PRINCIPLES AND FORMULATION OF SOLAR REFLECTING AND LOW INFRARED EMITTING COATINGS FOR DEFENCE USE

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ABSTRACT

The near infrared (NIR) reflectance of paint schemes may be increased by replacing dark pigments which are highly absorptive in the visible and infrared regions, by visually similar pigments with low NIR absorption. On exposure to sunlight, these low NIR absorbing pigments reduce heat build-up and thermal infrared (TIR) signature. Resins also absorb and emit radiation, frequently in the thermal infrared region. This report covers the formulation of coatings to reduce heat buildup, prolong Service life and control infrared emission from Defence equipment. A number of Service requests are cited to illustrate solar and infrared requirements.

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PRINCIPLES AND FORMULATION OF SOLAR REFLECTING AND LOW INFRARED EMITTING COATINGS FOR DEFENCE USE

1. GENERAL INTRODUCTION

The manner in which pigments and resins contribute to the spectral properties of paints is of considerable importance in formulating coatings to control reflectance and reduce radiation emission in desired spectral regions. Coatings may be required to:

(i) reduce excessive heating of equipment from absorption of solar radiation.

(ii) reduce detection by decreasing radiation in either the visible or infrared regions.

(iii) absorb the maximum amount of solar radiation and re-emit the minimum amount of thermal infrared radiation, e.g. solar heating systems.

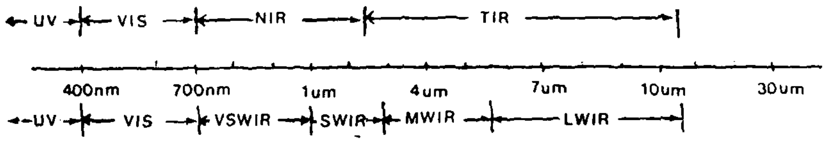
(iv) transmit visible light while preventing the transmission of other infrared wavelengths, e.g. heat through architectural glass [1].

The object of this paper is to examine paint formulating parameters which affect the spectral radiation of coatings in the visible and infrared regions. Factors influencing heat build-up and infrared emission are discussed in relation to Service requirements.

2. VISIBLE AND INFRARED RADIATION

Solar radiation, visible radiation, near infrared (NIR) radiation, very short wavelength infrared (VSWIR) radiation, short wavelength infrared (SWIR) radiation, thermal infrared (TIR) radiation, medium wavelength infrared (MWIR) radiation, long wavelength infrared (LWIR) radiation, etc. are common terms that may cause confusion because of the overlapping wavelength region to which some of these refer.

The visible region of the electromagnetic spectrum is commonly considered to be the wavelength range between 0.4-0.72 μm (400-720 nm). The infrared band of concern for solar and infrared absorbing (emitting) coatings occurs within the wavelength range 0.7-14.0 μm. This infrared region is sometimes segmented into the following regions; VSWIR occupying the region between 0.72-1.0 μm, SWIR between 1.0-2.9 μm, MWIR between 2.9-5.5 μm and LWIR between 7.5-14.0 μm.



The infrared spectrum has also been divided into the near infrared (NIR) region between 0.7-2.5 µm and the intermediate infrared or thermal infrared (TIR) region between 3-14 µm. For practical purposes only the two TIR windows 3-5 µm and 8-14 µm are generally used, due to the atmosphere's wavelength-dependent absorption of radiation. The ultraviolet region relevant to solar radiation is considered to be the region between 0.2-0.4 µm.

The wavelength range (and intensity) of radiation emitted by an object varies with temperature resulting in the peak radiation moving to shorter wavelengths at higher temperatures. Sunlight at sea level has an intensity of approximately 0.1 W/cm^2 with peak intensity (sun surface temperature 6000°K [2]) in the visible region around 0.5 µm. The energy in the solar spectrum under clear conditions consists roughly of 5% ultra-violet radiation, 45% visible radiation and 50% infrared radiation. Ninety six per cent of total solar radiation falls within the wavelength range 0.2-2.5 µm (200-2500 nm), approximately 1.7% within the 3-5 µm range and 0.1% in the thermal infrared wavelength band between 8-14 µm [2].

Objects on the earth's surface having temperatures around 300°K, are strong sources of thermal infrared (TIR) radiation even though they are not hot enough to emit visible radiation. These objects emit approximately 98% of their total radiation in the wavelength range 3-30 µm [3]. In general, the overlap between reflected solar radiation and self emitted radiation is confined to the 3-5 µm region, e.g. 'at room temperature, the power emitted at 5 µm by an efficient radiator is as great as the power from sunlight falling on the same area' [4]. In the 8-14 µm region, the reflection of solar radiation is much less important than in the 3-5 µm region, e.g. energy self-emitted by a black body at 100°C in the 8-14 µm band is approximately 4×10^{-2} W/m^2 whereas the intensity of sunlight in this region is of the order of 1×10^{-4} W/m^2.

Hence, coating requirements to control radiation emissions from an object fall into two categories:

(i) coatings which act by controlling reflectance of incident solar radiation. These coatings operate predominantly in the visible and NIR regions.

(ii) coatings which control emissions resulting from a combination of reflected incident solar radiation and thermal self emitted radiation which is a function of the emissivity and temperature of the radiating surfaces. These coatings operate in the visible, NIR, MWIR and the LWIR regions.

3. VISIBLE AND NEAR INFRARED (NIR) RADIATION OF COATINGS

Light in the visible and NIR regions falling upon a coating either enters the paint film or is reflected at the surface. The light entering the film is either diffusely reflected by the pigment particles, absorbed by the pigment and resin or transmitted through the film to reach the substrate or an underlying paint coating. At the surface of the underlying paint film, the transmitted component is again reflected or transmitted and within the underlying paint film the transmitted component is also absorbed, reflected or transmitted. Light finally reaching the substrate is again absorbed or reflected back through the film. Radiation not reflected from the film either by diffuse or specular processes is converted to heat or chemical energy.

Light-scattering in the visible and NIR is at a maximum when large differences exist between the refractive indices of the pigment and medium and when pigment particle size (which may include voids), relative to wavelength of the non-absorbed component, is such as to offer maximum resistance to the passage of light [5]. Absorption of radiation, determined by the chemical nature of the pigment, will also be subject to wavelength dependent variation. It is possible to measure scattering and hiding* power in the NIR region in a similar manner to that for the visible region by measuring the reflectance values of paint films at NIR wavelengths when applied over a highly reflecting white (RW) and a highly absorbing black (RB) surface.

It has been reported [5] that a large difference in the values of RW and RB indicates poor NIR hiding power (i.e. high infrared transmission) whereas reflectance values of similar order indicate good hiding power. Furthermore, where the reflectance values are similar but low, absorption is the major factor involved, whereas similar but high values indicate that hiding power is largely achieved by diffuse reflectance. Using this procedure, one group of pigments was found which was strongly reflecting, another which was transparent and a third which was strongly absorbing. Generally, it was found that pigments exhibited similar properties in the NIR region to those in the visible region. Thus, inorganic pigments including the lead chromes and metallic oxides were found to confer good hiding power in the NIR as they do in visible light, while many yellow and red organic pigments are seen to be relatively transparent to NIR radiation. In all cases, the contrast ratios (100 RB/RW) were found to be lower in the NIR than in the visible indicating greater transmission. Absorbers were also found to cause very significant reductions of reflectance in the NIR [5].

3.1 Effect of Pigments on Reflection of Visible and NIR Radiation

Hughes [6] showed that the higher the ratio of refractive indices of pigment and vehicle, the higher the scattering power of the paint. For a selected value of this ratio, m, Jaenicke [7] concluded that the maximum scattering power for a wavelength, λ occurs at a particle diameter, d, given by:

$$d = \frac{0.90\lambda}{n\Pi} \frac{(m^2 + 2)}{(m^2 - 1)}$$

where n = refractive index of the vehicle in the paint coating. For titanium dioxide in a typical resin of refractive index 1.48, m will be 1.90 and d = 0.42 λ. For visible radiation with peak intensity at 0.5 μm, particle sizes of 0.2 μm are characteristically

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* The hiding power of a paint coating is defined as the ability to totally mask the substrate and is usually expressed quantitatively as the area covered per unit volume of paint.

used in commercial preparations as would be predicted by Jaenicke's formula. Tomkins and Tomkins [8] have suggested that the Mie scattering theory, shows to a good approximation, that the same relationship may be used for different wavelengths with correspondingly different optimum particle sizes. They also suggest that while commercial white pigment preparations are unsuitable for infrared reflection, reflectivities of 98% are possible with larger particle size preparations.

Cohen and McLeskey [9] found that large particle size titanium dioxide and magnesium silicate significantly increased the reflectance at 1.2 μm in agreement with Tomkins and Tomkins [8] predictions on size dependent NIR reflection. Preparations using this pigment and filler were used [9] to develop white and grey solar heat reflecting undercoats that provided comparable reflective properties to MIL Specification paints at 66% reduction in dry film thickness. (The formulation of grey undercoats was designed to provide reduced contrast to the grey topcoats in military use).

The principle of using inorganic pigments of large particle size to improve solar and heat reflecting camouflage paint properties is employed in a number of US MIL Specifications, e.g. MIL-E-46061 and MIL-E-46096B where particle sizes of 1.25-1.55 μm are required. MIL-C-46127 for a solar reflecting undercoat requires 75% of the titanium dioxide particle size to be between 10 and 20 μm.

3.2 Effect of Resins on Visible and NIR Radiation

A number of resins absorb in the UV spectral range. These resins, which tend to be straw coloured, transmit around 90% of the incident radiation in the visible range. Even lower absorption in the visible occurs with clear resins. Infrared absorptions from bond vibrations commence around 3.0 μm outside the NIR region, e.g. carbon-hydrogen and oxygen-hydrogen bond absorption.

3.3 Formulating Coatings for Visible and NIR Radiation Requirements

Early Defence specifications for coatings required visual camouflage and/or temperature reduction of an object exposed to sunlight. Temperature reduction is widely achieved in civilian operations by minimising the spectral absorptance of solar radiation with light coloured reflective pigments. However, Defence operations often preclude the use of such coatings, requiring instead, coatings that visibly camouflage objects by merging them into the immediate surroundings. In early times, it was possible to conceal an object simply by the application of a paint coating exhibiting colours similar to those of natural materials in the vicinity. Camouflage paints are generally black, earth coloured or dull green flat coatings. Black roughly represents shadow, the earth colours represent sand and rocks and dull green represents vegetation. Flat paints are used to avoid specular reflections and to avoid the problem that gloss causes a loss in the surface colour definition at certain angles thus destroying the advantage of camouflage [10].

However, dark coloured low gloss paints are liable to excessive heating when exposed to light. If dark colours are used, it is not possible to reflect the visible part (45%) of the solar radiation. However, if the highly absorbing pigments used in the paints, e.g. carbon black, are replaced by pigments which do not absorb in the NIR then the colour will be retained but the NIR radiation will be absorbed to a lesser extent.

By the fifties and early sixties, NIR camouflage was required against photographic detection of the object. NIR photography detects radiation up to 0.95 μm, this radiation consisting of the infrared component of daylight reflected from the object. (Up to 1970, references in the paint literature to infrared radiation have been almost exclusively directed at NIR radiation). This NIR requirement further extended the spectral range required of paint coatings. Earth colours, (sand, rocks, etc) are often coloured by mineral oxides so that it was not difficult to match their infrared reflectance requirements with corresponding oxide pigments, e.g. iron oxides of yellow, red or brown. A survey of NIR signatures of natural formations in desert regions found that they were not greatly different from that in the long-wavelength visible, a gently rising (reflectance) characteristic being the rule [11]. The green coloration is more difficult to achieve as chlorophyll, the green pigment of vegetation, absorbs strongly in the red but only moderately in the NIR, resulting in an infrared/red reflectance ratio of 8 or more. The surprisingly high NIR reflectance of green foliage makes it appear highly lit in NIR photographs. Taylor [5] suggests that with the exception of chromium oxide green, none of the green pigments approaches the level of NIR reflectance of vegetation. However, a number of US Specifications for green paints are based on mixed pigments which approximate more closely to the chlorophyll reflectance curve and yield more effective camouflage, particularly with 'false-colour' photography than chromium oxide. In 'false-colour' photography, the photographic emulsion layers are sensitised to radiation in wavelength regions which differ from those of normal colour film. Many of the green pigments appear turquoise in NIR photography whereas chlorophyll appears magenta coloured. Consequently a number of US Specifications have magenta requirements. Black colours are traditionally made with carbon black, however this pigment is a strong absorber of NIR radiation resulting in heating of the substrate. In recent years, synthetic black pigments have been designed [12, 13] with lower infrared absorptance to partly offset this problem.

3.4 NIR Reflective Paint Schemes: Two Approaches

Two fundamentally different approaches have been adopted [14] to improve the NIR reflectivity of paint schemes. The approach adopted in the UK (e.g. by Radar Research Establishment) is to replace highly absorptive pigments in the paint film by alternatives which are transparent in the NIR but absorptive in the visible. As such, the colour is retained but the infrared radiation will pass through to the undercoat. If then a good reflective undercoat is used beneath the infrared transparent finish, the NIR radiation will be reflected by the paint scheme as a whole. The study then becomes one of examining pigments in terms of their absorption and transmittance in the visible and infrared range. This system has two limitations; firstly, the film thickness of the topcoat must be as thin as possible since however efficient the material is, there is always some absorption, and secondly, maintenance is a problem which requires that an undercoat be applied when the topcoat is being recoated.

The US Army Coatings Laboratories [9] have concentrated their research on pigments which strongly reflect infrared radiation rather than transmit it to the undercoat. However, the US materials apparently were transparent to some degree in the infrared range since "the undercoat directly beneath the solar reflecting topcoat was a critical factor" [14]. The US also found that the metal substrate under the coating also played a role in NIR reflection.

4. THERMAL INFRARED RADIATION

By the seventies, camouflage against thermal infrared (TIR) surveillance up to 14 μm (14,000 nm) was receiving increasing attention. At these longer wavelengths, thermal self emission contributes increasingly to total emission. The sensitivity of detectors in this region is such that temperature differences as low as 0.08°C are detectable even by commercial instruments. However, the real problem is not the detection of small temperature differences because the practical situation generally involves the detection of target signatures in the presence of a background having natural fluctuations of many degrees. The permissible target variation is suggested [4] to be 4°K from ambient, presumably for terrestrial situations.

The extension of camouflage requirements to the TIR region is such that the 'colours' of paints have been matched to the background over progressively broader spectra. Raisbeck et al [4] have suggested that until now, mismatch has occurred in the MWIR, and seriously so in the LWIR. However, there are no physical laws to suggest that the spectral match cannot be extended to LWIR given further development.

Control of emission can be obtained for coatings which radiate in spectral regions not used for detection, however it has been suggested that this capability is costly and limited [10]. Most paint vehicles in use today are brightly emitting in the TIR so that there is no real possibility of extending the spectral range just by adding pigment. It is felt [4] that the whole paint system, i.e. resin, pigments, fillers, etc will have to be redesigned.

In principle, the total emission in the TIR region can be adjusted either by controlling the scattered incident illumination and the thermal radiation separately [10]. However, if the emission of the surface is matched to the surrounds by controlling thermal radiation (temperature matching) only, changes in sunlight will result in changes in background radiance but not surface radiance. If the temperature is matched to the background by controlling the target's scattered radiation only, and the surrounding temperature changes, then again the background radiance* changes but not the target radiance [10].

A fundamental consequence of the above is that the total emission must be considered. If the target absorbs heat when illuminated during the day and cools off at night, the rate of heating and cooling must be controlled so that the diurnal fluctuation in total target emission matches environmental emission.

Low emissive paints (LEP) are now commercially available [15] which are claimed to reduce by as much as 50% the loss of energy radiated owing to surface temperature. It is recommended by the suppliers that these low emissive paints (LEP) should be applied to ships, tanks and vehicles that are subject to solar heating during the day which require reduction of the heat loss at night. LEP coatings are used externally with reflectance of about 50% in the 8-14 μm region and can generally be made in any colour.

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* Radiance usually in W cm^{-2} sr^{-1}, is the infrared equivalent of the visual waveband term brightness).

4.1 TIR Absorption (Emission) by Pigments

The infrared absorption bands of pigments composed of inorganic materials tend to be broad and fewer in number than organic materials. Phosphates, silicates, sulphates, carbonates and chromates exhibit internal vibrations as a result of tight internal bonding which results in strong TIR absorption in the 7-14 μm region [16].

A number of the metal oxide fillers or pigments e.g. zinc oxide, are relatively weak absorbers in the TIR region [16]. Their relatively weak emissions in the TIR make them suitable for camouflage in this region. On the other hand, organic pigments with their complex carbon-nitrogen-oxygen structures and strong TIR emission are unsuitable in this region.

4.2 TIR Absorption (Emission) by Resins

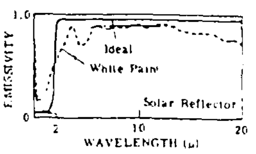
The primary criterion for a resin employed in a highly reflective coating is low absorption of TIR radiation. The infrared absorption spectra of organic polymers are complex. They can be qualitatively predicted in terms of the individual bonds in the molecule, but quantitative estimates of an infrared spectrum are not simple. Many organic polymers contain carbon-hydrogen bonds for which a stretching band can be expected in the TIR between 3.0-3.7 μm. If oxygen or nitrogen is present bonded to hydrogen, an absorption band between 2.7-3.3 μm will be observed. To eliminate absorption in the TIR, such bonds between light elements must be absent. One method aimed at decreasing these absorptions has been to use chlorinated resins, e.g. PVC film adhesively bonded in patches on camouflage netting [16]. The vinylidene chloride copolymers, e.g. vinylidene chloride-acrylonitrile also show very weak absorption in the 3-5 μm area [8].

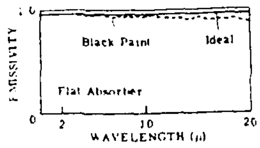
Aromatic and olefinic bonds are often strongly absorbing in the TIR. Ester, ether, alcohol, epoxide carbon-oxygen, methylsiloxane and organofluorine groups also absorb in the TIR region while weaker absorptions in this region are due to methylene rocking and carbon-carbon stretching [17].

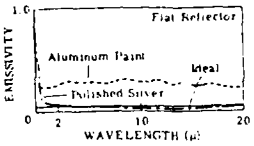
The wide variety of organic groupings which absorb in the TIR has resulted in examination of nonorganic binders for suitability. The use of an inorganic resin [18] and a diamond-like vapor coating [19] are two of the methods that have been employed. The inorganic resin was based on a chromate-phosphate complex. Both chromate and phosphate ions absorb strongly in the TIR, however the composite matrix has been cured at high temperature to form a glassy material which is presumed to have removed the hydroxyl groups in view of the fact that nonspecular reflectances of greater than 60% were achieved. The diamond-like coatings are used in second-surface mirror systems where the diamond-like coating forms a protective transparent coating over a reflective material.

5. SOLAR REFLECTORS AND FLAT (LOW EMISSIVITY) REFLECTORS

A spectral emissivity which varies greatly with wavelength automatically results in a total emissivity which varies with temperature. Since white paint reflects solar radiation up to 1-2 μm, it is sometimes referred to as a solar reflector. On the other hand, aluminium pigmented paint which reflects in both the visible and infrared regions, is referred to as a flat reflector (black paint, which absorbs in both, is referred to as a flat absorber) [20].







The distinction between the white paint and aluminium paint was not appreciated when it was initially noted that aluminium paint did not prevent temperature increase as well as white paint [21] suggesting that the latter were better heat reflectors than the aluminium paints. Subsequently, furnaces and radiators were unexpectedly found to remain hotter when painted with metallic pigmented paints rather than with white paint [22, 23].

White paint is a solar heat reflecting coating by virtue of its low spectral absorbance in the visible and NIR. In the TIR, white paint has a low reflectance, i.e. high emittance, and is thus an efficient radiator at these wavelengths. If it were not for this ability of white paint to reradiate absorbed energy at longer wavelengths, external fuselage surfaces of airliners would be left in a natural aluminium finish since this material absorbs less energy from the sun than white paint. However, aluminium has a low emissivity over the whole spectrum and thus cannot dissipate heat by radiating in the TIR region as readily as white paint [24].

6. SERVICE REQUESTS FOR SOLAR HEAT REFLECTING PAINTS

Defence requirements for paint schemes to control radiation emissions are generally directed at systems (i) or (ii) Section 2, i.e. reducing surface temperatures or controlling infrared emissions to match environmental levels. Examples in recent times within the Australian Defence Forces (ADF) have included minimising the heat load on aircraft shelters [25], Rapier missiles [26], Minehunter vessel [27], bomb disposal vehicles [28], telecommunication shelters [29], RAAF helmets [30] and aircraft fuel storages [31]. Control of infrared reflection levels are specified for a number of Service painting schedules [32] while commercial development of thermal infrared (TIR) low emittance paint coatings is receiving greater attention in view of the interest of allied Services [15].

Increases in the level of solar and infrared reflectance of Defence paint schemes have also raised questions concerning the detectability of these coatings by infrared emissions. There has been a perception among some Service personnel that by increasing the NIR reflectance of surface coatings, the ease and range of infrared detection may be unfavourably changed. However the following examples of Service material illustrate the significant decrease in temperature that may be achieved by reducing the NIR absorption characteristics of the applied paint coating. These lower temperatures will result in a reduced thermal signature.

6.1 RAAF Pilot Helmets [30]

Mirage aircraft pilot helmets have traditionally been coloured white, producing reflection from the interior surface of the canopy and making the pilot very conspicuous in flight. A grey paint was prepared at MRL by adding carbon black to the white lacquer and applied to a helmet. However, RAAF medical officers were concerned that the dark colour would increase the heat stress level on the pilot. Investigations showed that certain black organic pigments reflect most NIR radiation whereas carbon black has a very low reflectance. Samples of grey lacquers, made using organic black tinters were trialled. One particular tint successfully reduced heat stress and improved pilot combat visibility by lowering light reflection. The heat reduction using this infrared reflecting grey with a white undercoat is shown [30] below in Table 1 (system 1).

Table 1 Temperature of Paint Systems for Pilots Helmets [30]

Paint System (Undercoat/topcoat)	% Near Infrared Reflection	Temperature °C
1. White/light grey (IRR)*	62	48
2. White/dark grey (IRR)	45	58
3. Light grey (IRR)	65	55
4. Dark grey (IRR)	48	62
5. Light grey	18	63
6. Dark grey	5	73
7. White lacquer	90	38
8. Black lacquer	3	76

* Distance between lamp and panel 460 mm. Ambient temperature 18-19°C.

6.2 Fibreglass Cabins of Army Bomb Disposal Vehicles [28]

The surface of the fibreglass cabins of Army Bomb Disposal Vehicles showed cracking and signs of heat distortion following operational service. At times, the air conditioners were unable to cope with the heat buildup inside the cabins. No problems had been reported with cabins of similar civilian vehicles which were painted white. The Army vehicles had been painted with a grey primer and a deep bronze-green finishing coat. Laboratory tests (Tables 2a & 2b) showed this lacquer had low infrared reflection characteristics resulting in heat buildup. MRL provided a paint scheme for future bomb disposal vehicles comprising a white undercoat and green finish with high near infrared reflection [28]. A more heat stable fibreglass resin was also recommended.

Table 2a **Temperature of Paints for Army Fibreglass Cabins for Bomb Disposal Vehicles [28]**

	Paint System	Maximum Temperature °C*
1.	Nil	93.5
2.	2 coats grey primer	79
3.	2 coats white primer	57.6
4.	2 coats grey primer + 2 coats green	108
5.	2 coats white primer + 2 coats white	63.5
6.	2 coats white primer + 2 coats green	104
7.	2 coats white primer + 2 coats IRR green	75.8

* Distance between lamp and panel 460 mm. Ambient temperature 18-19°C

Table 2b **Near Infrared Reflectance of Paints for Fibreglass Cabins of Army Bomb Disposal Vehicles [28]**

Coating	% Reflection at 800 nm
Grey primer	19
White primer	91
Green finish	10
White epoxy	80
Green IRR finish	45

6.3 RAN Minehunter - Inshore [27]

Australia's new minehunters are of foam sandwich/glass reinforced plastic (GRP) construction, susceptible to excessive temperatures in the foam which leads to foam shrinkage and structural compromise. The reflectance properties of the paint system are therefore critical. Two paints using organic black tinters were compared to the standard Navy Admiralty Grey which uses carbon black pigmentation. A dramatic difference [27] in IR reflectance was clearly demonstrated (Table 3). This approach of using organic black tinters (Table 4a) differs from the US approach of using a number of inorganic pigments of increased particle size to formulate grey paints (Table 4b). A number of different coloured solar heat reflecting paints in other US specifications use similar pigments (Table 5). The relative advantages of the US and Australian approaches need to be investigated.

Table 3 **Near Infrared Reflectance of Paints for Minehunter-Inshore Vessel [27]**

Coating	% Reflection at		
	750 nm	800 nm	850 nm
Admiralty Grey	22	20	19
Grey (Paliogen black)	78	78	77
Grey (Helio black)	58	72	75

Table 4 **Solar Heat Reflecting Grey Paint Schemes for Australian and US Military Equipment**

(a) Australian GPC-E-24 'Silicone Alkyd Solar Heat Reflecting Coating'

The infrared reflectance of the paint at 800 nm shall not be less than 75%. (In order to meet the infrared reflectance requirements the paint should be free of carbon black or other high infrared radiation absorbing pigments. Grey colours may be achieved by the use of, for example, perylene black.

(b) US Military Specification 46127 'Coating, Grey (Solar Heat Reflecting)'

The following hiding pigment combination has produced a color conforming to this specification:

Component	Weight
Titanium dioxide, rutile	60.00
Phthalocyanine blue	0.13
Lead chromate (87%)	4.50
Violet (carbazole dioxazine)	0.10

Table 5 **Solar Heat Reflecting Olive Drab Paint Formulation**

Military Specification 46117 for 'Enamel, Solar Heat Reflecting, Olive Drab' suggests that 'the following hiding pigment combinations have produced olive drab color conforming to this specification'.

Component	Weight
Titanium dioxide, rutile	3.6
Phthalocyanine blue	1.7
Lead chromate (87%)	92.0
Violet (carbazole dioxazine)	2.7

7. DISCUSSION

From the examples and Tables cited in this report, it is evident that significant reductions in temperatures may be achieved by replacing NIR absorbing pigments with NIR transparent or reflecting pigments. The requirement for temperature reduction in the examples cited has been to prolong the life and improve the performance of Service equipment. However, as TIR emission is a function of temperature, TIR signatures are also reduced by the changed formulations.

Formulation of paints to give low absorptances and emittances in the TIR region is rendered difficult by the large number of chemical groups in organic resins which absorb in this region. Approaches to overcome the MWIR absorption of bonds between light elements such as carbon-hydrogen have involved investigations of chlorinated resins such as PVC [17] and vinylidene chloride copolymers [8], as well as inorganic binders [18] and diamond-like deposits [19].

The increase in NIR reflectivities of modern camouflage paint schemes has raised questions from Service personnel on the effect of these changes on detection levels. There is a belief that changes in the paint schemes will lead to an increase in the range of detection. This perception is considered to have arisen from the fact that the term 'increased infrared reflectance' used with the new paint schemes has created an impression that the thermal infrared signal is also increased whereas the reverse is usually true.

Passive countermeasures such as infrared and visible camouflage paint are cheap and effective for long periods providing an attractive technique for operational requirements [33]. It is said [4] that 'one cannot make a target impossible to see, one can only make it more difficult to see, delay its detection and increase the likelihood of overlooking it or misidentifying it'. Correctly used, camouflage can spell the difference between a successful campaign and defeat. The use of newer detection and targetting techniques requires that the present camouflage paint schemes be progressively extended into longer wavelength regions to control temperature and infrared emission.

The examples cited in this report show that significant reductions in temperature (and hence thermal signature) have been achieved by the reformulation of coatings. This situation has changed from that of earlier times when it was considered that [33] 'the use of paints with high visible reflectivity or low infrared emissivity are not recommended. While these treatments have been shown to give a reduction in signature, they do not provide a sufficiently significant reduction to warrant their use in general'. In this report, paint coatings with similar visible characteristics but which significantly lower temperature and hence thermal signature are cited. These coatings may be formulated at marginal cost increases to those in Service. As such, consideration should be given to the replacement of coatings on further items of Defence equipment, where Service life or TIR signature are important. If the major component of TIR detection can be assigned to an excessive temperature increase, as a result of solar radiation absorption, coatings which increase NIR reflection (preferably without increase in TIR emissivity) should be considered.

8. CONCLUSIONS

This study describes methods of formulating paint schemes to minimise surface contrasts against backgrounds in the visible, near infrared and thermal infrared wavebands. The physical processes involved in reflection and emission from coatings and their substrates have been described as they provide a basis for formulation principles.

Since a major component of the thermal infrared signature of an object exposed to sunlight can often be assigned to an excessive temperature increase as a result of solar radiation absorption, coatings which increase near infrared reflection should be considered for thermal infrared camouflage.

9. REFERENCES

1. Lampert, C.M. (1982). Durable innovative solar optical materials - the international challenge. Society of Photo Optical Instrumentation Engineers (SPIE) Proceedings, **324**, 1.

2. Wolfe, W. and Zissis, G.J. (1978). The Infrared Handbook, Office of Naval Research, Department of Navy, Washington, DC.

3. Dachselt, W-D., Munz, W-D., Scherer, M. (1982). Low emissivity and solar control coatings on architectural glass. Society of Photo Optical Instrumentation Engineers (SPIE) Proceedings, **324**, 37.

4. Raisbeck, G., Aronson, J.R. and Key, M.E. (1981). Design goals for future camouflage systems (Report ADL 83670-26). USA: Arthur D. Little Inc., AD-A099-223.

5. Taylor, D. (1958). Optical properties of pigments in the near infra-red. Journal of the Oil and Colour Chemists' Association, **41**, 707.

6. Hughes, W. (1952). Physical characteristics of white pigments with particular reference to titanium dioxide. Journal of the Oil and Colour Chemists' Association, **35**, 535.

7. Jaenicke, W. (1956). Light scattering and tinting strength of white pigments. Elektrochem., **60**, 163.

8. Tomkins, L.M. and Tomkins, E.H. (1958). The design of heat-reflective paints. Journal of the Oil and Colour Chemists' Association, **41**, 98.

9. Cohen, M. and McLeskey, J.J. (1970). Development of a solar heat reflecting gray undercoat (Report No. 277) (Unclassified). Maryland, USA: US Army Aberdeen Research and Development Center.

10. Brunswick Corporation. (1976). Cuide to camouflage for DARCOM equipment developers. Report Prepared for MERADCOM under Contract DAAG53-76-C-0126 (Unclassified).

11. Beckwith, P. (1981). Near-infrared reflectance in desert regions (Technical Note MRL-TN-455). Maribyrnong, Vic.: Materials Research Laboratory.

12. Paliogen Black, BASF.

13. Helio Black, Bayer Australia Pty Ltd.

14. Hill, L.A. (December 1978). Solar heat reflecting paints. 14th Progress Review, Paints Group, Materials Research Laboratory.

15. Low emissive paint in the IR thermal region. (undated). US Aestra Corp., New York, Aestra GMBH, Dusseldorf.

16. Lofgren, Per-Ake. (March 1987). Camouflage concepts for the nineties. Proceedings of the International Conference on Polymers in Defence, Plastics and Rubber Institute - Western Section, Bristol. Section C, 17/1.

17. An infrared spectroscopy atlas for the coatings industry (1980). Federation of Societies for Coatings Technology, USA.

18. Calvert, R.L., Gagliardi, J.A. and McLachlan, A.D. (1984). Surface coatings for low emittance in the thermal surveillance band (Report MRL-R-937). Maribyrnong, Vic.: Materials Research Laboratory.

19. Troughton, G. (1984). Pers. Comm. Royal Signals and Research Establishment, Cited in Ref. 18.

20. Wolfe, W. (1965). Handbook of military infrared technology, Office of Naval Research, Washington, DC.

21. Gardner, H.A. (1972). Paint testing manual physical and chemical examination of 13th Ed. ASTM. Paints, Varnishes, Lacquers and Colours, Pennsylvania.

22. Nelson, H.A. and Jamieson, R.W. (1928). Effect of weathering on the heat-reflecting efficiencies of paints on metal tanks. Ind. Eng. Chem. **20**, 702.

23. Allen, J. (1920). J. Am. Soc. Heat and Vent. Eng., **226**, 109.

24. Hawker-Siddeley Dynamics. (1968). Technical Report FPD/DR/055/1/3, Infrared Target Manual, Ch. 3.

25. Hill, L.A. (April 1976). Solar HR paint for aircraft shelters (MRL Internal Report A8/206/2). Maribyrnong, Vic.: Materials Research Laboratory.

26. Gagliardi, J. (April 1980). Solar heat reflecting paint for rapier missile, (MRL Internal Memo 64/4/10). Maribyrnong, Vic.: Materials Research Laboratory.

27. Hall, D.J. and Robson, B.L. (1984). A review of the design and materials evaluation program for the GRP/foam sandwich composite hull of the RAN Minehunter, composites, **15**, (4), 1984, 266-76.

28. Grey, C.A. and Hill, L.A. (April 1980). Heat absorption of fibre glass vehicle bodies (bomb disposal vehicles) (MRL Internal Report 64/4/10). Maribyrnong, Vic.: Materials Research Laboratory.

29. Hill, L.A. (March 1985). Repainting of aluminium telecommunication shelters and radar equipment - solar heat reflecting (MRL Internal Report 64/4/9). Maribyrnong, Vic.: Materials Research Laboratory.

30. Gagliardi, J. and Hill, L.A. (May 1982). Heat reflective paints for pilot's helmets (MRL Internal Report 64/4/9). Maribyrnong, Vic.: Materials Research Laboratory.

31. Wake, L.V. (February 1988). Painting of RAAF Avtur fuel tanks (MRL Internal Report 64/4/9). Maribyrnong, Vic.: Materials Research Laboratory.

32. Australian Government Paint Committee Specification. (Jan 1980). Enamel, Semi Gloss, Olive Drab, GPC-3-6.

33. McQuistan, G.W. and Gambling, D.J. (Feb 1973). Infrared countermeasures for RAN destroyers (WRE Report 843). Salisbury, SA: Weapons Research Establishment.

TERMS

$$\text{emissivity (e)} = \frac{\text{radiant power emitted/area}}{\text{radiant power emitted by a blackbody/area}}$$

The absorbing properties of the surface are characterised by the absorbance defined as

$$\text{absorptance (\&)} = \frac{\text{radiant power absorbed}}{\text{radiant power incident on surface}}$$

At thermal equilibrium, e = & (Kirchoff's Law), i.e. good absorbers are good emitters.

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Principles and formulation of solar reflecting and low infrared emitting coatings for defence use

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ABSTRACT

Coatings may be formulated to increase solar heat reflection for paint colours required on Defence equipment. Pigments in coatings have a strong influence on the absorption and reflection of radiation in the visible and infrared regions. Dark pigments, such as those in camouflage patterns, are often highly absorptive in the near infrared region resulting in excessive heating of military equipment when exposed to sunlight. Resins also absorb and emit radiation, frequently in the thermal infrared region. Coatings may similarly be formulated to reduce the energy emitted in the thermal infrared region for a given surface temperature. This report covers the formulation of coatings to reduce heat buildup, prolong Service life and control infrared emission from Defence equipment. A number of Service requests are cited to illustrate solar and infrared requirements.