AD-A267 555

FORMULATING INFRARED COATINGS FOR DEFENCE APPLICATIONS

AR-008-254

L.V. WAKE AND R.F. BRADY

MRL-RR-1-93

MARCH 1993

DTIC
ELECTE
JUL 23 1993
D

APPROVED
FOR PUBLIC RELEASE

© Commonwealth of Australia

DISTRIBUTION STATEMENT A
Approved for public release;
Distribution Unlimited

MATERIALS RESEARCH LABORATORY
DSTO

Published by

DSTO Materials Research Laboratory
Cordite Avenue, Maribyrnong
Victoria, 3032 Australia

Telephone: (03) 246 8111
Fax: (03) 246 8999
© Commonwealth of Australia 1993
AR No. 008-254

APPROVED FOR PUBLIC RELEASE

Contents

1. INTRODUCTION 7

2. PHYSICAL PRINCIPLES 8
2.1 *Spectral Bands of Interest* 8
2.2 *Blackbody Radiation* 8
2.3 *Solar Radiation* 10
2.4 *Control of Infrared Properties by Coating Formulation* 10
2.5 *Properties of Coatings Determining Infrared Performance* 12
2.5.1 *Reflection of Radiation* 12
2.5.2 *Scattering of Radiation* 13
2.5.3 *Absorption of Radiation* 14

3. RAW MATERIALS 15
3.1 *Measurement of Near Infrared Properties of Pigments* 15
3.2 *Selecting Pigments for Applications in the Near Infrared* 19
3.3 *Selecting Pigments for Applications in the Thermal Infrared* 21
3.4 *Spectral Properties of Resins* 22

4. FORMULATION 22
4.1 *Preparing for Formulation* 22
4.2 *Control of Colour* 23
4.3 *Control of Emissivity in the Thermal Infrared* 23

5. COATINGS WITH TAILORED INFRARED REFLECTANCE 24
5.1 *Low NIR or Low TIR Signature?* 24
5.2 *Solar Heat (near infrared) Reflecting Coatings* 24
5.3 *Thermal Infrared Reflecting (low emissivity) Coatings* 25
5.4 *Camouflage Coatings* 25
5.4.1 *Coatings for Forest and Jungle Areas* 26
5.4.2 *Coatings for Desert Regions* 29
5.4.3 *Coatings for Ocean Environments* 29
5.4.4 *Coatings for Aircraft* 31

6. SUMMARY 33

7. REFERENCES 33

2. Physical Principles

2.1 Spectral Bands of Interest

The radiation bands of interest are the NIR region between 720 and 2500 nm, the TIR region between 2500 and 15 000 nm (2.5 and 15 mm), and the far infrared region between 15 and 50 mm.

The "photographic infrared" is traditionally regarded as the range from 700 to 950 nm, although modern infrared film is sensitive at much longer wavelengths than this range. Electronic scanning arrays are usually preferred over photographic detectors. They are used in aerial reconnaissance and cover the range from 700 to 1350 nm. Generally, the conditions under which NIR radiation emissions pose a significant threat are (i) lowlight or starlight situations where detection is usually by reflected radiation rather than by thermal emission, or (ii) by reflection of NIR laser illumination.

Two windows in the thermal infrared region, 3 to 5 mm and 8 to 14 mm are of primary importance in missile and surveillance applications because these regions are relatively free of atmospheric absorption and energy can be transmitted over moderate distances. Sensors operating in these two bands are the basis of some of the principal types of seekers in smart anti- armour munitions [1].

Some of the newer thermal detection systems also incorporate NIR targeting elements. A number of the aircraft-mounted detection systems couple forward looking thermal infrared (FLIR) sensors tailored for target detection and lock-on with a laser target designator and rangefinder operating in the NIR at 1.06 µm.

2.2 Blackbody Radiation

In addition to reflecting incident energy, coatings also radiate energy. The spectral exitance M_λ ($W.m^{-2}$) of a blackbody at wavelength λ and in a spectral range $\Delta\lambda$ is a function of temperature and is given by Planck's Radiation Formula (Equation 1) [2]

$$M_\lambda = \frac{2\pi hc^2}{\lambda^5} \cdot \frac{1}{\left(e^{hc/k\lambda T} - 1\right)} \Delta\lambda \qquad (1)$$

(in which h is Planck's constant (6.626×10^{-34} J s), c the velocity of light (2.998×10^8 m s^{-1}), k the Boltzmann constant (1.38×10^{-23} J K^{-1}), and T the absolute temperature).

The rate of energy emitted per unit area obtained from Equation 1 has been plotted for three temperatures in Figure 1. This figure shows that, with increasing temperature, the rate emitted increases markedly and the wavelength of maximum emission shifts from the TIR region toward the NIR region. Thus, it can be seen that an increase in the energy content of a body, such as that caused by the absorption of NIR radiation, results in increased emission and detectability in the 8 to 14 mm TIR region.

2.3 *Solar Radiation*

A specific example of a blackbody radiator is the sun. The spectral energy distribution of solar radiation at sea level with a slant path corresponding to an air mass of 1.5 [3] is shown in Figure 2. For convenience, this energy is usually divided into three bands. The ultraviolet band between 200 and 400 nm contains 5 percent of the total energy in sunlight, the visible band between 400 and 720 nm has 45 percent and the NIR band between 720 and 2500 nm contains 50 percent of the energy. Sunlight at sea level has a total intensity of approximately 1 kW m^{-2} [3]. Solar absorptance, α_s in the NIR is defined as the ratio of NIR radiation absorbed by a body to that incident upon it.

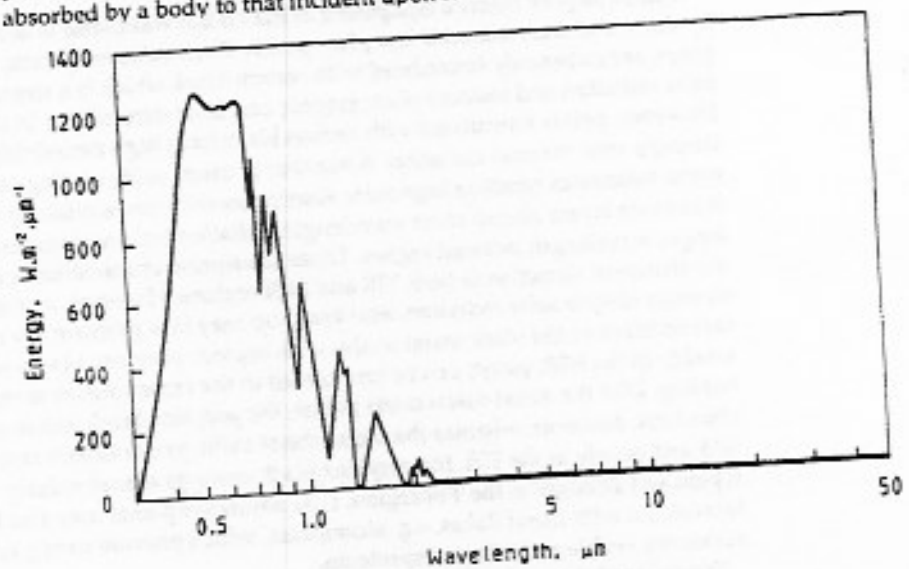


Figure 2: Spectral energy distribution of solar radiation.

2.4 *Control of Infrared Properties by Coating Formulation*

Incident radiation is reflected or both reflected and refracted at a coating surface. Both reflection and refraction are dependent on the refractive indices of the two media, the reflection being determined by Fresnel's Law and refraction by Snell's Law. In paint terminology, a description of the mirror-like reflection or specular reflection at the surface of the coating is termed gloss, as distinct from the reflectance of the coating which is also dependent on pigments and fillers in the coating. Specular reflection is strongly increased by leafing pigments such as metal flakes. Gloss is principally dependent on the angle of incidence and the smoothness of the surface, being high for smooth surfaces and low for irregular surfaces.

Infrared radiation entering a paint coating is refracted at the interface before encountering the pigment and filler particles. The radiation is partially reflected and partially refracted at the surfaces of these particles and in normal pigmented paints the process of multiple reflection and refraction thoroughly diffuses the beam. A proportion of this radiation propagates back to the coating surface where

2.5 *Properties of Coatings Determining Infrared Performance*

2.5.1 *Reflection of Radiation*

The specular and diffuse reflectance of infrared radiation from a coating results from reflecting and scattering processes occurring at the surface and within the coating. The reflectivity is defined as the ratio of the reflected to the incident energy. At flat surfaces, specular reflection will occur in accordance with Fresnel's Law from which the reflection coefficient (ρ) may be derived [4]:

$$\rho = \frac{(n-1)^2 + n^2\chi^2}{(n+1)^2 + n^2\chi^2} \tag{3}$$

(in which n is the ratio between the refractive indices of the two media and χ is the extinction coefficient).

From Equation 3, we see that when $n\chi$ is large (good absorbers) compared to $n + 1$, the reflecting power is nearly unity, i.e. strong reflection is associated with strong absorption. This result is in agreement with experimental observation [5]. Highly conductive materials, e.g. metals, do not allow electromagnetic propagation at optical or infrared frequencies. The electromagnetic fields are attenuated so rapidly that, at thicknesses exceeding the skin depth, the reflection coefficients are close to unity. However, metals in the form of very small particles will allow the passage of decaying electromagnetic fields, and because of their high absorption, the emissivity of paints containing such particles may approach unity. The small particles will also provide diffuse multiple scattering, particularly when the particle sizes approach light wavelengths. This is the basis of the action of the metallic blacks.

From Kirchhoff's Law (Equation 4), it can be seen that coatings which are good reflectors have low emissivities [6],

$$\varepsilon_\lambda = \left[1 - \rho_\lambda\right]\left[1 - e^{-4\pi\chi_\lambda t/\lambda}\right] \tag{4}$$

(where ε_λ is the emissivity, ρ_λ the fraction of the radiation reflected, $4\pi\chi_\lambda$ the absorption coefficient and t the depth). The first term in Kirchhoff's Equation, $1 - \rho_\lambda$ which is the proportion of radiant flux penetrating the body, becomes quite small for good reflectors. The second term, $1 - e^{-4\pi\chi_\lambda t/\lambda}$ is the proportion of flux penetrating the body and absorbed by it. In the infrared spectral region, even a small thickness of matter will usually absorb the entire refracted flux, so that equation 4 reduces to

$$\varepsilon_\lambda = 1 - \rho_\lambda \tag{5}$$

For materials of high conductivity, the reflectance (and emittance) can be reduced to equations dependent only on conductivity [7], viz

$$\rho = 1 - 2\sqrt{\frac{4\pi \cdot \varepsilon_0 \cdot c}{\sigma \cdot \lambda}} \tag{6}$$

(where σ is the conductivity and c the velocity of light).

Substantial changes in scattering power cannot be achieved by the choice of resin because conventional paint resins do not show a large variation in refractive index. Common organic resins have refractive indices between 1.45 and 1.50 and conventional alkyd and epoxy resins have refractive indices near 1.48. Fluoropolymers possess comparatively low refractive indices [9] in the range of 1.34 to 1.42 and fluoropolymer coatings made with titanium dioxide [10] scatter light very effectively because of the large value of m.

For a fixed value of the scattering power m, the wavelength most efficiently scattered by a particle of diameter d is given by Equation 7 [11],

$$\lambda = \frac{d}{\kappa} \tag{7}$$

in which

$$\kappa = \frac{0.90\left(m^2+2\right)}{n\pi\left(m^2-1\right)} \tag{8}$$

In Equation 8, n is the refractive index of the resin in the paint. Table 1 contains values of n, m and κ for common paint pigments dispersed in an alkyd resin having a refractive index of 1.48. In a later study using the Mie scattering theory it was shown that, to a good approximation, the same relationship may be extended to different wavelengths with correspondingly different optimum particle sizes [12].

Commercial titanium dioxide pigments are manufactured with a particle size of 200 nm, the optimum value for scattering visible radiation with a peak intensity of 500 nm [13]. As can be seen in Equations 7 and 8, larger particle sizes will be required to scatter the longer wavelengths of infrared radiation. For titanium dioxide and red iron oxide, 1 mm particles would effectively scatter near infrared radiation at 2.3 mm, but for other pigments, larger particle sizes would be needed to scatter light at the same wavelength. To scatter thermal infrared radiation, particles several micrometers in diameter would be required.

2.5.3 *Absorption of Radiation*

The coefficient of absorption of radiation will, in general, vary with wavelength. When radiation passes through a gas, certain wavelengths are preferentially absorbed. These are the same as those observed in the emission spectrum of the gas. In homogeneous condensed materials, molecular interactions broaden the electronic states.

Infrared radiation incident upon a paint may cause polarization of the electrical and magnetic (polar) components within the compounds which comprise the paint. Alignment of permanent dipoles is ineffective at high frequencies (infrared frequencies) because the movement of dipoles is too slow to follow field variation [4]. The external electric field component reacts with the electric field of the atom or molecule displacing the electrons relative to the nucleus. Spectra observed in the infrared are mostly due to transitions between the energy levels of molecules rather than atoms. Strong absorption of infrared radiation occurs only for transitions between states with different dipole moments. Thus there are no

and selective absorption of light by pigments determines the hiding power of the paint, that is, its ability to screen the substrate from incident light energy. Measurement of scattering of infrared radiation at 2.5 μm is a useful method to evaluate pigment dispersion [18].

Hiding power and reflectance are characteristics of a paint film rather than of a pigment. The behaviour of a pure pigment will change when it is incorporated into a paint. For example, non-absorbing pigment particles which reflect as pressed powders allow considerable transmission of infrared radiation when incorporated into paint films at conventional pigment volume concentrations [19].

A representative group of pigments was selected for the present study of their infrared properties. In view of the large differences in oil (resin) absorption by pigments in paint films, each pigment was dispersed in a standard resin at the same percentage of its critical pigment volume concentration (CPVC) [20] rather than at a fixed concentration. (The CPVC is the level of pigmentation, i.e PVC, where just sufficient binder is present to fill the voids between the pigment particles. Sharp changes in film properties occur at this point.) An approximate value for the CPVC, which makes allowance for oil absorption, was calculated by Equation 9 [21]

$$CPVC = \frac{1}{1 + \frac{SG_p \times OA_p}{SG_r \times 100}} \qquad (9)$$

in which SG_p and SG_r represent the specific gravity of the pigment and resin, respectively, and OA_p is the oil absorption of the pigment in grams of oil per 100 grams of pigment. In order to produce the semi-gloss finish of most camouflage coatings, the pigments were dispersed in a resin to produce a paint having PVC/CPVC = 0.5, a value characteristic of semigloss paints [22] but this value may be adjusted depending on the intended application. Total paint solids, i.e. pigment plus binder, were adjusted to 50 percent by volume, and drawdowns with a 125 μm blade produced dry films 75 to 88 μm thick.

A spectrophotometer operating in the visible and infrared regions and equipped with an integrating sphere was used to measure the diffuse reflectance spectra of the dry films over the wavelength range 400-2300 nm. Measurements of diffuse infrared reflectance are made over highly reflecting white (R_w) and highly absorbing black (R_b) surfaces. Data obtained with a Cary Model 2300 recording spectrophotometer for some representative pigments are given in Table 2.

The infrared properties of pigments can also be estimated simply and rapidly by measuring their infrared reflectance in a narrow NIR band. This technique is useful and convenient, but gives much less information than measurement of the diffuse reflectance spectrum. An EEL Reflectometer (Evans Electroselenium Ltd., Essex, U.K.) modified with cadmium sulfide detectors and Wratten 88A filters was used for measurements [23]. The sensitivity of this instrument starts from zero at 730 nm, rises fairly sharply to a peak response at about 770 nm, and then decreases steadily to zero at about 890 nm [24]. Data from this technique are given in Table 3, and compare favorably with the spectrophotometric data in Table 2. Using films 75 to 88 μm thick, the contrast ratio (CR_{IR}) at 800 nm in the infrared was calculated for each pigment using Equation 10 and is also given in Table 3.

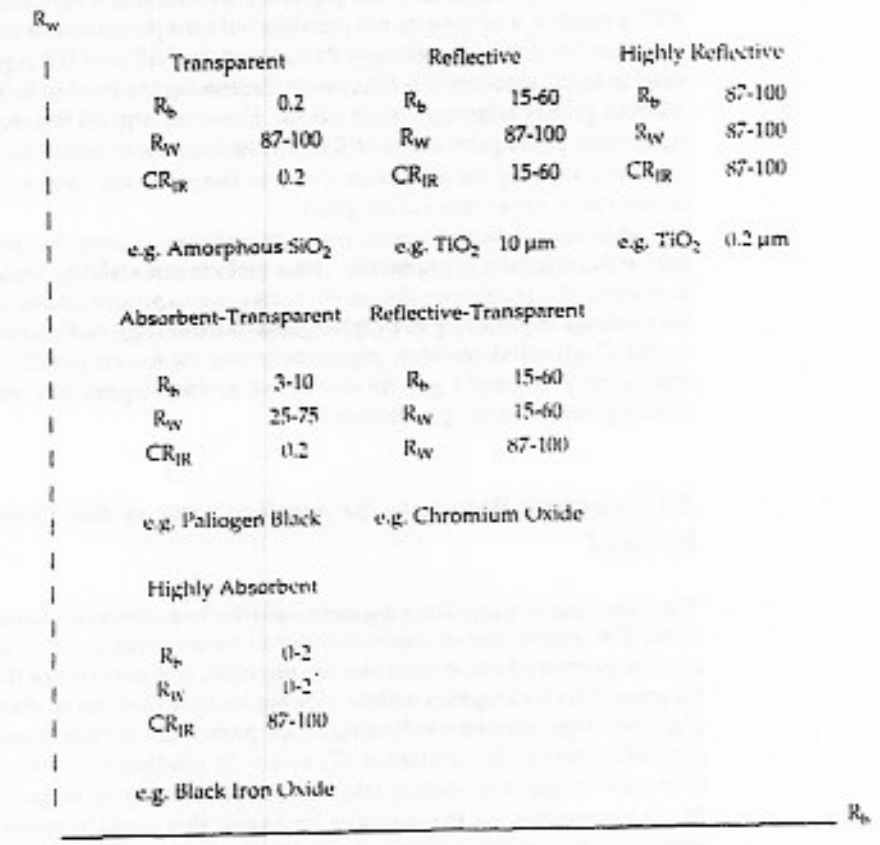
Table 2 (Contd): Diffuse reflectance values (in percent) of paint films applied over white (R_w) and black (R_b) backgrounds.[a,b]

Pigment		Wavelength (nm)									
		1400	1500	1600	1700	1800	1900	2000	2100	2200	2300
Barytes	R_w	73	67	71	70	70	64	61	44	46	33
	R_b	0	0	5	9	11	9	5	0	0	0
Carbazole Dioxazine Violet	R_w	71	78	71	63	66	55	57	44	48	30
	R_b										
Chromium Oxide	R_w	37	37	37	32	35	43	43	37	34	26
	R_b	35	33	31	31	35	39	35	28	27	26
Heliogen Black	R_w	76	68	73	68	70	62	59	39	41	25
	R_b										
Iron Oxide, Red	R_w	44	39	41	40	42	38	34	28	34	28
	R_b	44	39	41	32	35	38	34	28	34	28
Iron Oxide, Yellow	R_w	68	32	32	54	59	54	54	37	39	26
	R_b	12	12	15	14	7	2	2	10	9	2
Iron Oxide, Lt. Brown	R_w	0	0	0	0	2	4	5	7	6	5
	R_b	0	0	0	0	2	4	5	7	6	5
Iron Oxide, D. Brown	R_w	0	0	0	0	0	0	0	0	1	1
	R_b	0	0	0	0	0	0	0	0	1	1
Iron Oxide, Black	R_w	0	0	0	0	0	1	2	2	1	0
	R_b	0	0	0	0	0	0	0	0	0	0
Paliogen Black	R_w	64	55	60	55	55	55	50	37	35	23
	R_b	2	2	2	4	7	9	14	14	17	15
Silica Amorphous, 25 µm	R_w	72	67	70	72	72	70	65	50	53	37
	R_b	1	0	0	0	0	1	5	7	10	9
Silica Amorphous, 22 µm	R_w	73	70	71	67	70	55	55	45	45	30
	R_b	0	0	0	0	0	0	6	7	11	11
Silica Amorphous, 16 µm	R_w	72	68	70	67	71	64	63	44	44	24
	R_b	0	2	7	4	0	0	0	3	10	4
Silica, Diatomaceous	R_w	76	72	75	72	73	65	64	47	50	30
	R_b	9	5	4	2	1	2	8	11	13	8
Talc	R_w	79	70	72	72	72	68	63	47	47	30
	R_b	0	0	0	0	0	4	10	12	14	15
Titanium Dioxide, 0.2 µm	R_w	73	70	70	63	63	55	55	45	45	30
	R_b	47	43	38	32	30	27	23	18	14	10
Titanium Dioxide, 10 µm	R_w	80	71	72	72	72	68	64	57	60	44
	R_b	23	23	24	24	25	30	30	30	30	28
White Background	R_w	80	70	72	75	74	72	67	55	52	50
Black Background	R_b	7	7	8	9	9	10	10	10	10	10

[a] Measurements are relative to a pressed white poly(tetrafluoroethylene) powder which was assigned a value of 100%.

[b] Changes in filters and detectors at 800 nm produced a discontinuous baseline at that point.

Table 4: Infrared properties of pigments



Titanium dioxide with a mean particle size of 10 µm reflects efficiently between 800 and 2300 nm but rather poorly in the visible spectrum between 400 and 800 nm. This pigment behaves as an extender in the visible with high reflectance in the infrared. It has little or no effect on the visual colour of the coating and can be substituted for other extenders to produce non-metameric (i.e., matching which is independent of spectral irradiance) colours with enhanced infrared reflectance.

Chromium trioxide and the iron oxides are moderate to strong absorbers of NIR radiation. They are valuable hiding pigments, but only enough should be used in infrared reflective coatings to achieve the desired visual hiding; excessive absorption will result if larger amounts are used.

Pigments which absorb in the visible region (required for visual coloration) but are transparent in the NIR can be considered to be extenders so far as NIR radiation is concerned; that is, they can be used to modify the visual appearance of the paint without affecting its infrared properties. Organic pigments such as the perylene blacks, phthalocyanine blues and greens, and carbazole dioxazine violet are useful for this purpose.

3.4 *Spectral Properties of Resins*

There are two principal requirements for resins in tailored infrared coatings. First, the resin must protect the pigments and preserve their infrared properties throughout the service life of the coating. In addition, the resin must be sufficiently transparent in the spectral region of interest.

Most organic resins are free from strong absorptions in the NIR region and can be used for many applications in this part of the spectrum.

However, in contrast to the characteristics of paints in the visible and NIR regions, paint behaviour in the TIR region is strongly influenced by the resin, and the performance of the coating is determined by the nature of both the pigment and the resin. Organic resins show strong absorption bands due to molecular vibrations of their functional groups; bands near 3.3 (C-H stretch), 5.7 (C=O stretch), 7.0 (C-H bending) and 8.0 mm (C-O stretch) are usually prominent. A collection [15] of infrared absorption spectra of organic resins is a useful aid in selecting a resin.

Strong absorption in the TIR can be avoided by choosing resins which do not contain common functional groups. Poly(vinylidene fluoride) resins are almost transparent to and unaffected by solar radiation, and have only weak absorption in the TIR region [27]. They have excellent weather stability and show great promise for tailored infrared coatings. Dimethyl silicone resins have emittance values lower than those of fully organic resins and have been used for low-emittance coatings [28]. Inorganic silicate oligomers form polymers which contain only silicon-oxygen bonds [29], these resins show low emittance except for a band near 9 μm.

Absorption by resins can also be diminished by the selection of pigments which, because of their refractive indices and particle sizes, scatter light effectively in bands where resins absorb. This technique can be used to great advantage in the TIR region. In addition, leafing metallic pigments which form a practically continuous film reduce the penetration of incident radiation and absorption by the underlying resin.

4. *Formulation*

4.1 *Preparing for Formulation*

Before beginning the formulation of any coating with specified infrared properties, the illuminants and conditions of illumination, the spectral response of the detector or viewer, the desired visual colour of the coating, and the spectral distribution of the radiation to be reflected or absorbed must be defined. The next step is to select a vehicle with good heat resistance and minimal absorption in the infrared bands of interest. Pigments are then selected and, the refractive index of the resin being known, the required particle size distribution is calculated using Equations 7 and 8. Special attention must be given to bands where the resin absorbs strongly and to the regions where reflection of infrared radiation is especially desired.

5. Coatings with Tailored Infrared Reflectance

5.1 Low NIR or Low TIR Signature?

Defence equipment used by Australian and overseas forces is painted in a range of schemes which are designed to absorb and/or reflect in the infrared region. In part, selection of the infrared characteristics is determined by the operational role of the equipment. The Australian Army's Disruptive Pattern Paint scheme used for camouflage employs three paints which have relatively low NIR reflecting values, each differing from the other to create a disruptive pattern in the NIR as well as in the visible. This scheme is designed to protect against systems (considered to be major threats) which use the NIR waveband and operate in low light conditions.

The painting practices for military aircraft suggest that the detection threat has not been clearly identified for the environmental conditions in which they operate. Where solar radiation is low, as in a number of NATO countries, solar heating and the consequent increase in TIR signature will be of little importance. However, in subtropical and tropical countries, low NIR reflecting paints result in excessive heat loads and significantly higher TIR signatures, particularly in the 8 to 14 μm region. As the threat to aircraft by NIR photographic detection is minimal and there are no anti-aircraft missiles using the NIR waveband, the advantage provided by these paints would seem to be outweighed by their disadvantages.

A number of military aircraft are painted in highly reflecting NIR paints and others in highly absorbing NIR paints. However, some local and overseas military aircraft are painted with highly absorbing NIR primers but employ highly reflecting NIR topcoats, a practice that is counterproductive. An understanding is required that the term low infrared reflecting paint generally means a paint that is highly absorbing in the NIR (with a consequently higher TIR signature on exposure to sunlight). Likewise, the term high infrared reflecting paint refers to highly reflecting NIR paint (with a consequently lower TIR signature on exposure to sunlight).

5.2 Solar Heat (near infrared) Reflecting Coatings

Coatings formulated to reflect a high proportion of solar radiation lower the absorption of solar energy and the consequent temperature of the surface.

Absorptance in the ultraviolet region contributes little to the total energy absorbed by a coating, and it is usually not profitable to direct attention to this portion of the spectrum. The visible reflectance of a coating is established; slight adjustments as discussed in paragraph 4.2 may be made if metamerism can be tolerated, but significant modification of absorption in the visible region is unlikely to be allowed owing to established convictions of visible camouflage requirements. Thus, the most effective way to produce a solar heat reflecting coating is to maximize the reflectance of solar energy in the near infrared region of the spectrum.

Table 5: Effect of paint composition on thermal emission

Time (minutes)	Temperature Rise (°C) [a]	
	Sides 1 and 2 Std Australian Navy grey paint[b]	Side 1 aluminium paint[c] Side 2 Std Australian Navy grey paint
0	31.0	31.0
1.0	63.0	46.0
2.0	84.0	56.0
3.0	98.0	63.0
4.0	106.0	69.0
5.0	112.0	72.5
6.0	115.0	76.0
7.0	117.0	78.0
8.0	119.0	80.0
9.0	121.0	81.5
10.0	123.0	81.5
15.0	125.5	81.4

[a] Panels at room temperature (20°C) at time = 0.
[b] Both sides painted with grey paint.
[c] Irradiated side painted with aluminium paint, reverse side painted with grey paint.

Pattern painting with various camouflage colours can also break up the silhouette of an object and make it less conspicuous. For maximum effectiveness, the various coatings used in the pattern must be significantly different in both optical and infrared reflectance [35]. Coatings having low emissivity are used to minimize temperature contrasts between vehicles exposed to solar radiation and their surroundings. They are most effective when the emissivity varies between patches of paint and the infrared outline of the vehicle is masked.

5.4.1 *Coatings for Forest and Jungle Areas*

Pigments used to produce green coatings for these areas are selected for their ability to duplicate the reflectance properties of chlorophyll, the green pigment responsible for the characteristic colour and high infrared reflectance of vegetation. The reflectance spectrum of chlorophyll shows a peak near 550 nm, low values in the visible red region, a dip in the far visible red at 650-680 nm, a sharp rise between 680 and 710 nm, and uniformly high values above 720 nm. The goal for woodland camouflage coatings is to match this spectrum. Coatings for camouflage must control reflectance in the NIR between 700 and 1200 nm; the band between 700 and 900 nm is most important [36].

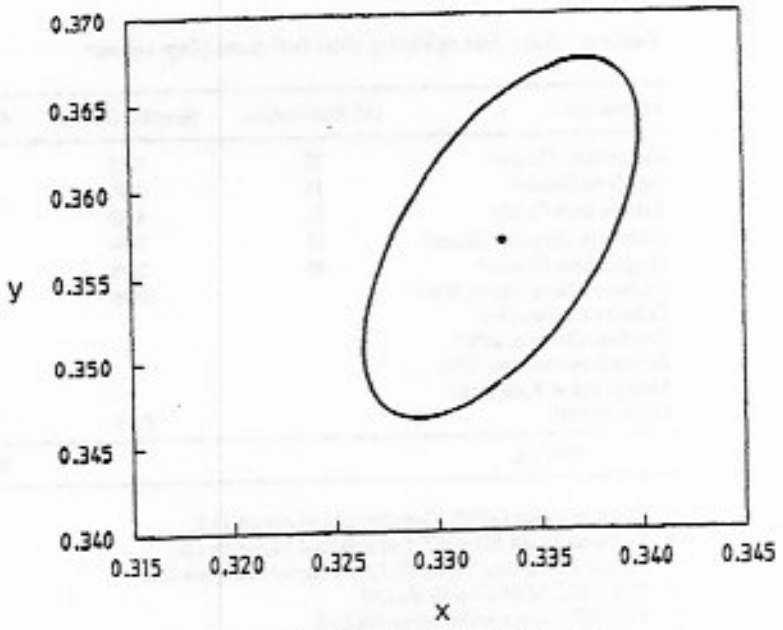


Figure 3: Chromaticity diagram for Forest Green camouflage paint.

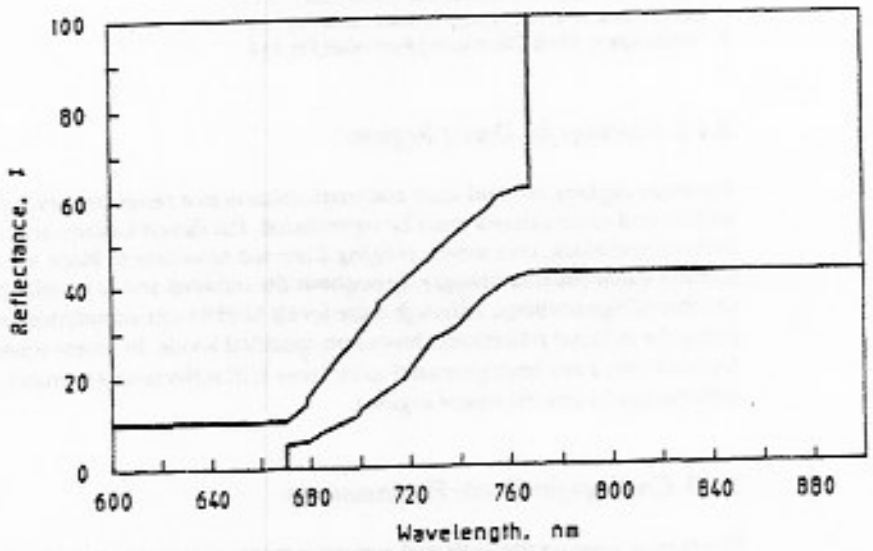


Figure 4: Permissible infrared reflectance values of US Forest Green.

Most of the common blue and black pigments absorb infrared radiation strongly, and even small amounts are effective in reducing infrared reflectance. Historically, naval coatings have contained significant amounts of carbon black [42, 43]. An early attempt [44] to formulate without carbon black produced solar heat reflecting coatings and low emittance coatings containing 15% of powdered aluminium [45, 46]. These coatings had poor weatherability and colour retention because antimony sulfide, a black pigment used in place of carbon black, is unstable and reacts with air to form white antimony oxide on prolonged exposure.

Effective solar heat reflective coatings have now been made in the grey shades established for warships. Carbon black has been replaced by an organic perylene black which absorbs strongly in the visible region but is transparent throughout the infrared. The formulation for a full gloss Australian naval coating conforming to Light Grey 631 [47] developed in the present study is given in Table 7. This coating reflects 77% of solar radiation at 800 nm in comparison to the standard coating which reflects 33% and has a 60° gloss of 74. Table 8 contains a formulation also developed in the present study for a semigloss solar heat reflecting coating for U.S. naval warships which has a haze grey colour [48] and a 60° gloss of 50. The spectral reflectance from 380 to 2300 nm is shown in Figure 5 for this coating and for the conventional coating. The reflectance of the new coating is approximately twice that of the older coating in the region from 720 to 2300 nm. The reflectance in the visible region between 380 and 720 nm indicates that the new colour is metameric to the older colour; this is a consequence of substituting phthalocyanine blue and red iron oxide for carbon black.

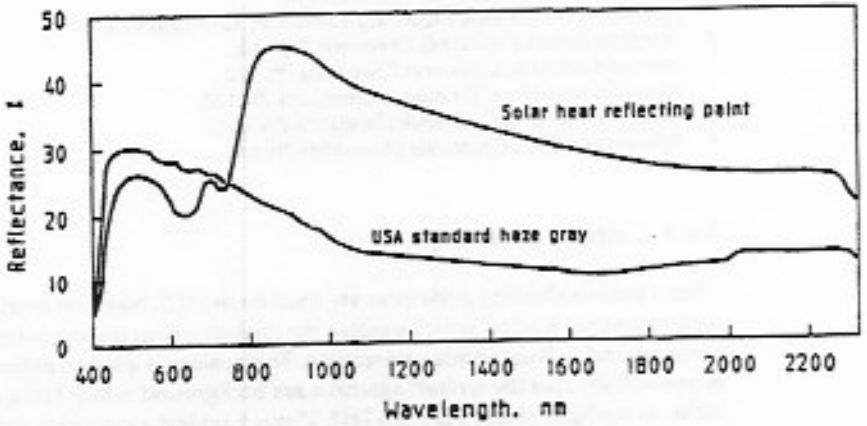


Figure 5: Infrared reflectances of two Haze Grey formulations.

Table 8: Solar heat reflecting Haze Gray camouflage enamel

Ingredient	Oil Absorption	Specific Gravity	Kilograms	Litres
Titanium dioxide, 200 nm[a]	17	4.00	327.80	6.96
Titanium dioxide, 10 µm[b]	17	3.90	82.37	21.15
Magnesium silicate[c]	45	2.75	10.33	3.74
Yellow iron oxide[d]	36	4.03	2.19	0.53
Red iron oxide[e]	18	4.90	2.40	0.49
Phthalocyanine blue[f]	45	1.65	0.70	0.41
Silicone alkyd resin, 70%[g]		0.96	115.44	120.43
Cobalt octoate, 6%[h]			0.79	0.90
Calcium octoate, 20%[i]			3.22	3.52
Zirconium octoate, 20%[j]			0.66	0.56
Methyl ethyl ketoxime[k]			5.08	5.03
White spirit[l]		0.79	25.80	31.15
TOTAL			275.78	194.87

a Ti-Pure R-960, duPont Australia Ltd.
b Tiona VC, SCM Chemicals Ltd.
c Talc TSF, Commercial Minerals Ltd.
d Yellow iron oxide YO-2087, Commercial Minerals Ltd.
e Paliogen black L0084, BASF Australia Ltd
f Sunfast blue 15:2 248-0532, T.R. Chemicals (Aust) Pty Ltd.
g Kemsil 2425/70, Kemrez Chemicals Division, ICI Australia Ltd.
h Hardadri cobalt, Colours & Chemicals Pty Ltd.
i Hardadri calcium, Colours & Chemicals Pty Ltd.
j Hardadri zirconium, Colours & Chemicals Pty Ltd.
k Exkin number 2, A.C. Hatrick Chemicals Pty Ltd.
l White spirit, Shell Chemicals (Australia) Pty Ltd.

Table 9: NIR reflectances of standard paints and solar reflecting paints for Orion camouflage paint scheme

Y	Standard Paint	NIR Reflecting Paint
49.5	52%	77%
37.5	43%	70%
23.5	24%	61%

10. Brady, R.F. Jr., Griffith, J.R., Love, K.S. and Field, D.E. (1989) in *Polymers in a Marine Environment*. The Institute of Marine Engineers, London, Paper 26, p. 191.

11. Jaenicke, W. (1956). *Zeitschift fur Elektrochemische*, 60, 163.

12. Tomkins, L.M. and Tomkins, E.H. (1958). *Journal of the Oil and Colour Chemists Association*, 41, 98.

13. Stamatakis, P., Palmer, B.R., Bohren, C.F., Salzman, G.C. and Allen, T.B. (1990). *Journal of Coatings Technology*, 62 (789) 95.

14. Wake, L.V. (1990). *Journal of the Oil and Colour Chemists Association*, 73 (2) 78.

15. *An Infrared Spectroscopy Atlas for the Coatings Industry* (1980). Federation of Societies for Coatings Technology, Blue Bell, PA.

16. Harkins, T.R., Harris, J.T. and Shreve, O.D. (1959). *Analytical Chemistry*, 31, 541.

17. Afremow, L.C. and Vandenberg, J.T. (1966). *Journal of Paint Technology*, 38 (495), 169.

18. Rutherford, D.J. and Simpson, L.A. (1985). *Journal of Coatings Technology*, 57 (724) 75.

19. Taylor, D. (1958). *Journal of the Oil and Colour Chemists Association*, 41, 707.

20. Bierwagen, G.P. (1972). *Journal of Paint Technology*, 44 (574) 46.

21. Hare, C.H. (1990). *Journal of Protective Coatings and Linings*, 7 (7) 47.

22. Patton, T.C. (1979). *Paint Flow and Pigment Dispersion*, 2nd ed., chapter 7. New York: John Wiley & Sons.

23. Marson, F. (1968). *A Simple Method for the Measurement of Infrared Reflectance of Paints* (MRL Technical Note 110). Maribyrnong, Vic.: Materials Research Laboratory.

24. Marson, F. (1982). *A Low Cost, Simple, Portable Instrument for the Measurement of Infrared Reflectance of Paints* (MRL Report MRL-R-857), Maribyrnong, Vic.: Materials Research Laboratory.

25. Sward, G.G. and Jacobsen, A.E. (1972). *Paint Testing Manual*, 13th Ed., G. G. Sward, Ed. Special Technical Publication 500, A. Soc. Test. Mater., Philadelphia, PA, p. 218.

26. Hagen, E. and Rubens, H. (1904). *Annalen. de Chimique Physique*, 2, 441.

27. McCann, J.E. (1990). *Surface Coatings Australia*, 27, 8.

46. Supcoe (to the United States of America). *U.S. Patent* 4,311,623, January 19, 1982.

47. Light Grey 631 is contained in *Colours for Specific Purposes, Br. Standard 381C*, 1964. The CIE chromaticity coordinates are x = 0.302 and y = 0.325, and the optical brightness Y is 29.2. The approximate Munsell reference colour is 7.5G 6/1.

48. Haze Gray color 26270. *Colors, Federal Color Standard 595A*, January 1968. The CIE chromaticity coordinates are x = 0.298 and y = 0.307, and the optical brightness Y = 25.6.

49. Beckwith, P.J. and Boyd, R.J. (1988). *Visibility of P3-C Orion Aircraft* (MRL Report MRL-R-1103). Maribyrnong, Vic.: Materials Research Laboratory.

50. *Report of Test Results No. AT-8R-83*, Naval Air Test Center, Maryland 20670, March 1983. Cited in Reference 49.

Formulating Infrared Coatings for Defence Applications

L.V. Wake and R.F. Brady

(MRL-RR-1-93)

DISTRIBUTION LIST

Director, MRL
Chief, Protective Chemistry Division
Dr D.B. Paul
Dr L.V. Wake
Dr R.F. Brady
MRL Information Service

Chief Defence Scientist (for CDS, FASSP, ASSCM) (1 copy only)
Director, Surveillance Research Laboratory
Director (for Library), Aeronautical Research Laboratory
Director, Electronics Research Laboratory
Head, Information Centre, Defence Intelligence Organisation
OIC Technical Reports Centre, Defence Central Library
Officer in Charge, Document Exchange Centre (8 copies)
Army Scientific Adviser, Russell Offices
Air Force Scientific Adviser, Russell Offices
Navy Scientific Adviser, Russell Offices - data sheet only
Scientific Adviser, Defence Central
Director-General Force Development (Land)
Senior Librarian, Main Library DSTOS
Librarian, MRL Sydney - data sheet only
Librarian, H Block
UK/USA/CAN ABCA Armies Standardisation Rep. c/- DGAT (8 copies)
Librarian, Australian Defence Force Academy
Counsellor, Defence Science, Embassy of Australia - data sheet only
Counsellor, Defence Science, Australian High Commission - data sheet only
Scientific Adviser to DSTC, C/- Defence Adviser - data sheet only
Scientific Adviser to MRDC, C/- Defence Attache - data sheet only
Head of Staff, British Defence Research and Supply Staff (Australia)
NASA Senior Scientific Representative in Australia
INSPEC: Acquisitions Section Institution of Electrical Engineers
Head Librarian, Australian Nuclear Science and Technology Organisation
Senior Librarian, Hargrave Library, Monash University
Library - Exchange Desk, National Institute of Standards and Technology, US
Exchange Section, British Library Document Supply Centre
Library, Chemical Abstracts Reference Service
Engineering Societies Library, US
Documents Librarian, The Center for Research Libraries, US

Commanding Officer, DWOSU, RAAF Base Edinburgh, SA
Director Air Warfare, Russell Offices, Canberra ACT
Owen Scott, Electronics Research Laboratory, Salisbury SA