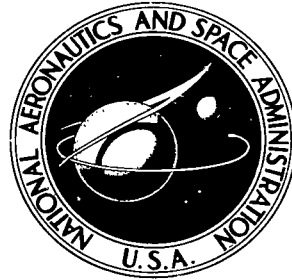


NASA TECHNICAL NOTE



NASA TN D-6756

0.1

NASA TN D-6756

LOAN COPY: RETURN
AFWL (DOUL)
KIRTLAND AFB, N. I



INVESTIGATION OF PHASE-CHANGE COATINGS FOR VARIABLE THERMAL CONTROL OF SPACECRAFT

by Warren C. Kelliber and Philip R. Young
Langley Research Center
Hampton, Va. 23365



NATIONAL AERONAUTICS AND SPACE ADMINISTRATION • WASHINGTON, D. C. • JUNE 1972



0133679

1. Report No. NASA TN D-6756	2. Government Accession No.	3. Recipient's Catalog No.	
4. Title and Subtitle INVESTIGATION OF PHASE-CHANGE COATINGS FOR VARIABLE THERMAL CONTROL OF SPACECRAFT		5. Report Date June 1972	6. Performing Organization Code
7. Author(s) Warren C. Kelliher and Philip R. Young	8. Performing Organization Report No. L-6283		10. Work Unit No. 114-03-50-01
9. Performing Organization Name and Address NASA Langley Research Center Hampton, Va. 23365	11. Contract or Grant No.		13. Type of Report and Period Covered Technical Note
12. Sponsoring Agency Name and Address National Aeronautics and Space Administration Washington, D.C. 20546	14. Sponsoring Agency Code		15. Supplementary Notes
16. Abstract <p>An investigation was conducted to determine the feasibility of producing a spacecraft coating system that could vary the ratio of its solar absorptance to thermal emittance to adjust automatically for changes in the thermal balance of a spacecraft. This study resulted in a new concept called the "phase-change effect" which uses the change that occurs in the optical properties of many materials during the phase transition from a crystalline solid to an amorphous material. A series of two-component model coatings was developed which, when placed on a highly reflecting substrate, exhibited a sharp decrease in solar absorptance within a narrow temperature range. A typical coating system consisting of a blend of 50% eicosane—50% (ethylene—vinyl acetate) copolymer, when applied as a 0.10-cm film on an electro-deposited silver substrate, underwent a reduction in the ratio of its solar absorptance to thermal emittance from 0.50 to 0.25 when the temperature changed from 35° C to 45° C. This substantial decrease demonstrates that a variable thermal control coating can have a significant amount of temperature regulation with the phase-change effect. Data are presented on several crystallite-polymer formulations, their physical and optical properties, and associated phase-change temperatures. Aspects pertaining to their use in a space environment and an example of the degree of thermal regulation attainable with these coatings is also given.</p>			
17. Key Words (Suggested by Author(s)) Thermal control coating Spacecraft thermal control Variable absorptance coating	18. Distribution Statement Unclassified - Unlimited		
19. Security Classif. (of this report) Unclassified	20. Security Classif. (of this page) Unclassified	21. No. of Pages 20	22. Price* \$3.00

INVESTIGATION OF PHASE-CHANGE COATINGS FOR VARIABLE THERMAL CONTROL OF SPACECRAFT

By Warren C. Kelliher and Philip R. Young
Langley Research Center

SUMMARY

To overcome the limitations of present passive and active spacecraft thermal control systems, an investigation was conducted to determine the feasibility of producing a surface coating which would provide regulation of the thermal balance of a spacecraft. A concept called the "phase-change effect" has been successfully developed and was so named because it uses the change that occurs in the optical properties of many materials during the phase transition from a crystalline solid to an amorphous material.

A series of coatings composed of low melting temperature crystallites dispersed throughout transparent higher melting temperature polymers were formulated to demonstrate this phase-change effect. These coatings are diffuse reflectors of solar radiation at room temperature. However, when the phase transition temperature of the crystallites embodied in the polymer matrix is reached, the coating becomes transparent. This transparent coating, when backed with a mirror substrate, is specularly reflecting and has a lower solar absorptance than the coating in its diffuse state. Model formulations have been obtained which exhibit a 50-percent decrease in the ratio of solar absorptance to thermal emittance, and the effect is both reproducible and reversible. The solar absorptance of these coating systems is affected by thickness, temperature, and choice of substrate whereas their thermal emittance is not affected by these parameters and remains high and fairly constant. Microscopic examination of the coatings has revealed that the phase-change effect is caused by a combined temperature dependent liquid—liquid solubility and liquid—solid phase equilibrium between the inclusion material and the polymeric binder. Data are presented on several crystallite-polymer formulations, their physical and optical properties, and associated phase-change temperatures. Preliminary evaluations of the effect of the space environment on the coatings and the degree of thermal regulation attainable with these coatings were also made. The results from the study of these coating systems indicate that a phase-change effect can be used to obtain surfaces with variable ratios of solar absorptance to thermal emittance and that a significant amount of temperature regulation can be realized by using this type of coating.

INTRODUCTION

Temperature control in present spacecraft is generally achieved through the use of passive and/or active thermal control systems. The passive coating systems (refs. 1 and 2) are simple and lightweight but cannot compensate for changes in the thermal environment of the vehicle. Active control systems (refs. 3 to 5) are capable of compensating for changes in the environment but are subject to mechanical failure as well as being heavy and cumbersome. In order to overcome the limitations of the present systems, a variable surface coating was proposed that would automatically regulate the thermal balance of a spacecraft. (See refs. 3 and 4.) Such a coating would be able effectively to vary either its solar absorptance or emittance by means of a thermal or electrical input to compensate automatically for internally and externally induced changes in the thermal balance of the vehicle.

A number of concepts for obtaining a variable coating have been investigated at the Langley Research Center. The most promising one involves the use of the change that occurs in the optical properties of many materials during the phase transition from a crystalline state to an amorphous phase. The proposed concept has been designated the "phase-change effect." These phase-change coatings offer numerous advantages in that the phase-change effect is reversible and thermally activated, and the coatings are not limited by the geometry of a spacecraft since they can be applied as a paint. A high degree of temperature regulation and a wide variation in thermal and optical properties of the coatings can be obtained.

PHASE-CHANGE CONCEPT

The method proposed to obtain a variable thermal control system employs either a single- or two-component phase-change coating on a specularly reflecting substrate. This coating will be a diffuse reflector of light below its crystalline phase transition point because of the numerous complex reflecting surfaces of the dispersed crystallites in the coating. Above the melting temperature of the crystallites, the coating becomes transparent and permits light to be specularly reflected from the mirror substrate. The amount of solar radiation absorbed is proportional to the length of the path that it travels in an absorbing medium. As depicted in figure 1, the average path length of the light may be considerably shorter (and its absorption lower) for a phase-change coating in its transparent state than in its diffuse state. A change in the absorptance of the coating system is therefore obtained in going from the diffuse state to the transparent state.

Thus, for a phase-change coating backed by a highly reflecting substrate, the change from a low temperature diffusely reflecting state to a high temperature specularly reflecting state can lower the solar absorptance of the coating system. Being based on a crystal-

lization phenomenon, a thermal control coating has the advantages of being both temperature activated and reversible.

MATERIALS SELECTION

A variable thermal control coating system can be obtained by using the phase-change effect provided that materials can be found that undergo a crystalline phase transition without the liquid flow normally associated with the crystalline melting point. One technique involving the use of a single component that was investigated to resolve the problem of liquid flow was to make use of the ability of polymeric materials to undergo crosslinking reactions to form a network type of molecular structure. These crosslinked polymers have an elastomeric nature and will resist flow at temperatures above the melting point of the polymeric crystallites. Four polymers (poly (vinyl stearate), polydodecene, polytetradecene, and polyoctadecene) chosen because their crystalline melting points were below 80° C were irradiated with gamma radiation to induce crosslinking of the molecular chains. Although sufficient crosslinks were formed to prevent liquid flow, the polymer had a very slow rate of crystallization compared with that of low molecular weight chemicals. This trait, in general, is characteristic of high molecular weight materials and is a distinct disadvantage for this application. A phase-change coating of this type would not have a sufficiently rapid response time to compensate for changes in the thermal balance of a space vehicle.

A different concept was explored involving a two-component system which consisted of a low molecular weight crystalline material and a compatible transparent amorphous polymer. The crystalline materials (table I) were selected for their low melting temperature and for their ability to change quickly and reversibly from a highly crystalline translucent state to an amorphous transparent state. The polymeric materials (table II) were chosen primarily for their transparency to solar radiation, their relatively high softening or melting points, and their low melt viscosity to aid blending at temperatures slightly above their softening point.

RESULTS AND DISCUSSION

Coating Evaluation

To evaluate the numerous formulations arising from various combinations of crystalline and polymeric materials, a set of criteria based on reasonable performance goals for a variable thermal control coating was established. Formulations were sought that had the following properties:

- (1) Phase transition temperature between 25° C and 70° C
- (2) High degree of opacity at temperatures below the phase transition point

- (3) High degree of transparency to solar radiation at temperatures above the phase transition point
- (4) Phase transition range no greater than 10° C
- (5) Flow temperature of the coating higher than 90° C
- (6) Rapid and reversible change from a crystalline to a transparent state when thermally cycled through the phase transition temperature.

Both solution and melt techniques were employed to achieve homogeneous crystallite-polymer blends of known composition. The most successful process was to mix the individual constituents while each was in a molten state. Some of the mixtures, although forming a homogeneous liquid blend, rapidly separated into two distinct phases upon cooling. Other mixtures exhibited no phase transition even upon cooling to temperatures below 0° C.

Measurement of the phase transition temperature range of those coatings that had a crystalline phase change was made on a Fisher-Johns melting point apparatus which has a temperature-calibrated heated stage with an adjustable heater control.

Only those formulations that met the criteria listed or that form a basis for comparison are given in table III along with comments on their relative merits. The formulations with the homopolymers (resins A and B) gave poor results, whereas the coatings containing the copolymers (resins C and D) had good phase-change properties.

Mechanism of Phase-Change Effect

The concept of phase-change effect, that is, control of the absorptance of a coating by variation of the path length of the incident light in a one-component system, is readily understood. The mechanism by which the coating is able to perform in a two-component system is not readily apparent. The data in table III show that selected crystalline materials formed good phase-change coatings with certain polymers and not with structurally similar polymers. Also, slight variations in the chemical structure of the crystalline material gave differing results with the same polymer. In order to explain these results, and determine the physical mechanism by which the phase-change coating operates, a detailed study was conducted with the use of paraffin and various percentages of both resins C and D (table III). Paraffin, in contrast to the resins, is a birefringent material in the crystalline state and thus its phase change could be determined visually with polarized light. By alternately viewing the magnified coating under plain and polarized transmitted light as it was heated and cooled through the phase transition region, the crystalline change in phase and the gross effective change in transparency could be distinguished. It was found that when transparency was achieved, a true homogeneous solution of polymer and paraffin was formed. No refraction or scattering was noted in the transparent state

and further heating did not cause the coating to revert back to a translucent state. These observations preclude the possibility that dispersion, colloid formation, or the matching of refractive indices was responsible for the phase-change effect. Formulations containing the other crystalline materials that had a phase change with resins C and D gave similar results.

In those coatings (table III) which had an upper critical solution or consolute temperature much higher than the freezing point of the crystalline material, two liquid phases were initially observed and on cooling, the molten crystalline material tended to coalesce into large droplets of liquid in the viscous polymer matrix. When this mixture was cooled below the freezing point of the crystalline material, a nonuniform distribution of crystals in the polymer was obtained and resulted in an unsatisfactory phase-change coating. In those coatings which had a consolute temperature much lower than the freezing point of the crystalline material, the liquid that separated out immediately froze into crystals and did not effectively reflect the light in the solar wavelength region.

The formulations most satisfactory as phase-change coatings were those compositions whose consolute temperatures occurred at or slightly above the melting point of the crystalline material. When these coatings were cooled, the consolute temperature was reached where the molten crystallite material began to separate from the polymer matrix and two phases developed. Under these conditions, the best dispersion and optimum size of solid crystallites in the polymer matrix was obtained. No lower critical solution temperature (where the two phases coalesced) was noted down to -65° C.

Variability of Phase-Change Coatings Materials

Since the formulation of a phase-change coating is based on a matching of physical properties and is not directly related to chemical structure, a wide variety of candidate materials can be considered. However, to obtain the correct liquid—liquid solubility and solid—liquid phase equilibrium, the solubility parameters, dipole moments, and melting or softening points of the polymer and crystalline material must be compatible. Unfortunately, these data are not readily available for the materials that would be considered in formulating a phase-change coating for use in spacecraft thermal control. The correct match of polymeric and crystalline material properties generally has to be obtained by an experimental investigation such as outlined in table III.

The data in table III demonstrate that by a judicious choice of crystalline materials, the phase transition temperature can be regulated to some degree without adversely disturbing the solubility and phase equilibrium relationships. For example, the behavior of phase-change coatings using eicosane is similar to that of the paraffin coatings, yet the eicosane coatings have a lower phase transition temperature. Eicosane is one of a series of alkane hydrocarbons which have a lower melting point than paraffin but whose crystal

structure and solubility characteristics are very similar to those of paraffin. Thus, by utilizing different members of an organic homologous series, the transition temperature range of a phase-change coating can be varied. The extent of this variation depends not only on the difference in melting points but also on the magnitude of the change in the solubility characteristics between members of the homologous series. Too great a change in solubility behavior can affect the consolute temperature and, therefore, the effectiveness of the phase-change coatings.

Performance Evaluation of Selected Formulations

On the basis of light transmission measurements, the six criteria previously stated, and the compatibility of consolute temperatures with crystalline melting points, three representative phase-change formulations were chosen for further testing: (1) 80% resin C and 20% paraffin; (2) 50% resin D and 50% paraffin; and (3) 50% resin D and 50% eicosane. All formulations are on a weight percent basis. The coatings containing resin C were hard and friable whereas those with resin D were flexible. All coatings had narrow (10° C) reversible phase transition ranges, a high degree of opacity, and no flow below 90° C.

Specimens of the three formulations were prepared in 0.025-cm, 0.05-cm, and 0.10-cm thicknesses by pouring the melted coatings on both reflecting and absorbing substrates. Mirror-polished steel plates on which silver was electrodeposited were used as the highly specular reflecting substrate, and steel plates on which a flat black paint was applied served as the highly absorbing substrate.

Total hemispherical reflectance measurements were made on the specimens as they were heated through the phase transition region. These results were integrated over a wavelength range of 0.22 to 2.10 micrometers which represented 95 percent of the solar energy distribution. The experiments were conducted on a double-beam, ratio-recording spectrophotometer (Cary Recording Spectrophotometer, Model 14). The samples were mounted in a holder designed to keep them at a temperature which would maintain the coating either in a crystalline or a transparent state during the measurements. A photograph of this apparatus is shown in figure 2.

The reflectance curves of the silver substrate and the 20% paraffin—80% resin C formulation in both its diffuse (25° C) and transparent or reflective state (76° C) are given in figure 3. As can be seen, the increase in reflectance and thus the decrease in absorptance for both curves are fairly constant through the 0.4- to 1.0-micrometer wavelength region. Since the other compositions gave similar results, these coatings are not spectrally dependent in this wavelength region which represents 60 percent of the solar energy distribution. Absorption in the 1- to 2-micrometer region is caused by specific organic groups and would necessarily be retained in spectra of both the crystalline and

transparent states. However, much of this absorption occurs in a wavelength region in which the solar radiation contributes little to the overall solar absorptance.

A solar absorptance value for each of three formulations was obtained by subtracting the spectral reflectance of the sample from unity and weighting the difference against the sun's energy distribution at Earth's mean distance (ref. 6). These values are given in table IV.

The data in table IV show that coatings on a reflecting substrate displayed substantial decreases in absorptance as a result of a small temperature change at the phase transition region. By graphically illustrating part of the data given in table IV, the significance of the variation in solar absorptance attainable with a phase-change coating is shown. Figure 4 shows the change in solar absorptance for the 0.05 cm 20% paraffin—80% resin C coating as it goes through its phase transition temperature range of 65° C to 70° C; photographs of the coating in its opaque and transparent states are included. This coating exhibited a 55-percent decrease in solar absorptance (from 0.34 to 0.15) as it was heated through the 5° C phase transition temperature range. As shown by the data in table IV, doubling the thickness of the resin D coatings did not appreciably alter the percentage decrease in absorptance although the low and high temperature values of the thicker specimens were generally slightly higher than those of the thinner specimens. Unfortunately, the 0.10 cm, 20% paraffin—80% resin C coating had sufficient flow at the elevated temperature that a reliable absorptance value could not be obtained.

In order to determine the effect of the substrate on the solar absorptance of the coating system, optical measurements were made of these three formulations on black, highly absorbing substrates (table IV). If the coatings were truly opaque, the substrate would have no effect on the low temperature absorptance but if the coatings transmitted a substantial quantity of incident light, then this absorptance would be markedly increased. The latter condition was observed, as shown in table IV. For 20% paraffin—80% resin C coating on reflecting and absorbing substrates, the solar absorptance increased from 0.34 to 0.66. Thus, the absorptance properties of a coating system are highly dependent on the reflectance of the substrate. The choice of a substrate for phase-change coatings is therefore most important in controlling the desired change in solar absorptance values.

Emittance values were obtained by use of a ratio-recording spectrometer equipped with a heated cavity. The data were obtained over the wavelength range of 2.5 to 15 micrometers which represents 55 percent of the radiant energy of a 295° K black-body. The samples were mounted on a probe through which temperature-controlled water was circulated to maintain the coatings in the desired crystalline or transparent state during the measurement. The thermal emittance of each sample was calculated by subtracting its spectral reflectance from unity and weighting the difference against the spectral

distribution of a blackbody at the sample temperature. The emittance values are given in table IV. A description of the spectrophotometers and the detailed procedures for calculating solar absorptance and thermal emittance are found in reference 6.

The materials used in these coatings are organic compounds which absorb very heavily in the infrared wavelength region (0.8 to 23 micrometers). (See ref. 7.) These coatings therefore have high extinction coefficients and infrared radiation does not penetrate very deeply into the material before it is absorbed. As a result, the type of substrate and specimen thickness used in this study did not affect emittance values, as the data in table IV indicate. Since emission is largely independent of the physical state of the compounds (ref. 8), the emittance is not appreciably affected by the change from crystalline to transparent state. In summary, the emittance of these systems is high and is not affected by the same parameters which influence solar absorptance.

Stability of Selected Formulations to Simulated Space Environment

The effect of space environment on the materials comprising the coatings was not considered during their selection. Therefore, the coatings were subsequently subjected to environmental tests to determine the problems that might develop from two-component phase-change systems. The resin D-paraffin coating was selected for gamma irradiation as it had a lesser tendency to flow than the resin C-paraffin coating. After approximately 22×10^4 J/kg of cobalt-60 gamma irradiation, no change in color, opacity, or phase-change temperature was noted. After a dose of approximately 5.5×10^4 J/kg, the tendency to flow at high temperatures was inhibited due to crosslinking of the polymer chains. Sufficient crosslinks were produced after approximately 1.9×10^5 J/kg of irradiation to completely prevent melt flow in this formulation. Although the phase transition temperature of this coating was not affected, it is anticipated that additional crosslinking would adversely affect the solubility characteristics of the polymer and would result in a change of the coating phase transition temperature.

The resin B-paraffin coating was subjected to a high vacuum (5×10^{-5} N/m²) for 20 hours at room temperature and no significant weight change was noted. When another sample of the coating was cycled only 10 times through its phase-change temperature under the same vacuum conditions, a 1-percent weight change was noted. Additional cycling in the vacuum resulted in loss of the phase transition, presumably because of volatilization of the paraffin from the coating. Therefore, the vapor pressure and volatility of the crystalline material must be considered when selections are made for formulating space-stable coatings.

When exposed for 100 hours to high intensity ultraviolet light (BH-6, 12 inches from specimen), both resin C—paraffin and resin D—paraffin coatings degraded from a white to yellow-brown color. It would appear that the ultraviolet light stability of the components must also be considered when formulating space-stable phase-change coatings.

Potential Application of Phase-Change Coatings

The temperature control of satellites and space vehicles is dependent to a large extent on the radiative properties of the spacecraft's outer surface. A plot of the equilibrium temperature of the spacecraft as a function of the ratio of solar absorptance to thermal emittance of a surface can be obtained if one considers the spacecraft as an imaginary coated flat plate of unit area, insulated on the back, with the front oriented normal to the sun and at a set distance from the sun. (See refs. 4 and 5.) Figure 5 gives the temperature equilibrium curves for a solar or heat flux of $4.62 \times 10^5 \text{ W/cm}^2$ and $1.92 \times 10^5 \text{ W/cm}^2$ onto this flat plate. With this coating on the idealized flat plate and heat input of $1.92 \times 10^5 \text{ W/cm}^2$, the plate would reach an equilibrium temperature indicated by point A in figure 5. If the heat input to the plate is increased to $4.65 \times 10^5 \text{ W/cm}^2$, the equilibrium temperature would increase to point B, the assumption being made that the plate maintained the same ratio of absorptance to emittance as before. However, as the temperature increases, the phase-change coating will be driven into its phase transition temperature range and will change the ratio of its absorptance to emittance as indicated by point C. Thus, the phase-change coating would regulate the temperature of the flat plate to a 5° C rise for the increased heat input whereas a passive control coating would have permitted a 60° C rise in temperature. The magnitude of the values from this hypothetical case is significant as it demonstrates that the phase-change coatings have an inherent high degree of temperature sensitivity (thermally activated with a 5° C temperature range) and temperature control (capable of regulating a heat input that would normally cause a 60° C change in temperature).

Development of Space-Stable Phase-Change Coatings

Based on this study, a series of material selection criteria can be summarized for producing space-stable phase-change coatings. The polymer should (a) have a high degree of transparency to the ultraviolet—visible part of the solar spectrum, (b) have a higher melting point than the maximum temperature anticipated for any particular mission, and (c) maintain its transparency and degree of solubility for the crystalline material in a space environment. The crystalline material should (a) have an index of refraction that differs significantly from the polymer to maximize opacity of the coating, (b) have a sufficiently rapid rate of crystallization in the polymer to respond to any thermal changes in the spacecraft, and (c) maintain its color stability and not volatilize from the coating in the space environment. The crystalline material polymer mixtures should possess two-phase solubility behavior so that an upper critical solution temperature is formed at or near the melting point of the crystalline material.

By using these criteria as a starting point, a contractual effort was undertaken to develop space-stable phase-change coatings. The results of this study show that such coatings can be obtained. These coatings withstood a combined environment of

1×10^6 J/kg of X-radiation, 100 equivalent sun hours of ultraviolet radiation, and 1.33×10^{-6} N/m² vacuum without a change in the ratio of solar absorptance to thermal emittance. These coatings have also been cycled 1000 times through the phase transition temperature with no changes in properties. (See refs. 9 and 10.)

CONCLUDING REMARKS

This experimental study demonstrates the feasibility of using a phase-change effect to obtain a variable thermal control coating. Model phase-change coatings developed in this program exhibited as much as a twofold decrease in solar absorptance within a temperature range of 10° C. Theoretical values of heat flux were assumed and equilibrium temperatures were calculated from experimental properties of these coatings as applied to a hypothetical spacecraft model. The results show that phase-change coatings have a potential high degree of temperature control sensitivity and stability.

Criteria necessary for formulating satisfactory phase-change thermal control coatings have been determined as a result of experiments on coating stability and phase-change mechanism. Based on this study and by use of these criteria, a contractual research program has demonstrated that the phase-change effect can be obtained with space-stable materials.

Langley Research Center,
National Aeronautics and Space Administration,
Hampton, Va., May 11, 1972.

REFERENCES

1. Plunkett, Jerry D.: NASA Contributions to the Technology of Inorganic Coatings. NASA SP-5014, 1964.
2. Van Vliet, Robert M.: Passive Temperature Control in the Space Environment. Macmillan Co., c.1965.
3. Schach, Milton; and Kidwell, Robert: Thermal Control of Spacecraft. Space/Aeronaut., vol. 44, no. 1, July 1965, pp. 55-61.
4. Bacha, C. P.; Honea, F. I.; and Watanabe, D.: Temperature Control Systems for Space Vehicles. ASD-TDR-62-493, Pt. I, U.S. Air Force, May 1963.
5. Grafton, J. C.; and Nordwall, H. L.: Radiation Transfer Analysis for Space Vehicles. ASD-TR-61-119, Pt. II, U.S. Air Force, Sept. 1962.
6. Teichman, Louis A.; and Burks, Harold D.: An Automatic System for Determining Solar Absorptance and Thermal Emittance of Surfaces From Spectral Normal Reflectance Measurements. NASA TM X-1113, 1965.
7. Bellamy, L. J.: The Infra-Red Spectra of Complex Molecules. Second ed., John Wiley & Sons, Inc., 1958.
8. Zbinden, Rudolf: Infrared Spectroscopy of High Polymers. Academic Press, Inc., c.1964.
9. Griffin, R. N.; and Linder, B.: Development of Phase-Change Coatings for Use as Variable Thermal Control Surfaces. Contract NAS1-5330, Gen. Elec. Co., [1967]. (Available as NASA CR-66394.)
10. Griffin, R. N.; and Linder, B.: Development of Phase-Change Coatings for Use as Variable Thermal Control Surfaces. Contract NAS1-6166, Gen. Elec. Co., [1968]. (Available as NASA CR-66695.)

TABLE I.- PHYSICAL PROPERTIES OF CRYSTALLINE MATERIALS
USED IN THERMAL CONTROL COATING STUDY

Crystalline material	Chemical structure	Refractive index, n_D	Melting or softening point, $^{\circ}\text{C}$
Paraffin	$\text{CH}_3(\text{CH}_2)_{17-28}\text{CH}_3$	1.440 (60 $^{\circ}$ C)	50 to 56
Eicosane	$\text{CH}_3(\text{CH}_2)_{18}\text{CH}_3$	1.435 (40 $^{\circ}$ C)	38
Hexadecane	$\text{CH}_3(\text{CH}_2)_{14}\text{CH}_3$	1.434 (25 $^{\circ}$ C)	20
Octadecanol	$\text{CH}_3(\text{CH}_2)_{17}\text{OH}$	-----	58
Hexadecanol	$\text{CH}_3(\text{CH}_2)_{15}\text{OH}$	1.428 (80 $^{\circ}$ C)	47
Tetradecanol	$\text{CH}_3(\text{CH}_2)_{13}\text{OH}$	-----	37
Dodecanol	$\text{CH}_3(\text{CH}_2)_{11}\text{OH}$	-----	23
Decanol	$\text{CH}_3(\text{CH}_2)_9\text{OH}$	1.437 (25 $^{\circ}$ C)	6
Octanol	$\text{CH}_3(\text{CH}_2)_7\text{OH}$	1.429 (25 $^{\circ}$ C)	-16
Hexanol	$\text{CH}_3(\text{CH}_2)_5\text{OH}$	1.418 (25 $^{\circ}$ C)	-52
Nonadecene	$\text{CH}_3(\text{CH}_2)_{16}\text{CH}=\text{CH}_2$	1.444 (25 $^{\circ}$ C)	24
Lauric acid	$\text{CH}_3(\text{CH}_2)_{10}\text{COOH}$	1.418 (80 $^{\circ}$ C)	45
Diphenyl methane	$\text{C}_6\text{H}_5 - \text{CH}_2 - \text{C}_6\text{H}_5$	1.577 (25 $^{\circ}$ C)	25

TABLE II.- PHYSICAL PROPERTIES OF POLYMERIC MATERIALS
USED IN THERMAL CONTROL COATING STUDY

Designation	Chemical composition	Refractive index, n_D	Melting or softening point, $^{\circ}\text{C}$
Resin D	Copolymer of α -methyl styrene and vinyl toluene	1.583 (25 $^{\circ}$ C)	120
Resin C	Copolymer of ethylene and vinyl acetate	1.488 (25 $^{\circ}$ C)	88
Resin B	Low molecular weight polyethylene	1.516 (25 $^{\circ}$ C)	105
Resin A	Low molecular weight polystyrene	1.592 (25 $^{\circ}$ C)	120

TABLE III.- COMPOSITION AND MELTING RANGES OF COATINGS CONSIDERED FOR PHASE-CHANGE COATINGS

Polymer	Crystalline material	Composition, percent crystalline	Phase-change temperature, °C	Comments			
Resin A	Paraffin	20	-----	All compositions formed opaque mixtures which slowly separate into two distinct phases.			
	Dodecanol	20	-----				
	Octadecanol	20	-----				
Resin B	Paraffin	90	56 to 59	All compositions remained partially translucent above phase transition point. Melt flow started around 80° C.			
		80	62 to 66				
		70	68 to 73				
		60	75 to 80				
		40	85 to 89				
		20	92 to 98				
Resin C	Paraffin	80	52 to 58	A flexible and tough coating with good phase-change characteristics was obtained. For paraffin content below 30 percent, no phase change was noted. Best properties were obtained at 50% crystalline level. Coatings were soft but not tacky above phase-change temperature and started to flow at 110° C.			
		60	52 to 58				
		50	52 to 57				
		40	52 to 61				
		30	52 to 66				
	20	-----					
	Eicosane	50	35 to 45				
		50	Below 25				
	Hexadecane	50	Below 20				
		20	-----				
	Resin D	Paraffin	80		70 to 112	Compositions formed friable coatings with good phase-change characteristics. Coatings became soft but not tacky above phase-change temperature. They started to flow above 90° C. Greatest opacity appeared to occur with a paraffin content of 20 percent.	
60			83 to 105				
40			80 to 97				
30			75 to 91				
Resin D	Paraffin	20	65 to 70	Coatings have lower phase transition temperature than the paraffin coatings. Other properties similar to those of paraffin.			
		10	50 to 56				
		Eicosane	55		31 to 59		
			35		33 to 58		
			30		40 to 53		
			25		36 to 47		
	20		35 to 40				
	Hexadecane	15	34 to 38				
		20	16 to 22				
		Resin D	Paraffin		20	58 to 70	Melting point of crystalline material had little effect on phase change of coating. Coatings with decanol and lower molecular weight alcohols tended to smoke above phase-change temperature. Whiteness and hiding power of coatings were better than that observed with the alkane series. The coatings became soft and somewhat more tacky than the paraffin coatings above phase-change temperature.
					20	57 to 69	
20				54 to 65			
20				49 to 59			
20	48 to 58						
20	43 to 52						
20	37 to 45						
Resin D	Diphenyl methane			20	-----	No phase change obtained.	
				20	-----		
Resin D	Lauric acid			20	-----	No phase change obtained.	
				20	-----		

TABLE IV.- EFFECT OF BACKGROUND, THICKNESS, AND TEMPERATURE ON ABSORPTANCE
AND EMITTANCE OF PHASE-CHANGE COATINGS

(a) Absorptance

Coating	Thickness, cm	Solar absorption of substrate	Solar absorption of system below phase-change temperature	Solar absorption of system above phase-change temperature	Phase-change temperature, °C
20% paraffin—80% resin C (reflecting substrate)	0.05	0.10	0.34	0.15	65 to 70
	.10	.10	.30	---	
20% paraffin—80% resin C (absorbing substrate)	.05	.96	.66	.95	65 to 70
	.10	.96	.62	---	
50% paraffin—50% resin D (reflecting substrate)	.05	.10	.33	.16	52 to 57
	.10	.10	.42	.21	
50% paraffin—50% resin D (absorbing substrate)	.05	.96	.94	.96	52 to 57
	.10	.96	.87	.96	
50% eicosane—50% resin D (reflecting substrate)	.05	.10	.37	.19	35 to 45
	.10	.10	.45	.23	

(b) Emittance

Coating	Thickness, cm	Thermal emittance of background	Thermal emittance of coating	Temperature
50% paraffin—50% resin D	0.025	0.06 (Reflecting)	0.90	Above and below phase-change temperature
	.025	.93 (Absorbing)	.94	

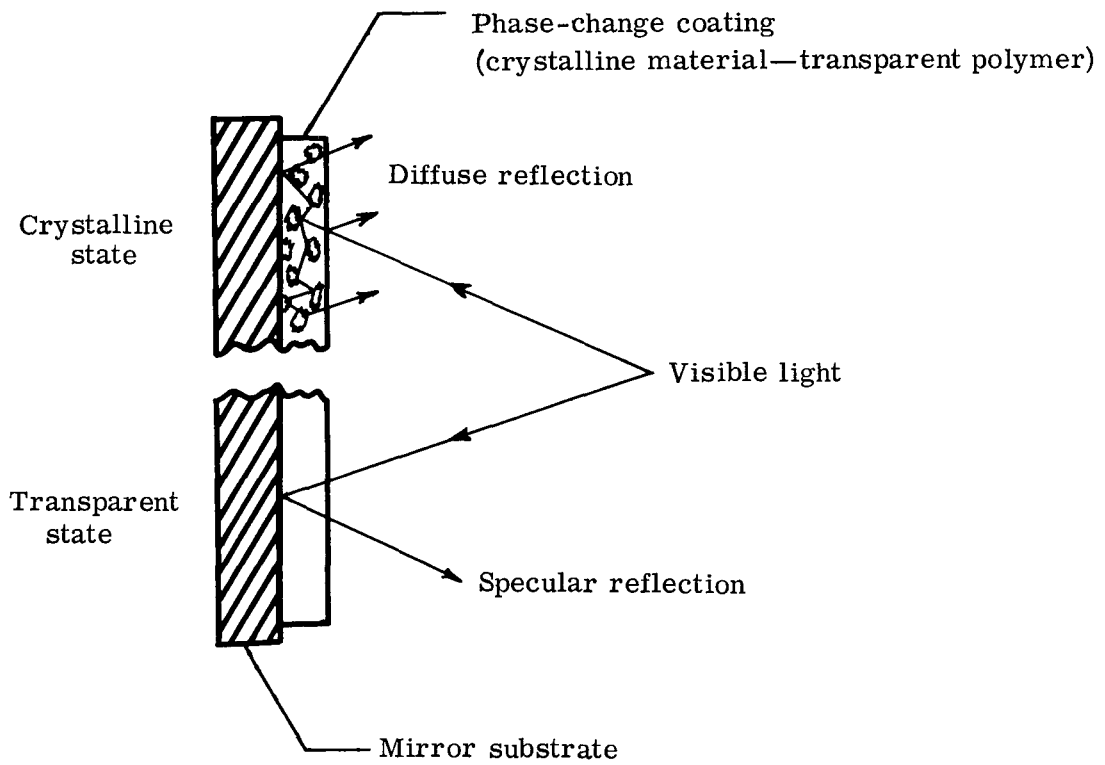
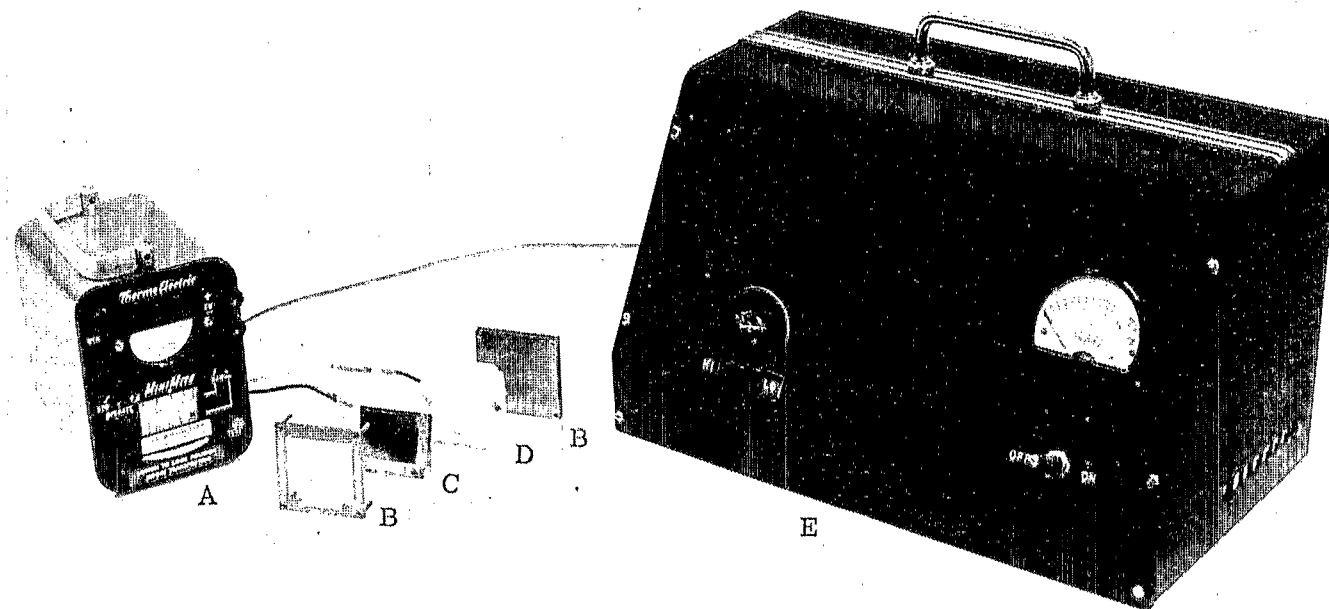


Figure 1.- Schematic of model phase-change coating system.



- A. Temperature readout
- B. Sample holder frame
- C. Silver-plated steel plate
(substrate for coating)

- D. Insulated nichrome heater
- E. Heater power supply

L-72-2422

Figure 2.- Temperature-regulated apparatus for solar absorptance measurements.

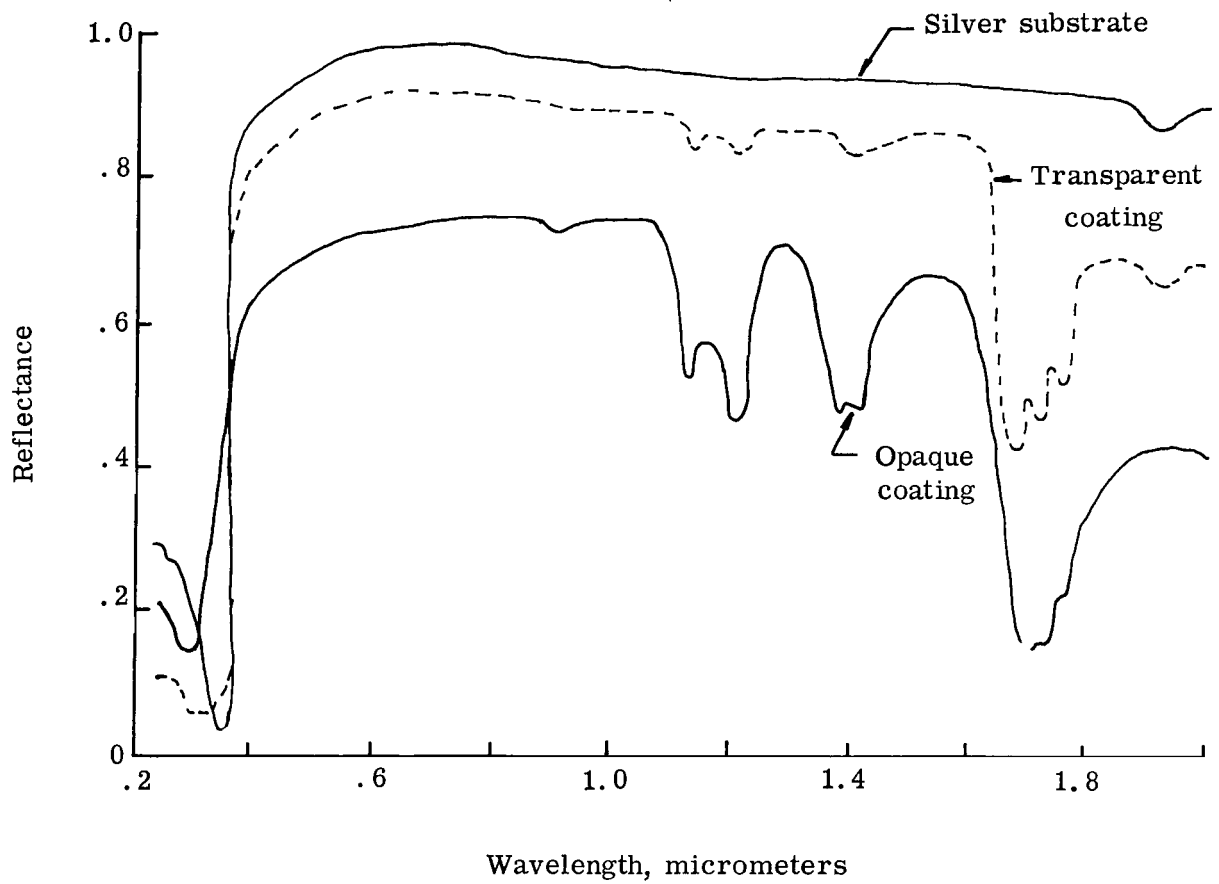


Figure 3.- Reflectance curves for 20% paraffin—80% resin C coating (0.05 cm thick).

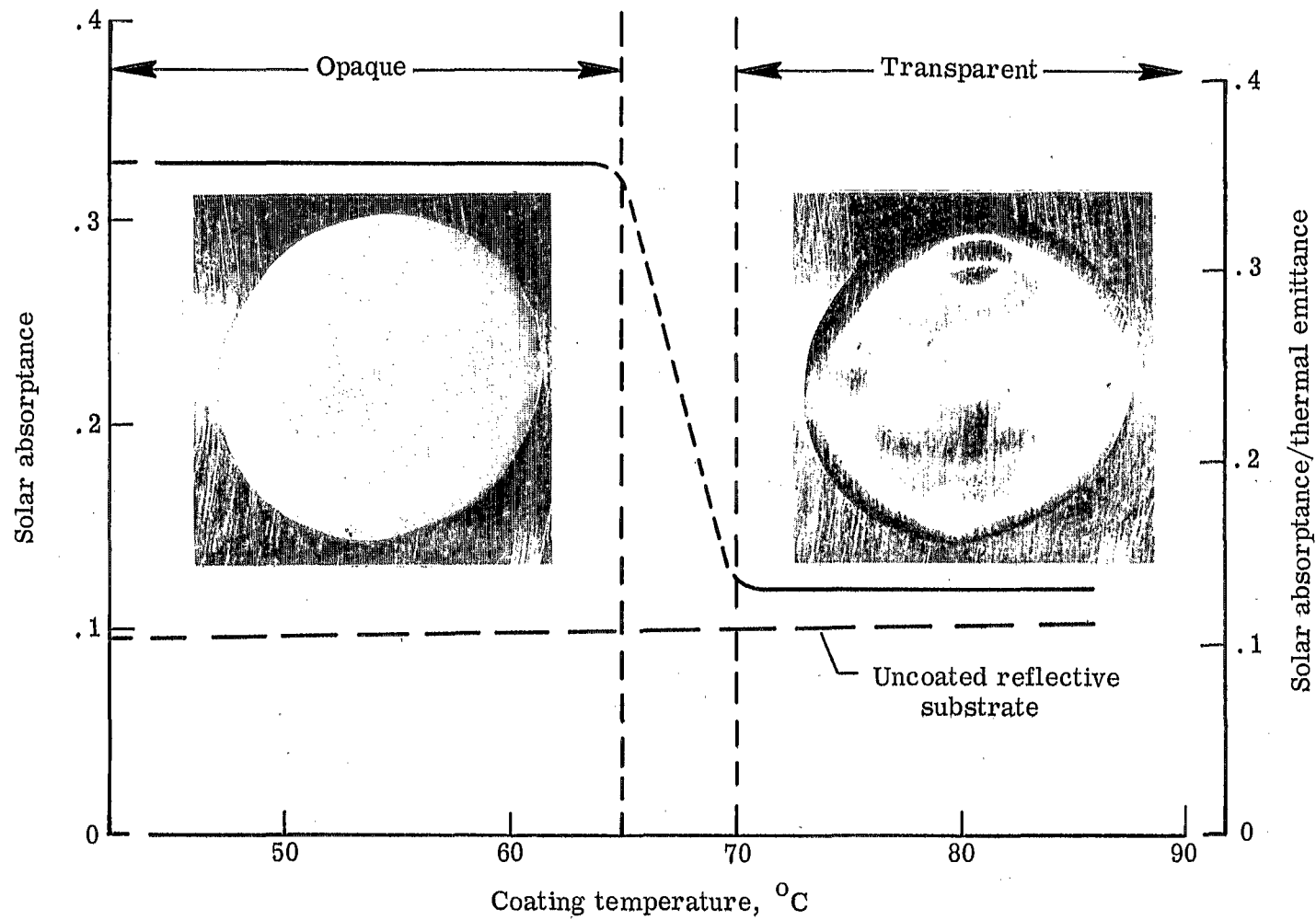


Figure 4.- Change in solar absorptance with temperature for 20% paraffin—80% resin C model.

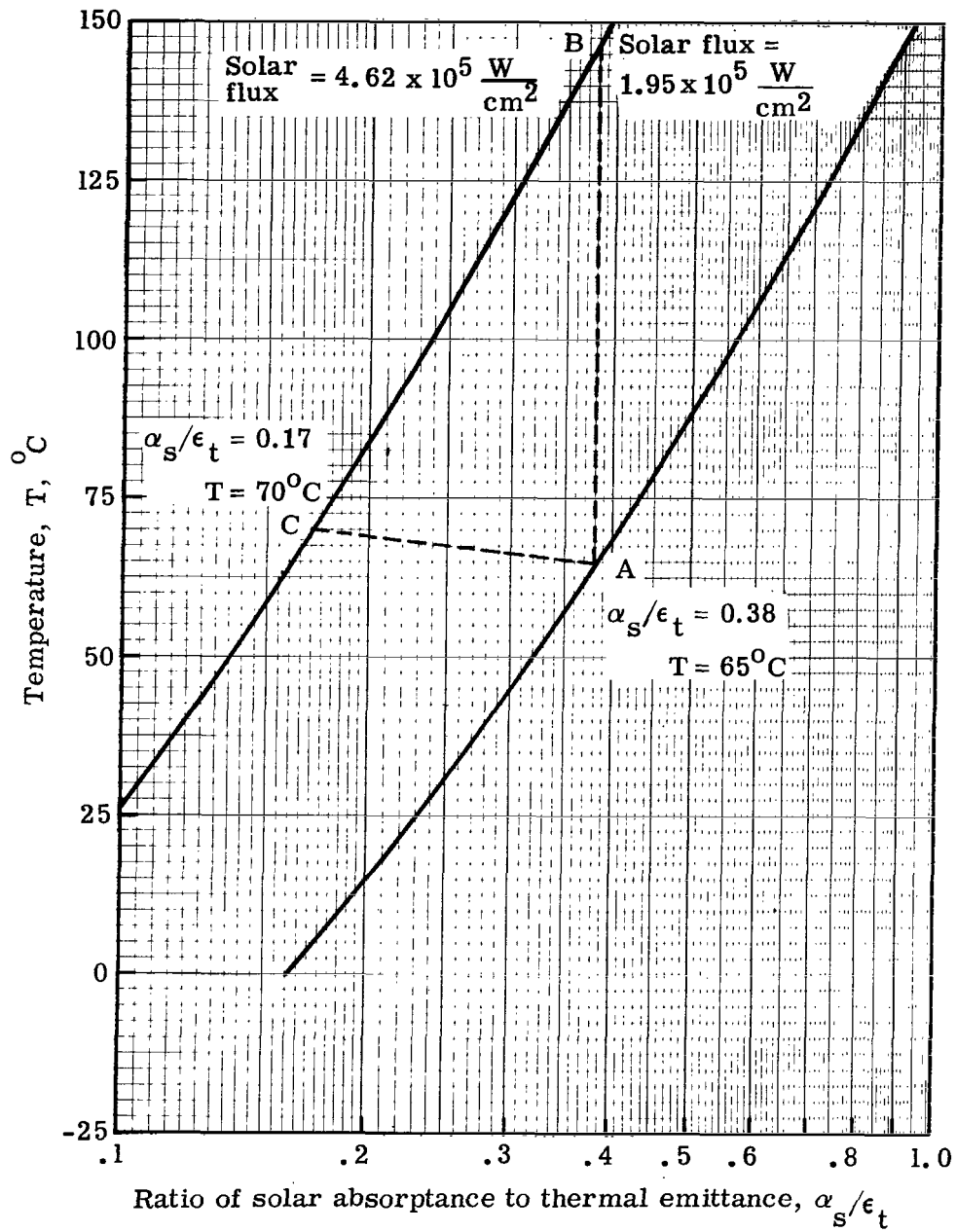


Figure 5.- Calculated curve for change in temperature with α_s/ϵ_t ratio for an insulated flat plate.

OFFICIAL BUSINESS
PENALTY FOR PRIVATE USE \$300

FIRST CLASS MAIL

POSTAGE AND FEES PAID
NATIONAL AERONAUTICS AND
SPACE ADMINISTRATION



NASA 451

012 001 01 0 33 720526 S20903DS
DEPT OF THE AIR FORCE
AF WEAPONS LAB (AFSC)
TECH LIBRARY/STOL/7
ATTN: A. L. KANNAN, CHIEF
KIRTLAND AFB TX 77117

POSTMASTER: If Undeliverable (Section 158
Postal Manual) Do Not Return

"The aeronautical and space activities of the United States shall be conducted so as to contribute . . . to the expansion of human knowledge of phenomena in the atmosphere and space. The Administration shall provide for the widest practicable and appropriate dissemination of information concerning its activities and the results thereof."

— NATIONAL AERONAUTICS AND SPACE ACT OF 1958

NASA SCIENTIFIC AND TECHNICAL PUBLICATIONS

TECHNICAL REPORTS: Scientific and technical information considered important, complete, and a lasting contribution to existing knowledge.

TECHNICAL NOTES: Information less broad in scope but nevertheless of importance as a contribution to existing knowledge.

TECHNICAL MEMORANDUMS: Information receiving limited distribution because of preliminary data, security classification, or other reasons.

CONTRACTOR REPORTS: Scientific and technical information generated under a NASA contract or grant and considered an important contribution to existing knowledge.

TECHNICAL TRANSLATIONS: Information published in a foreign language considered to merit NASA distribution in English.

SPECIAL PUBLICATIONS: Information derived from or of value to NASA activities. Publications include conference proceedings, monographs, data compilations, handbooks, sourcebooks, and special bibliographies.

TECHNOLOGY UTILIZATION PUBLICATIONS: Information on technology used by NASA that may be of particular interest in commercial and other non-aerospace applications. Publications include Tech Briefs, Technology Utilization Reports and Technology Surveys.

Details on the availability of these publications may be obtained from:

SCIENTIFIC AND TECHNICAL INFORMATION OFFICE

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

Washington, D.C. 20546