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A Review of Emissivity Measurement of Materials at Cryogenic Temperature

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Abstract:
Radiation being the most prominent mode of heat transfer, determination of emissivity of different materials, surfaces, coatings at cryogenic temperatures is important. Knowledge about emissivity is critical in designing cryogenic systems. The main objective of this work is to do a systematic and informative review on techniques developed for emissivity measurement of various materials at cryogenic temperatures. During the last few decades' various research techniques were applied for emissivity measurements in terms of their basic principles, system structure, range of measurements and limitations. Through continuous and regressive analysis, the precision of emissivity measurement values at low temperature improved, using methodologies such as Calorimetric, Radiometric or optical measurement. The comprehensive description of the apparatus and measuring process are reviewed especially with respect to how they are applied for measuring emissivity of materials at cryogenic temperatures. The pros and cons of these techniques are assessed based on their applications and accuracy of measurement.

1. INTRODUCTION

Emissivity which is one of the key factors affecting radiation heat transfer can be defined as the ratio of energy emitted by a surface to that of a black body at the same temperature. Emissivity is extremely significant in heat transfer at low pressure low temperature equipment like satellite and in experimental fusion reactors.

1.1. Importance of Emissivity Measurements at Cryogenic Temperatures

Molecular motion is primary occurring in translation and rotation for low energy level. When the energy level of the molecules increases, the molecular kinetic energy increases and molecular vibration and frequency of collision take predominance in the transfer of energy. The energy is usually dissipated in the form of Thermal radiation. Any molecule in an environment having Temperature above absolute zero uses thermal radiation to transfer energy. Kirchhoff's law which govern the energy transfer associated with Thermal radiation shows that Radiation is dependent on the material properties, it thermal potential, absorptivity and emissivity. In usual physical phenomena, the energy emitted from one molecule is usually absorbed by the adjacent molecule making heat transfer by radiation a surface phenomenon.

The mechanisms of thermal energy transfer(Q) at temperatures near absolute zero in the absence of convective currents are heat conduction through solid material $Q_{conduction\ ,\ solid}$, gas heat conduction $Q_{cond\ uction\ ,\ gas}$ and thermal radiation $Q_{radiation}$ [3]

$$\mathbf{Q} = \mathbf{Q}_{\mathbf{conduction,\ solid}} + \mathbf{Q}_{\mathbf{conduction,\ gas}} + \mathbf{Q}_{\mathbf{radiation}}$$

To minimize the heat transfer to a system operating at cryogenic Temperatures, all the above components of heat transfer must be minimized. Solid heat conduction can be minimized by the manipulating the constructional geometry and by careful selection of suitable materials. Heat conduction in the gas is due to the energy transfer due to collisions between the molecules and between molecules and wall surface. This effect is associated with the mean free path and can be effectively manipulated, by increasing the Knudson Number, which occurs at lower chamber Pressures. At high Knudson number flows, the flow becomes rarefied and inter molecular gas molecule collisions become less frequent. The molecules collide predominantly with the vessel wall. Heat transfer depends only on the number of molecules and varies linearly with Pressure. The influence of gas heat conduction can be neglected as acryopump is normally operated under molecular flow conditions. [17]

When the pressure falls below about 0.3 Pa, heat transfer via conduction and convection is negligible. To appreciate the difference, if two black parallel plates of size 1000 cm^2, separated by 3 cm were in a vacuum of 0.3 Pa, and one plate kept at room temperature while the other at 10K, the radiative heat transfer between the two plates would be about 40 watts compared to 0.05 watts through conductive heat transfer. Convective heat transfer is negligent due to the established vacuum conditions. Radiant heat transfer will be of primary concern for cryogenic systems.

For the proper design of cryogenic devices knowledge of thermal radiative properties of various types of materials and various coatings are often required. Radiative properties depend not only on material and its temperature, but also on bulk material treatment as well as on surface finish. [1] [10] Streamlining is conceivable just if the exact information of aggregate hemispherical emissivity of surfaces and surface coatings utilized in the cryopump are accessible. Radiative properties are anticipated based on speculations like "anomalous skin effect theory" [2] Be that as it may, exploratory information for correlation at low temperatures are rare and information of hemispherical emissivity of most materials at cryogenic temperatures are not accessible in writing. Inaccessibility of such information might be because of trouble of estimation, particularly at low temperatures. Because of these investigations diverse low coatings has been produced which helped in enhancing and making better warm administration frameworks for space specialties and satellites. With forthcoming race for interplanetary missions every one of the components that gets presented to space temperature must be considered alongside the emissivity to guarantee its legitimate working, so the emissivity ponder turn into a need.

Information about the low-temperature emissivity of materials and coatings can be basic to the plan of combination cryoplants and in the warm demonstrating for space satellite missions. [14] The emittance of warm shields, light bewilders, and different parts at operational temperatures regularly can't be anticipated from room temperature information, yet to figure radiative burdens and infrared foundations this cryogenic information are frequently required. For appropriate and consistent task of cryopumps, it is basic to forestall and expel any warm vitality coming into contact with it. Cryopump are intended to limit warm loads because of conduction and convection. The gas conduction warm load is low, since the operational weight levels of the pump are low. This makes an exceptional condition where warm exchange because of radiation is prevalent. The greatness of warmth exchange because of radiation relies upon the emissivity of surfaces and surface coatings. [1]

2. Review of measurement techniques used for measuring emissivity at cryogenic Temperatures

There are various methods proposed for the determination of sample emissivity. The most used and adapted methods are calorimetric method, radiometric methods and heat flux method. Calorimetry involves analysingon a sample surface radiating out to a blackbodyand performing an energy balance. Two types of calorimetric methods are used to determine the emissivity of a surface: steady state method, and transient calorimetry. Radiometric methods measure emitted and/or reflected electromagnetic radiation and measuresboth spectral and directional emissivity. The heat flux-based emissivity measurement technique directly measures the heat flow through the emitting surface. The different techniques adopted for emissivity measurement are reviewed and analysed below.

2.1 Calorimetric Techniques

Calorimetric technique applies the warmth balance standard to quantify the warmth stack on test surface transmitting to a dark body. [2] Emissivity is estimated by dissecting the cooling rate of the protected test example utilizing a thermocouple implanted inside the example. Two sorts of calorimetric strategies for the most part utilized are 1. Relentless state and 2. transient strategies. Unfaltering state calorimetric technique estimates the power conveyed to the test example and in addition the surface temperature of the example and the surroundings in a vacuum over a predetermined time. [2,3] The setup is then permitted to achieve warm harmony. Warmth is viewed as adjusted and it is utilized to decide the emissivity utilizing the Stefan-Boltzmann law of radiation. A fenced in area of uniform temperature equipped for holding high vacuum is utilized to go about as a blackbody. Except for the emanating surface, the test example should be protected on all sides utilizing heat protecting. Parasitic warmth misfortunes must be represented to upgrade exactness of warmth exchange through the test example. This confines calorimetric method to quantify one example at some random time. The temperature control inside test setup should be exact in order to accomplish relentless state before emissivity information is estimated. Information is gotten for a solitary temperature amid each test and test must be rehashed at different temperatures to produce a bend of emissivity versus temperature.

Analysts have connected the calorimetric procedure to quantify emissivity. Giulietti et al. [4] utilize this method for estimating absolute emissivity of strong materials and coatings at low temperatures. They examine the emissivity estimations of business copper and dark paint covered copper at four unique temperatures (293K, 273K, 195K and 77K) and contrasts and the hypothetical forecasts. An example, as a thin thwart, suspended inside a cleared chamber whose dividers are kept up at a steady temperature TO. In the event that the example is illuminated with a light emission I, the temperature of the example will increment to a balance esteem Te. At this temperature the power retained from the light bar is transmitted by the example's surface and lost by warm conduction through the strings that interfaces the example to the chamber's dividers. At the point when the light source was killed, the example's mean temperature changed from Te TO. This adjustment in temperature alongside warm extension of test were estimated for emissivity count. This strategy has the upside of more noteworthy rate in performing estimations.

Giulietti et al. [5] also find out the emissivity and absorptivity of some high-purity metals at low temperature. The same calorimetric method explained in [4] was used to measure emissivity and absorptivity on Copper, Aluminium and Tantalum samples of high purity at temperatures ranging from from 300K to 77K and measured emissivity has been compared with the theoretical predictions. The method also permits one to measure other thermal properties of solid materials, such as the specific heat, thermal expansion coefficient, etc. Tsujimoto et al. [6] studied the thermal radiative properties of some cryogenic compatible materials and predicted the temperature dependence of radiative properties at low temperatures using the steady state calorimetric method. A general method was established to predict the thermal radiative properties of metals and alloys for a wide range of temperature below room temperature. The specimen was cooled by thermal conduction. The temperature of specimen was controlled with the help of a heater and resistance thermometer and was measured using Au - chronel thermocouple. The pressure in the cryostat was kept at 5 x 10 -5 Pa, and the incident angle of light was 10°. The normal reflectivity at low temperatures were determined by comparing the reflected intensities with those at room temperature. The normal reflectivity (or absorptivity) of Al and Al alloys are measured below 16K. The effect of surface treatment on normal reflectivity and the contribution of additional scattering effect due to conduction electrons at the surface layer were studied.

V. Musilova et al. [7] analized the radiative warmth exchange between two parallel surfaces utilizing calorimetric strategy. The trial set up comprises of a framework for the estimation of warmth exchange between two parallel surfaces, an example surface and a dark surface. Warmth exchanged by warm radiation from the warmed surface (radiator at the temperature) to the cool surface (safeguard at the temperature) courses through a thin-walled steel bolster (warm resistor) into a warmth sink (LHe shower). The exchanged warmth is ascertained from the temperature slope estimated on the warm resistor. Radiative warmth exchange between a dark surface and an example surface are estimated for a temperature extending from 4 to 140 K. The wavelengths in this investigation were restricted to 6 small scale meter. Aluminum, Copper, Zinc, Brass and Stainless steel were utilized as the example. The impact of various surface medications methods like substance and mechanical surface getting done with, strengthening, mechanical cleaning were considered. Both absorptivity and emissivity were estimated. Both absorptivity and emissivity are assessed as a proportion between the exchanged warmth and warmth produced by a dark body surface warmed to the radiator temperature. Notwithstanding the mistake caused by the estimation of temperatures (1-3 %), the estimation of the deliberate radiative property is methodicallly lessened on account of the accompanying reason 1. a piece of the exchanged radiative warmth spills out of the hole between the safeguard and radiator, and 2. the absorptivity of the darkened surface does not achieve 100%. Together they decreased the deliberate absorptivity and emissivity by 5– 10% of their esteem. The diagrammatic portrayal of test setup created by Musilova et al.

Musilova et al. [8] led examination to contemplate the impact of various medications of copper surfaces on its aggregate hemispherical absorptivity underneath 77K utilizing a similar setup talked about in [11]. The ease of use of substance and mechanical Copper surface completing and additionally Copper plating with nickel and gold are evaluated. They displayed the aftereffects of absorptivity estimation of treated copper surfaces at low temperatures. Add up to hemispherical absorptivity of copper test was estimated and is contrasted with tests of copper with nickel and gold plating. They found that passivation of synthetically cleaned surface builds absorptivity, turning of copper expands its absorptivity generously and incomplete recuperation of the first absorptivity can be acquired by vacuum strengthening, which, notwithstanding, isn't pertinent in all cases.

Hanzelka et al. [9] estimated the warm radiative properties of a Diamond like covering (DLC) coatings in a wide temperature go from room temperature to cryogenic and contemplated the reliance of radiation temperature. The trial set up and technique clarified by Musilova [7] was utilized. A copper plate secured by an epoxy layer was utilized as the radiator surface. They expected that the temperatures of the external shell of the vessel containing the cryogenic fluid and the radiation shields were the same all through the volume. Additionally, the warmth trade between the cryogenic fluid vapor and the neck divider is thought to be great. Alternate presumptions were that the particular warmth of the cryogen vapors is steady and the warmth spill by the leftover gas in the vacuum space is dismissed. It was additionally expected that the temperature reliance of warm conductivity of basic materials and cryogenic fluid vapors can't be disregarded.

Information of warm properties of materials at low temperatures and in the infrared otherworldly area is required for application in cryogenics. Hameury et al. [10] built up an enduring state warm equalization strategy to gauge the radiative properties of materials in the infrared range utilizing an unfaltering state warm offset technique with two examples. The reflectance, the transmittance and the emissivity of materials in the infrared range is estimated utilizing an enhanced instrument created by Laboratoire National de Métrologieetd'Essais (LNE). They outlined a mechanical assembly to gauge the aggregate hemispherical emissivity of strong materials for temperature scope of 473K to 253K, however not in the cryogenic range.

The heater, used to heat two identical samples surrounded by a thermal guard, is suspended at middle height of a black vacuum chamber thermo stated with boiling nitrogen. Computer controls the measurements of the electrical power supplied to the samples and the measurements of the temperatures in the samples and in the thermal guards. A Eurothermcontroller controls the temperatures of the samples heater and of the thermal guard. The main sources of uncertainties are:

- the heat flux between the samples and the rings, which depends upon on the difference of temperature between the samples and the rings
- the surface temperatures of the samples which depends on the conductivity of the material and of the level of temperature
- heat flux between the meter plate and the guard ring

Distinctive covering were utilized to build the emissivity of copper or aluminum surfaces that holds applications in cryogenics. Kim et al. [11] estimated the emissivity of covered copper and aluminum tests at 80 K utilizing unfaltering state calorimetric technique. For estimation, the example was put into a fluid nitrogen protected Dewar with thermometer and a radiator connected to it. The volume inside the Dewar was emptied to weights under 10-6 Torr. Test cooled until the point that it achieves harmony with the foundation radiation temperature of around 120 K. Keeping in mind the end goal to gauge the example emissivity of the example the radiator is fueled and the example temperature is observed until the point that it achieves radiative warm harmony.

They gauged the emissivity of various coatings from the warmth balance between ingestion, from the foundation radiation and the warmer and the emanation powers. Distinctive covering used to build the emissivity of copper or aluminum surfaces were examined. Test coatings utilized are Carbon-Lampblack with VGE-7071 varnish, Carbon-Lampblack with dark SiC corn meal and zinc-dark. The material of the Dewar inward surface is treated steel with a dull surface complete and emissivity estimation of 0.12 ~ 0.25. The harmony temperatures are estimated when the warmer power is changed and emissivity is assessed utilizing them. Commitments of the accompanying elements in this mistake in estimation of the emissivity are talked about: (1) transmitted warmth spill from the example to the most minimal warm astound, (2) conductive and convective warmth spills, (3) exactnesses of instruments, (4) vulnerability of the emissivity of the Dewar inward surface, and (5) measurable blunders.

The transient calorimetric technique utilizes a comparable setup [11] yet as opposed to depending on a balance express, the example is connected to a substrate of known particular warmth limit and the get together is permitted to chill off in the chamber. The emissivity can be figured from the particular warmth, the aggregate territory of the example, and the cooling rate. Parasitic warmth misfortunes was represented as they may influence the estimation. The time required for cooling can be significant, even up to a little while in the utilization of low emissivity test. Transient calorimetry is an exceedingly time concentrated strategy. Calorimetric strategies can't gauge sudden changes in the emissivity of a functioning warm control surface, yet can just quantify the emissivity for each state independently. Edward et al. [15] figured the low-temperature emissivity of copper and aluminum utilizing a transient calorimetric method in the temperature scope of 140-300K and the outcomes were contrasted and the hypothetical expectations. A profoundly cleaned metal examples like mechanically cleaned copper, electrolytically cleaned copper and electrolytically cleaned aluminum, is suspended inside a vacuum chamber. Amid the test, a vacuum of 10-6 torr is kept up in the chamber utilizing an oil dispersion pump through a cool trap loaded up with fluid nitrogen. At the point when the vacuum chamber is cooled to fluid nitrogen temperature, the example, which is at first at room temperature, starts to cool gradually by radiation to the dividers of the chamber. As the example cools, temperature versus time information is recorded and from this, the cooling rate is portrayed as a component of temperature. The vitality misfortune through thermocouple wires are likewise ascertained. The examples are mechanically cleaned copper, electrolytically cleaned copper and electrolytically cleaned aluminum. For reference the best information got in their examination for electrolytically cleaned Cu and Al are plotted alongside the best low-temperature information for these metals. The low-and high-temperature information are believed to fit together. The dissimilarity among hypothesis and analysis apparently increases relentlessly with expanding temperature. The undeniable end to be drawn from this is the established hypothesis, is lacking to speak to the genuine conduct of unadulterated non-Ferro attractive metals with respect to their warm emissive properties.

By utilization of a transient calorimetric strategy, Zuppardo and Ramanathan [13] found the aggregate hemispherical emissivity of unadulterated nickel and iron estimated at different temperatures in the scope of 400 to 1100 K. In the transient calorimetric system, a vacuum-encased, thermally detached example is first warmed by RF enlistment to a foreordained temperature. It is then permitted to cool by transmitting to dark surroundings kept at a consistent temperature. From a persistently recorded cooling bend of the example, the rate of cooling is gotten for any coveted temperature, at which the rate of lessening of interior vitality is equivalent to the whole of the rates of vitality exchange by radiation. A clarification of the emissivity most extreme must be founded on the hypothesis of electromagnetic-wave spread in a directing medium, which is relied upon to hold useful for metals well over their Debye trademark temperatures, as in their examination.
It may be seen that calorimetric method measurement has the following advantages:

- Using calorimetric method measurements can be taken in a rapid manner.
- The method is of high sensitivity and the
- measurements are performed on samples nearly in thermal equilibrium.

The main disadvantage of calorimetric methods are they cannot measure sudden changes in the emissivity of an active thermal control surface, but can only measure the emissivity for each state individually.

2.2 Calorimetric with Bolometric Techniques

The strategies connected in most of the past investigations were intended for estimation in a moderately restricted temperature scope of warm sources. They are additionally normally pertinent for estimating either the example emissivity or absorptivity. This acknowledgment makes a change, so that the existed gadget was altered by joining both calorimetric and bolometric strategies which permit the estimation of emissivity and absorptivity in a vast temperature scope of warm radiation, running from cryogenic to room temperatures. In more exact analyses a temperature drop on the warm connection gives the deliberate warmth control. From a general perspective, the beneficiary (safeguard) together with the temperature sensor and warm connection in this manner make a bolometer, which then again can be adjusted utilizing an electrical radiator. The rule was utilized in estimations of absorptivity [13, 9], and emissivity. Musilova et al. [14] present a strategy for the estimation of aggregate hemispherical emissivity and absorptivity of exceedingly intelligent surfaces from 320 K down to 20 K. The gadget clarified in [7] was outlined with slight adjustment for estimation in a restricted temperature scope of warm source. The vulnerability examination of emissivity/absorptivity of very intelligent examples are additionally displayed. The technique is particularly reasonable for the estimation of very intelligent materials like metals. The investigation checked the technique by contrasting the outcomes for unadulterated aluminum and distributed outcomes with a few different strategies.

2.3 Radiometric Techniques

Radiometric strategies for temperature estimations are non-contact and non-obtrusive systems, which can be worthwhile in different modern applications where the utilization of contact techniques (e.g., thermocouples, opposition thermometers, and so forth.) isn't admissible because of cruel or outrageous estimation conditions. Be that as it may, there are two noteworthy issues related with the utilization of such radiometric procedures for temperature estimations. The first is the obscure emissivity of the protest, which is important to decide in this manner the question's actual surface temperature. The second issue is the impact of foundation radiation from close-by objects and the discharge from and assimilation by the earth. These issues essentially impact the radiation achieving the locator and accordingly in the subsequent temperature perusing. Radiation thermometers (RTs) measure the radiation (brilliance) discharged by a protest, and by utilizing the known basic physical recipe (Planck's law of radiation or Stefan–Boltzmann's law), the comparing surface temperature of the question related with the transmitted radiation can be resolved.

Radiometric strategies measure discharged or potentially reflected electromagnetic radiation with a touchy bolometer as a recipient and on the other hand incorporate otherworldly and directional estimations. [1] Radiometric methods of estimating emissivity include lighting up an example with infrared vitality and estimating the level of vitality reflected from the surface, utilizing a reflectometer or spectrophotometer. The absorptance (α) is figured from the reflectance (ρ) by a radiative vitality balance. The radiometric technique is for the most part less work serious than the calorimetric strategy, yet the estimations must be rehashed at all edges and after that numerically coordinated to acquire the genuine aggregate hemispherical emissivity. By and large this isn't polished and the typical emissivity is utilized to estimated the hemispherical emissivity, now and then utilizing a transformation recipe relying upon the sort of material. Despite the fact that the multifaceted nature of estimating the emissivity of spatially and transiently factor emissivity surfaces can be beaten utilizing refined testing gear intended for ordinary emissivity estimation procedures in a lab situation, the utilization of such frameworks in space is related with a huge weight, vitality utilization, and information volume. The schematic portrayal of the radiometric emissivity strategy utilized by is delineated Herve et al [17].

In spite of the fact that radiation thermometry strategies have experienced huge changes in the most recent decade, the exact assurance of the emissivity of an obscure material stays one of the many testing issues which impacts the unwavering quality of such radiometric techniques. Vuelban, et al. [15] introduced the guideline of the "virtual-source" strategy for deciding the emissivity of an example without the need to consider the example temperature itself. The guideline of this technique depends on the equivalency of emissivity and reflectance as per Kirchhoff's law. It utilizes comparable standards, for example, in the gold-container estimation strategy [16] with the distinction that a plane mirror is utilized (rather than a hemispherical intelligent surface) and no immediate contact with the deliberate surface is required. Radiometric methods for emissivity and temperature estimations of Inconel 600 examples are displayed. The outcomes exhibited that the portrayed techniques can be dependably used to decide the right emissivity and temperature of an obscure example.

Multiwavelength thermometry is basically in view of the estimation of the brilliance of a source at a few wavelengths and, following a few suspicions on the emissivity conduct of the question, on the induction of the temperature of the source from these estimations. The methodology can be executed in various constructional ways. Previously, it was normal to part or select the approaching radiation by methods for optical channels with the outcome that it was constrained to a couple and settled working wavelength groups [6,7]. These days, the utilization of direct PDA or CCD cluster finders related to a frightfully specific gadget (e.g., a monochromatic or a spectrograph) permits acknowledging gadgets with a high level of adaptability both as far as the numbers and places of the working wavelength groups. In any case, by and by these points of interest are not adequate to make the multi-wavelength approach solid and has many negative results; especially the high affectability to the estimation clamor and the issues in displaying mistakes. (mistakes emerging from an off base presumption of the conduct of the ghostly emissivity).

Herve et al. [17] lead an examination where add up to emissivity at cryogenic temperatures was estimated straightforwardly. Coordinate estimation technique appeared in Fig .3, is utilized for estimating optical properties of various materials at cryogenic temperatures from 20 K to 200 K and the successful otherworldly range decided for estimations covers 6– 800 micrometers. A two phase helium icebox was utilized to chill off the examples and the example holder were put in a twofold walled nook cooled with fluid nitrogen. Internal mass of packaging was covered with velvet dark paint. All gadgets are thermally protected and chilled off to 80K. Bolometer which estimated the intensity of episode radiation, went about as an identifier, and was related with a secure enhancer. A chopper regulated the power of flag and a speaker enhanced the flag to commotion proportion and show relating transition got. Flag got at locator was the whole of radiation from the example, reflected radiations from mass of vacuum chamber and radiations discharged by optics. At the point when chopper sharp edges shroud the example, identifier gets the total of warm radiations produced by the cutting edges. The temperature on the identifier surface changed with episode radiation and a voltage flag is created. Secure intensifier got motion from locator and recognize the distinction and in this way ascertains emissivity esteems. So as to stay away from various reflections between the example and the identification optics, the signs are estimated at the very least edge of 200 with the typical to the example surface. The setup permits to position distinctive examples at once. In this work five examples are set in the meantime on the holder, the outcomes demonstrate that they are not affected by the situation of the examples. The coatings of thin dielectric films arranged on copper or aluminum substrates were contemplated. At low temperatures, the coatings wind up straightforward so the impact of reflection diminishes with decrease in temperature.

4. Conclusions

The emissivity is a property which reveals how much radiation agiven body emits as compared to a blackbody.The emissivity is highly influenced by the surface state and is dependent on surface roughness, oxidation, machining process, etc. Due to this influence, it is advisable to measure the emissivity of a sample in the operating conditions. Correct measurement of emissivity is essential for developing next generation energy systems and in aerospace applications.

This paper provides a review of measurement techniques thatcan be applied for measuring emissivity outlining their system structure, principles of measurement, range of application as well as the advantages and disadvantages associated with using the techniques in various materials and applications. This review provides an insight into what has been used historically for measurement but also highlights several techniques that have the potential to be used to emissivity at cryogenic temperatures. With the development of new techniques and/or improvement of existing ones, there will be multipleoptions validation of experimental data. It is believed that this knowledge will enable measuring techniques to be better understood and ultimately enable the development of improved experimental set up for wider range of materials at cryogenic range. Calorimetric methods incorporate parasitic heat losses, and therefore the data obtained through this technique is found to be more accurate.

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