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Development of Polishing Procedure for Producing Highly Specularly Reflecting Surface for Sun Shield Panels of INSAT II TS VHRR Radiant Cooler

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Abstract

VHRR Radiant Cooler used for cooling of infrared detector of VHRR instrument onboard INDIAN NATIONAL SATELLITE SYSTEM [INSAT II] is being developed at Thermal Systems Division of ISAC/ISRO, Bangalore. This development work is being carried out with the participation of various organizations. One of the most critical requirements for maintaining the patch temperature of the cooler at cryogenic low temperature purely by passive methods is the development of the highly specularly reflecting surfaces for the sun shield of the cooler. The polishing techniques and procedures for this were developed successfully. This paper presents the theoretical criteria developed, procedures evolved for polishing of sunshields of the cooler and the measurements made to evaluate the quality of polishing.

Key words: metallic mirrors, specular reflection, optical polishing, space qualified.

Introduction

Very High Resolution Radiometer (VHRR) is one of the payloads onboard INSAT II TS series of satellites. The radiometer will be used for meteorological purposes for taking the pictures of earth in the visible and the infrared region. The visible imaging will be in 0.55 μ - 0.75 μ wavelength region while the imaging in infrared region will be in 10.5 μ - 12.5 μ range. For imaging the IR range it is necessary to maintain the IR detector at a cryogenic temperature of 105^0K.

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A passive Radiant Cooler is used for maintaining the IR detector of the VHRR at cryogenic temperatures. This is being developed indigenously at the Thermal Systems Division of ISRO Satellite Centre, Bangalore. It is a passive device which utilizes the deep cold space for cooling. The cooling is achieved in three stages (Fig.1). The third stage is called the patch,

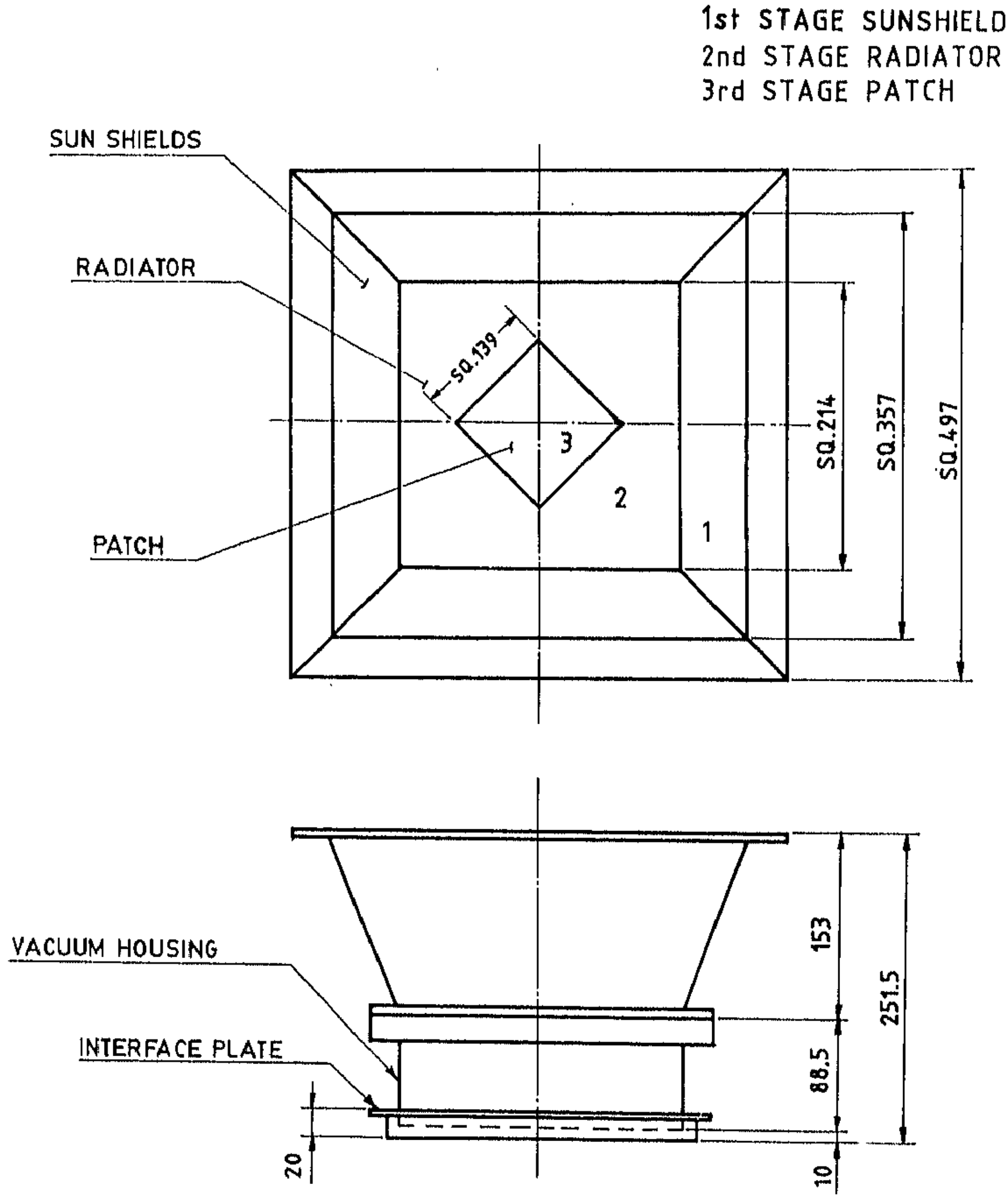

Figure 1. Schematic of VHRR Radiant Cooler.

second stage is called the radiator and the first stage sunshield and vacuum housing assembly. Each of the stages is isolated to minimize the conduction and radiation coupling. The patch is the coldest stage and the IR detector is mounted on it. Radiator is the intermediate temperature stage. Patch is supported on the radiator by four fibreglass reinforced plastic (FRP) tubes. Patch/Radiator assembly is attached to the vacuum housing with eight FRP supports. To further improve the isolation from radiative coupling all the surfaces of these stages facing each other are gold plated. This configuration gives thermal isolation between different stages and progressively load on patch is reduced to minimum through staging. The cooler is mounted on the north panel of the satellite which would receive the minimum sunload. It is important to design the cooler such that the coldest stage patch does not receive any solar radiation direct or indirect. To shield the patch from receiving direct sunload, the sunshields are used. As the name implies, the sunshields have been designed in such a way that any solar radiation falling on it is reflected back to space. The sunshield assembly consists of four trapezoidal shape panels joined together and attached to the vacuum housing. The sunshield surfaces facing the patch are required to be highly specular in nature in solar spectrum region. However if the sunshields do not have a right kind of finish, the diffused part of the reflected radiation may reach the patch.

It is well-known that it is impossible to achieve 100% speculaity with metal surfaces. This paper presents the theoretical criteria developed to arrive at surface finish parameters which would comply with the requirement of no load on the patch due to solar radiation, the discussion of polishing procedure evolved to achieve it and comparison with the experimental results.

It is to be noted that process for development of sunshield surface is quite complex and involves different operations like precision machining, electroplating, optical polishing, characterization, vacuum deposition and quality assurance tests. These were carried out with the participation and active cooperation of Government Tool Room & Training Centre, Bangalore, National Aeronautical Laboratory, Bangalore, Indian Institute of Astrophysics and ISRO Satellite Centre, Bangalore.

Theory

(i) Effect of surface roughness

The specular component $\rho_{s\lambda}$ of the total reflected radiation $\rho_{T\lambda}$ at wavelength λ is a function of the rms surface roughness σ of the surface and is given by (Bennett & Bennett 1967; Bennett & Porteus 1961)

$$\rho_{s\lambda} = \rho_{T\lambda} e^{-\left(\frac{4\pi\sigma}{\lambda}\right)^2}$$

for normal incidence.

For space work, the wavelength region of interest is over solar spectrum. Therefore it is necessary to determine the specularity of a surface over solar spectrum.

$$\rho_s, \text{ Solar} = \frac{\int_{\lambda_1}^{\lambda_2} \rho_{s\lambda} E_\lambda d\lambda}{\int_{\lambda_1}^{\lambda_2} E_\lambda d\lambda}$$

where E_λ is solar spectral irradiance, $\lambda_1 = 0.2\mu$ and $\lambda_2 - 2.5\mu$. Fig.2 shows the variation of ρ_s, solar/ ρ_T, solar as a function of surface roughness i.e., 50 Å gives 99% specularity, 100 Å leads to 96% specularity etc.

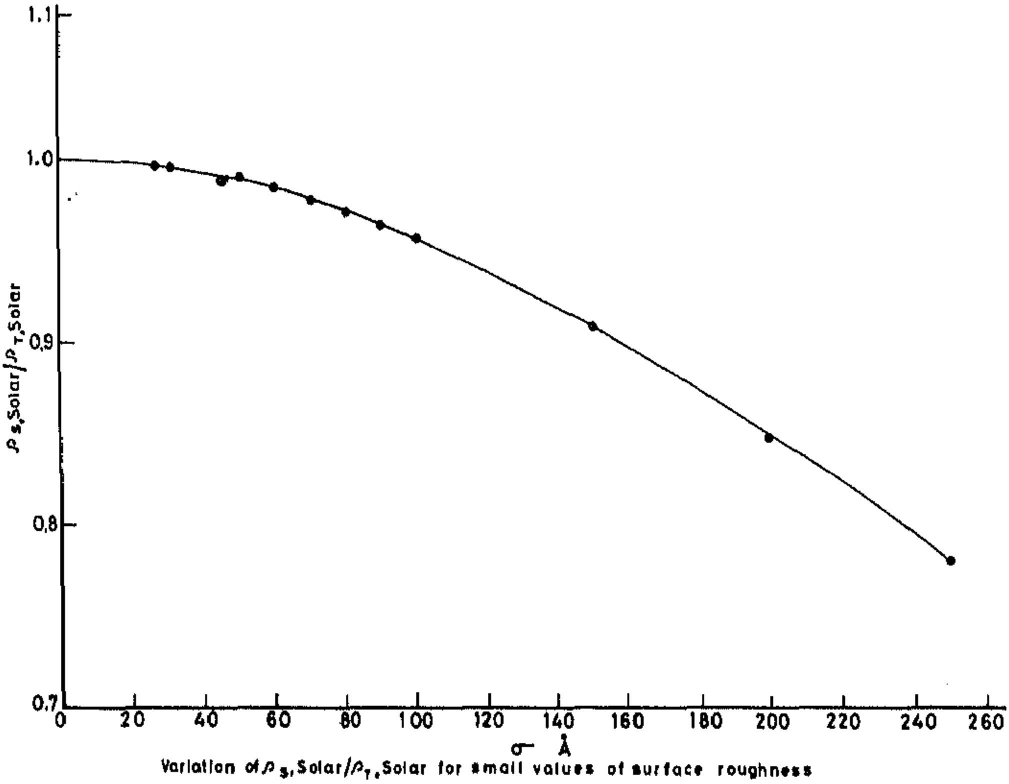

Figure 2. Variation $\rho_s solar/rho_T$ solar for small values of surface roughness.

Angular dependence of diffused radiation

The diffused component, if it lies over 2π angle following Lambert cosine law would lead to 25 mW load force each 1% diffuse component. However for low surface roughness values, the bidirectional reflectance distribution factor BRDF defined (Houchens & Hering 1967).

$$\text{BRDF} = \frac{\text{diffusely reflected energy at an angle}(\theta)\text{from specular direction}}{\text{diffusely reflected energy in specular direction}}$$

$$= \frac{(1+cos\theta)^2}{4} e^{-(4\pi\sigma/\lambda)^2[(1+cos\theta)^2-4]} e^{-\pi^2(a/\lambda)^2 sin^2\theta}$$

where a is another surface parameter called the autocovariance length (Guenther et al. 1984). Calculations of BRDF indicate that diffused component lies in a semicone angle of less than

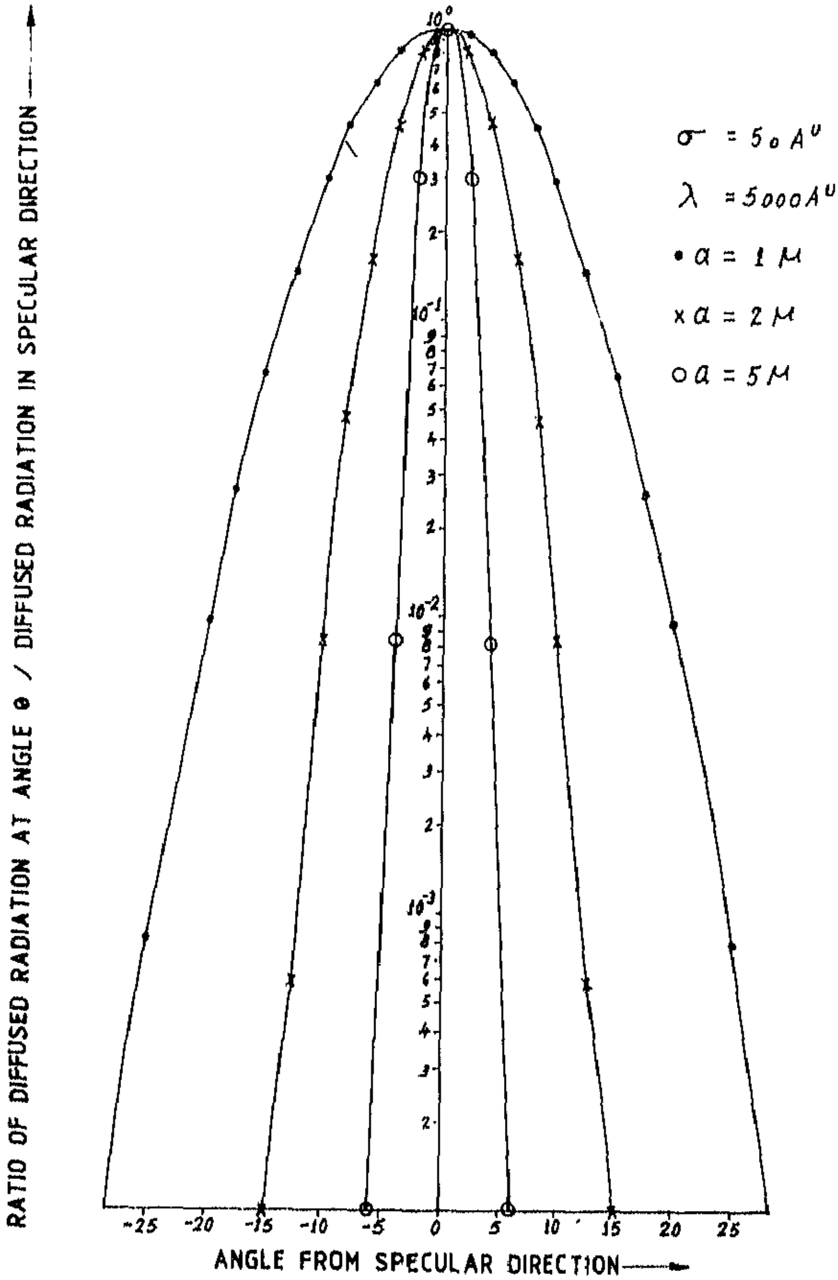

Figure 3. Angular distribution of BRDF for different values of autocovariance length.

15^0 around the specular direction for small roughness values (Fig.3) of $50\text{-}70^0$ A.

Analytical studies conducted parallely have shown that there is no reflected load reaching the patch if the diffused component of reflected radiation is within 20^0 of specularly reflected component (Bhandari & Uma Kumari 1990).

Low α_s and ϵ_{IR} requirement

Since the inner surface is facing patch, the emitted load from sunshields would be reaching the patch and has to be minimized. For this the requirements are low (solar absorptance) α_s and infrared emittance ϵ_{IR}. Thus after polishing of nickel, vacuum deposition of aluminium is necessary. It is also necessary to take care that the diffused component of reflected energy does not increase after aluminization.

Requirements in a nutshell are
$\sigma = 50\text{-}70\ A^0$ range - high specularity with narrow cone angle
$\epsilon_{IR} = 0.03$ (low)
$\alpha_s = 10$ (low)

Fabrication of Panels & Results

With these requirements on the surface of the sunshield, work was taken up at the sample level on electroplated nickel on 6061 Al alloy. For reasons of better mechanical strength and good thermal conductivity 6061 Al alloy is selected as the shield wall substrate material for electroplating of nickel. The feed back to the quality of polish achieved was monitored by measuring the surface roughness using stylus and interferometer techniques. The total, specular and diffuse reflectance were measured using various accessories on spectrophotometer.

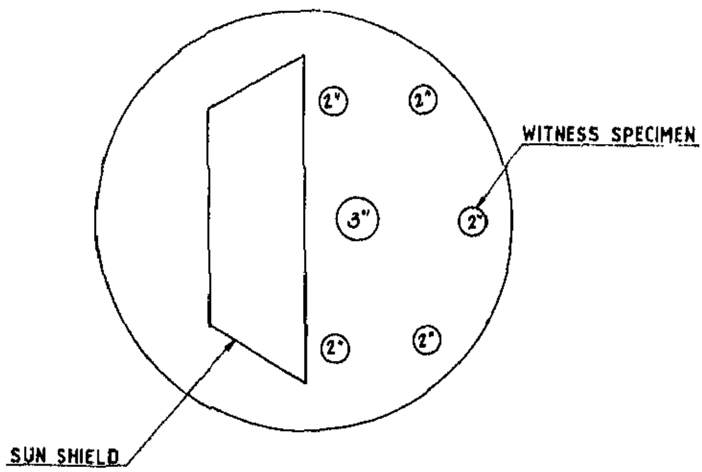

Figure 4. Schematic of 3/4" thick glass blanking plate.

Once the suitable polishing procedure was evolved at sample level, polishing was taken up for the sunshield panel. The panel being trapezoidal in shape, it has to be mounted in a circular holding/blanking plate to avoid edge roll off during polishing. Also it is necessary to polish some witness specimen along with the panel for making different measurements. The panel and witness specimen have to be mounted in the blanking plate in one plane for uniform polishing. After a number of trials with a metal blanking plate, it was found necessary to fabricate a glass blanking plate (3/4″ thick) to mount the panel and specimen. Fig.4 shows a schematic of the glass blanking plate.

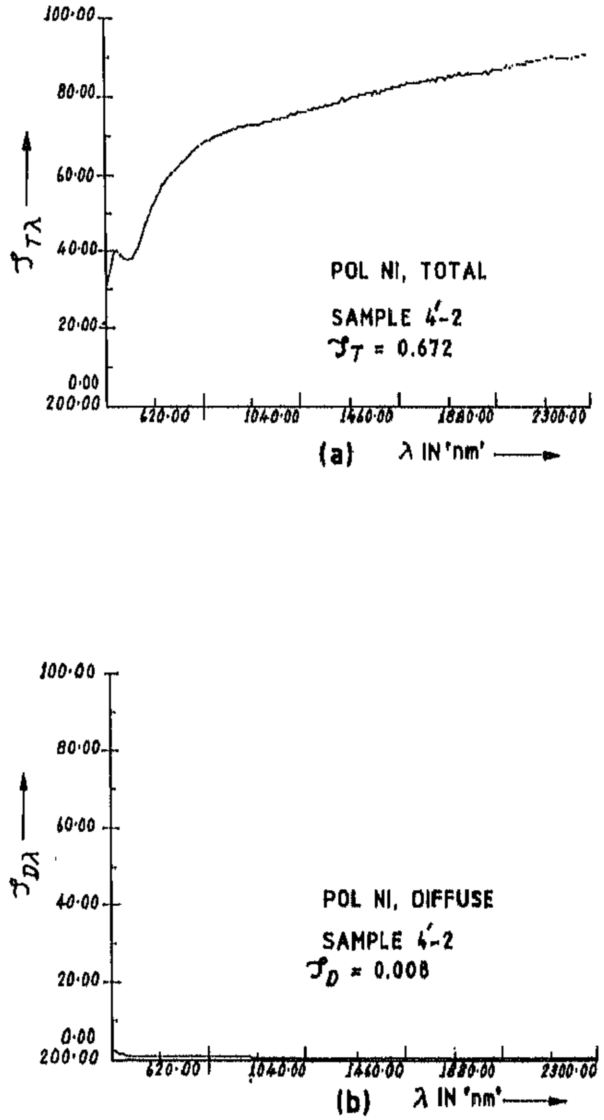

Figure 5. (a) Total spectral reflectance curve for polished nickel sample. (b) Diffuse spectral reflectance curve for polished nickel sample.

With the glass blanking plate it was possible to polish the panel successfully and subsequent to this vacuum deposition of aluminium was done. The sunshield panels of two models of VHRR cooler have been polished successfully.

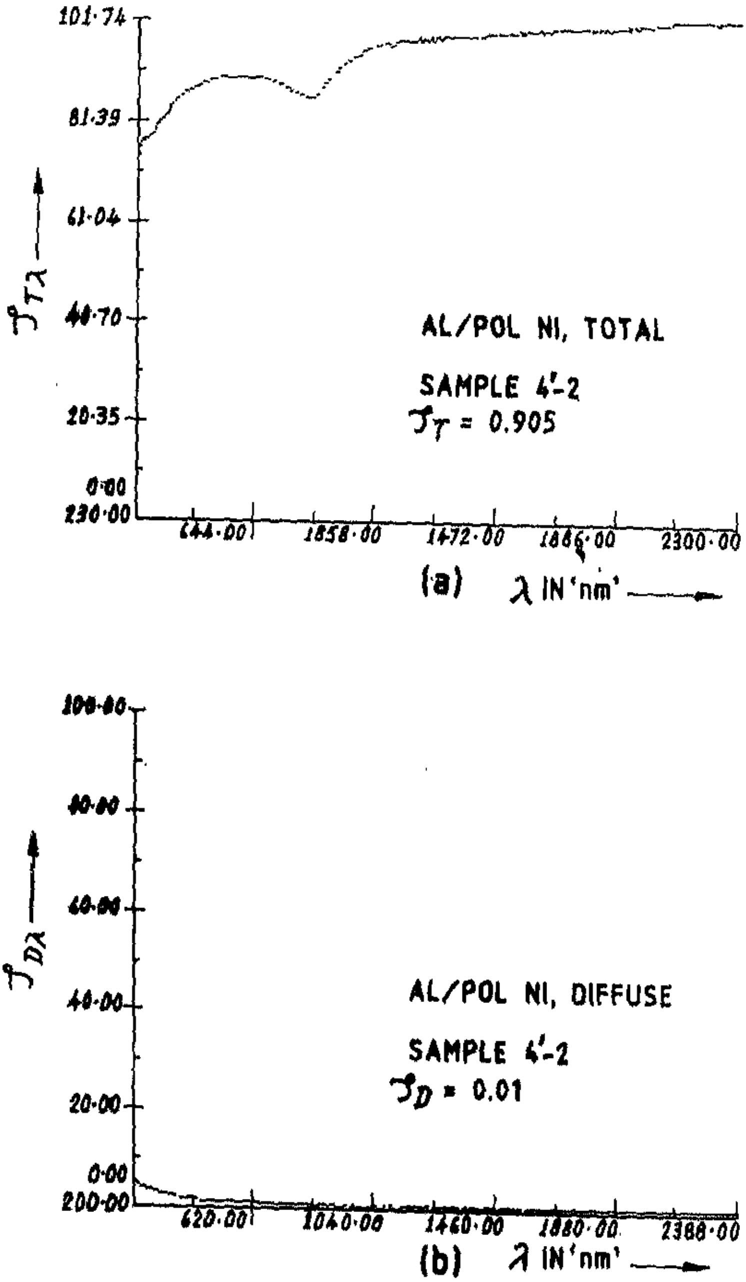

Figure 6. (a) Total spectral reflectance curve for aluminised polished nickel sample. (b) Diffuse spectral reflectance curve for aluminised polished nickel sample.

Fig. 5 shows a typical diffuse and total reflectance curve for polished nickel sample. Fig. 6 shows the diffuse and total reflectance curve after aluminization for the same sample. The calculated ρ_D value lies in 1-1.5% for these samples.

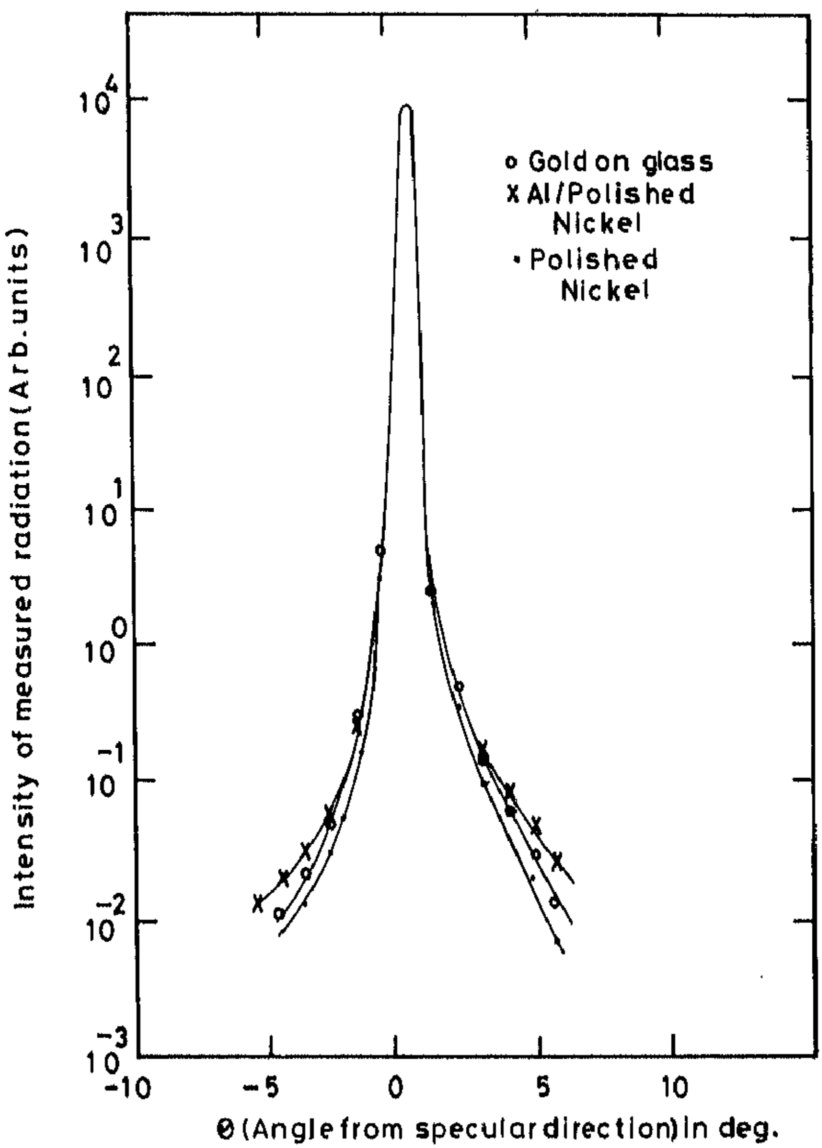

Figure 7. Experimental scattering curve for diffuse radiation about specular direction for samples.

The measurement of reflected light distribution was done using He-Ne laser. Fig.7 shows the curves for polished nickel, aluminized polished nickel, and a gold deposited glass slide. As can be seen from the above,the reflected diffused radiation lies in a cone of about 5^0 about the specular direction. Also the reflected energy distribution from polished samples compares extremely well with that from the gold on glass sample thereby demonstrating excellent finish obtained. Table 1 presents a comparison of the theoretical and experimental results obtained.

Table 1

Sample No.	Description	ρ_T	ρ_D	$(\rho_s/\rho_T)_{Exp}$	$\sigma^0(A)$	$(\rho_s/\rho_T)_{Th}$
3-1	Al/pol. Ni	.9167	.0303	.96695	70	.9791
1-4	pol. Ni	.6698	.009976	.9851	53	.988
2-4	pol. Ni	.6758	.00811	.9880	56	.9865
4-1	Al Ni	.6778	.0052	.9922	57	.986
	Al/pol. Ni	.8885	.0079	.99	40	.993
3-3	pol.Ni	.67152	.00829	.9877	57	.986
	Al/pol. Ni	.8859	.007	.9916	40	.993

Exp: Experimental; Th : Theoretical

Conclusion

The developmental process on polishing of sunshield panels for VHRR cooler has culminated in a successful effort and has established the polishing procedure for producing highly specularly reflecting mirror like metallic surface of sunshield panels. The measurements on witness specimen show a specularity of better than 98% before and after aluminium deposition. The surfaces have the desired value of specular and total reflectance as well as low emittance.

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