranges. [4]. [5]Hanzelka P et al. studied emissivity of different Diamond like carbon coatings in the temperature range 15 K -300 K [5]. [6]Herve P. et al. developed an emissivity measurement setup using which the emissivity of the sample was measured in the temperature range of 20 K – 200 K [6]. [7]Jaworske et al. developed a finite element analysis thermal model of transient technique used to measure the emittance of surfaces and coatings with an approximate error of less than 4% in the temperature range of 173 K - 673 K [7]. [9]Tomas Karlik et al. developed an experimental setup for measuring emissivity and absorptivity of highly reflective surfaces in the temperature range of 320 K – 20 K with 7 % uncertainties [9]. [10]Musilova V et al. developed a setup to measure emissivity of different samples like Al tapes, Mylars, etc. in the temperature range of 30 K – 140 K [10]. [11] Musilova et al. experimentally determined the total hemispherical absorptivity of samples of coppers treated differently, in the temperature range of 5 K – 40 K [11]. [12, 13, 14]Tuttle J et al in the year 2012 developed an experimental setup for the measurement of emissivity of the ball infrared samples at low temperature. The setup was capable of measuring emissivity with high resolution. In the years 2014 and 2015 the emissivity of painted Aluminium honeycomb samples and various black surface preparations were determined in the temperature range of 20 K – 300 K [12][13][14]. The calorimetric method suits best for the measurement of total hemispherical emissivity as it is relatively simple and widely used. The other alternative methods could have the problem with background radiation coming from other surfaces, leading to inaccurate values of emissivity.

II. SYSTEM DESCRIPTION

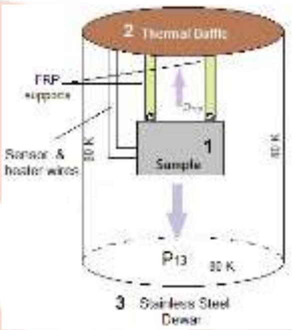


Figure.1 Schematic of the experimental setup

A. CRYOSTAT

Figure.3 Photograph of Cryostat

Figure.4 Photograph of vacuum vessel and Assembly of experimental setup

Cryostat is shown in figure 3 Cryostat is a cylindrical vessel capable of holding liquid nitrogen with inner diameter of 215 mm and a height of around 900 mm. It consists of an inner and outer cylindrical vessel with super insulating material in between and the intermediate space evacuated to reduce radiation heat transfer and gas conduction respectively. It has two openings one for filling liquid nitrogen and the other for nitrogen vapour venting. Cryostat is shown in figure 3.

B. VACUUM VESSEL

The vacuum vessel/chamber is the test area of the experimental setup as shown in figure 4. The vacuum chamber is a cylinder with an inner diameter of 165 mm and a height of 760 mm. This chamber is placed inside the cryostat and cooled by concentric liquid nitrogen.

C.VACUUM PUMPING SYSTEM

The pumping system consists of a turbo-molecular pump with a backing rotary pump with a capacity of maintaining 10^{-6} mbar pressure. The vacuum valve is a right angled bellow sealed valve used in the vacuum pipelines to isolate the vacuum vessel from the atmosphere. The gas in the chamber is pumped out using the turbo molecular pump. The vacuum pumping system was continuously operated to maintain the high vacuum in the vacuum chamber.

D.THERMAL BAFFLES

The thermal baffles are made of thin copper sheets with a diameter of 145 mm and are used to reduce the radiative heat leak from the ambient temperature (top side of the cryostat). It is mounted on the top flange of the vacuum vessel.

E.HEATER AND SAMPLE

The stainless steel plate heater with resistance of 12.5 Ohms and 50 Watts is used. It has the dimension of 110 mm × 90 mm and a thickness of 2.5 mm. The samples for which the emissivities are to be measured can be attached on the surface of the heater. Two sensors are mounted the heater surfaces. The heater or the source was suspended in the vacuum vessel at the base of the lowest thermal baffle using low thermal conductivity FRP strips. The heater was used for heating the specimen to obtain emissivity values at different temperatures.

The experimental setup consists of the cryostat, vacuum chamber, vacuum pumping system, heater and the instrumentation and control devices. The details of the components are given below

Figure.5 Photograph of the experimental setup

III. EXPERIMENTAL PROCEDURE

The following assumptions were used.

- Gas conduction was neglected since vacuum condition was maintained.
- Heat transfer through the wires of the heater was neglected.
- Conduction heat transfer through FRP supports was neglected.
- Thickness of the heater was not considered for calculating the emitter surface area since it was very small.

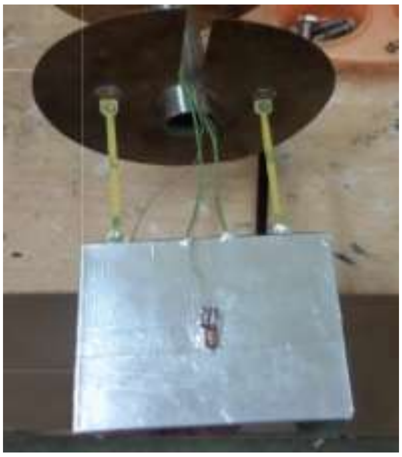


Figure.6 Heater coated with aluminum tape


Fig. 7 Coated with aluminium tape

Stage 1: Samples mounted on emitter

The experiments are carried out using stainless steel heater. The sample whose emissivity is to be determined is coated or pasted on heater. Heater is suspended from a thermal baffle inside a vacuum chamber. The vacuum chamber is surrounded by liquid nitrogen so that chamber is maintained at 80 K. The vacuum vessel is evacuated using turbo molecular pump with a black up rotary pump to a pressure of $1*10^{-6}$ mbar. Liquid nitrogen is filled into the cryostat in order to maintain vacuum chamber at 80 K. Temperature readings are noted until the state of thermal equilibrium reached. Upon attaining thermal equilibrium heater is powered using constant power source. Again readings are noted The template is used to format your paper and style the text. All margins, column widths, line spaces, and text fonts are prescribed; please do not alter them. You may note peculiarities. For example, the head margin in this template measures proportionately more than is customary. This measurement and others are deliberate, using specifications that anticipate your paper as one part of the entire proceedings, and not as an independent document. Please do not revise any of the current designations. until thermal equilibrium is reached. Time to attain a thermal equilibrium is about 4 - 5 hours. Using voltage drop across heater, Power supplied to the heater is calculated. By assuming the emissivity of receiving surface, the emissivity of samples is calculated.

Stage 2: Samples coated on receiver

In order to obtain the emissivity of samples at 90 K, a copper vessel of outer diameter 160 mm and height of 150 mm is inserted into the vacuum vessel. Initially copper vessel is coated with sample; sensor is fixed on the copper vessel to measure the temperature. The vacuum vessel is evacuated to about $1*10^{-6}$ mbar using turbo molecular pump. Liquid nitrogen is filled into cryostat so that the temperature of sensor on the copper vessel reaches 90 K. Experimental data is recorded as explained earlier and final steady state temperatures are noted along with voltage drop across the heater. By using emissivity of heater obtained in stage 1, emissivity of copper vessel is calculated.

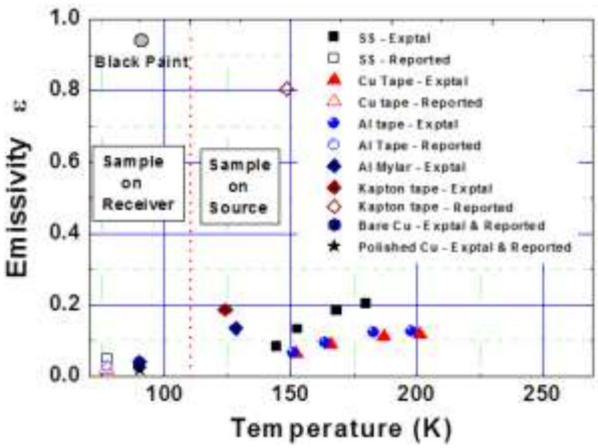
IV. EMISSIVITY CALCULATION

The radiation heat transfer between two diffuse, grey surfaces with areas A_1 and A_3, emissivities ε_1 and ε_3 atTemperatures T_1 and T_3 respectively (for example 1 refers to heater surface, 3 refer to surface of vacuum vessel), is given by:

$$Q_{13} = \frac{A_1\sigma(T_1^4 - T_3^4)}{\frac{1}{F_{13}} + \frac{A_1}{A_3}\left(\frac{1}{\epsilon_3} - 1\right) + \left(\frac{1}{\epsilon_1} - 1\right)} \qquad (2)$$

Where $\sigma = 5.678 \times 10^{-8}$ W/m^2K^4 is the Stefan-Boltzmann constant and F_{13} denotes the view factor. The view factor (or shape factor) F_{13} is defined as the fraction of the radiation leaving surface 1 that is intercepted by surface 3 and is determined by the geometric configuration only. Q_{13} is the heat transfer from the emitter to the receiver by radiation. The above equation forms the basis of a calorimetric technique of emissivity measurement.

V. RESULT



For stainless steel the emissivity is found by using the bare heater as the source. The emissivity is found to vary from 0.085 at 144 K to 0.204 at 180 K. The emissivity of copper was found both using sample on source (heater) and sample on receiver (copper vessel). Using sample on heater the obtained emissivity values are 0.065 at 152 K, 0.089 at 165 K, 0.112 at 187 K and 0.118 at 201 K. Using the bare copper vessel as sample the emissivity was found to be 0.03 at 90 K. Using a chemically polished copper vessel sample a lower emissivity of 0.02 at 90 K was observed. For aluminium sample attached to the heater the emissivity values were found to vary from 0.068 at 151 K to 0.128 values at 198 K. For a similar sample of aluminium on the copper vessel an emissivity value of 0.04 was observed at 90 K. For kapton sample the emissivity values were found to be 0.787 at 145 K. For aluminized mylar the emissivity values were found to be from 0.135 at 128 K to 0.454 at157 K. For black paint on copper vessel an emissivity of 0.95 was observed at 90 K vessel temperature.

VI. CONCLUSION

An experimental setup for the measurement of the total hemispherical emissivity has been designed and fabricated. The final design and experimental procedure was arrived at after a careful review of the available literature.

Experiments were performed using various samples namely bare stainless steel heater, aluminium tape, copper tape, kapton tape ,aluminized mylar and black paint by giving various heater power inputs. The emissivity values obtained are in close proximity to literature values and errors in values may be due to the difference in surface finish and contamination of the sample.

VII. ACKNOELEDGEMENT

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REFRENCE

[1] Shafi K.A., Mathew Skaria, Rijo Jacob Thomas, Vasudevan K., Krishnachandran C., Prakyath ArunMudya, Manjunath Hatti, S. Kasthurirengan, Ranjana Gangradey and Samiran Mukerjee, Design and Development of an Emissivity Measurement Setup for use at 100 K, Paper presented at the 26th National Symposium on Cryogenics and Superconductivity (NSCS 26), 22-24 February 2017, VECC Kolkata(2017)

[2] Duckworth R.C., Demko J. A., Gouge M. J. andUrbahn J. A., Measurement of the emissivity of clean and contaminated silver plated copper surfaces at cryogenic temperatures, Advances in Cryogenic Engineering, **52**, 61-68(2006)

[3] Giulietti D, Lucchesi M, Emissivity and absorptivity measurements on some high-purity metals at low temperatures, Journal of Physics, **14(5)**, 877-881(1981)

[4] Giulietti D, Lucchesi M. and Stampacchia R, A calorimetric technique for measuring total emissivity of solid materials and coatings at low temperatures, Journal of Physics, **12(12)**,108-118(1979)

[5] Hanzelka P., Kralik T., Maskova V., Musilova J. andVyskocil, Thermal radiative properties of a DLC coating , Cryogenics, 2008

[6] Herve P., Rambure N., Sadou A., Ramel D., Francou L., Delouard P. and Gavial E., Direct measurement of total emisivities at cryogenic temperatures: application to satellite coatings, Cryogenics, **48(11)**, 463-468 (2008)

[7] Jaworske A., Thermal modelling of a calorimetric technique for measuring the emittance of surfaces and coating, Cryogenics, **236(1-2)**, 146-152 (1993)

[8] Jignesh Patel A., Low Temperature Emissivity Measurement System, International Journal o f Engineering Research and Applications, **4(5)**, 172-174 (2014)

[9] Kralik T., Musilova V., Hanzelka P. and Srnka, A Method for measurement of emissivity and absorptivity of highly reflective surfaces from 20 K to room temperatures, Metrologia, **53(2)**, 743-753 (2016)

[10] Musilova V., Hanzelka P., Kralik T., and Srnka A., Low temperature radiative properties of materials used in cryogenics , Cryogenics, **45(8)**, 529-536(2005)

[11] Musilova V.,Kralik T., Hanzelka P. and Srnka A., Effect of different treatments of copper surface on its total hemispherical absorptivity below 77 K , Cryogenics, **47(4)**, 257-261(2007)

[12] Tuttle J., CanavanE., Dipirro M., Franck R., Green, A high resolution measurement of the low temperature emissivity of ball infrared black, AIP Conference Proceedings :Advances in Cryogenic Engineering,**1434**, 1505-12(2012)
[13] Tuttle J., Canavan E., Dipirro M., Li x., Franck R. and Green, The total hemispheric emissivity of painted aluminium honeycomb at cryogenic temperatures, AIP Conference Proceedings :Advances in Cryogenic Engineering ,**1573**,.590-596 (2014)
[14] Tuttle J. and Canavan E., Recent NASA /GSFC cryogenic measurements of the total hemispheric emissivity of black surface preparations, IOP Conference Series :Material Science and Engineering, **102**, 1-8(2015)
[15] Hameury J., Hay B. andFiltz J. R., Measurement of total hemispherical emissivity using a calorimetric technique , International Journal of Thermophysics, **28 (5)**, 1607-1620(2005)
[16] Kim S.H.,Conway Z.A.,Ostroumov P.N. and Shepard K.W., Emissivity Measurement of coated copper and aluminium samples at 80 K, AIP Conference Proceedings: Advances in Cryogenic Engineering, **1573(1)**, 500-506(2014)