ISMR 2209

POWDER CURING USING INFRARED HEATING

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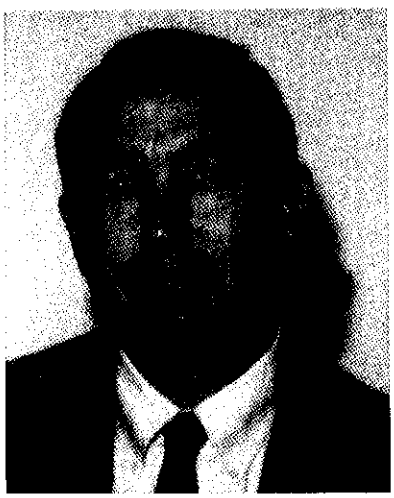

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Abstract

The use of electric infrared heat for curing of powder coatings has become more widely accepted in recent years. Operational advantages include faster curing times, smaller ovens, and flexibility not achievable with convection ovens.

A properly designed infrared system requires more information than that required to design a convection heating system. Different parameters impact the cure of powder coatings, and therefore the ultimate design of an infrared heating system. In an attempt to better understand the significant parameters related to powder curing, the Southern Company has sponsored research over the last year with the Georgia Institute of Technology. The results of Phase one of this research is the subject of this paper.

Research materials used in this paper were taken from the Master's Thesis authored by Ms. Veta Williamson, entitled,

Investigation of the Infrared Spectral Absorptivity of Polymeric Materials

Executive Summary

Industry has utilized infrared radiation (IR) for many years in applications such as drying and curing of a number of products ranging from non woven fabric to coated metal parts. Historically, many of the IR heating applications have utilized gas as an energy source, and thus the infrared radiation used was in the medium to long infrared regions of the spectrum. In recent years, there have been improvements in electric-based IR equipment, particularly in emitter materials and controls. Electric IR provides the capability to adjust the region (short, medium or long wavelength) in which most of the radiation is emitted as well as the amount of radiant energy emitted (flux density). However, methods and equipment for specifying optimal electrical IR heating systems have not been fully developed and utilized.

The introduction of new technologies to manufacturers has been a primary purpose of the Southern Company's Technology Application Center (TAC). The goal of the TAC is to help industry become/remain competitive in the global market place through the wise application of new technologies to manufacturing processes. One such technology is powder coating. It can improve productivity and product quality while providing significant opportunities for replacing wet coating applications with much more environmentally friendly coatings.

Another technology that can provide additional improvement in productivity is infrared heating to rapidly heat or "cure" the powder coatings. The combination of these two technologies was the focus of the work reported on in this paper. As an electric utility the Southern Company recognized the great potential for the use of IR heating in the curing of powder coatings. With this in mind, the Southern Company sponsored research through its Georgia Power Company subsidiary and the Georgia Institute of

Technology to better understand and quantify key parameters that determine successful applications of electric infrared heat for heating powder coatings.

The research was divided into two phases. Phase one investigated the key parameters affecting the absorption of infrared heat by powder coatings. Phase two is investigating the parameters affecting radiant output of commercially available infrared emitters. Phase two will provide sufficient information to properly "select" correct combinations of emitters and powders to provide the most efficient use of radiant energy for powder curing.

Key Parameters Affecting IR Absorption

The following parameters were investigated in Phase one:

- Polymer
- Pigment
- Thickness
- Cure vs. Uncured
- Gloss

Significant Results of Phase One:

- The polymer type in the powder coating did not significantly affect the absorption of infrared energy.

- Pigment had very significant effects on infrared absorptivity. Carbon black caused the coatings to have high absorptivities throughout the infrared spectrum and high average absorptivities for a wide range of emitter temperatures. The limited number of other pigments studied had much less effect (red, green, white). White (titanium dioxide) had a significant effect of reducing absorptivity in the near (short) IR region.

- Film thickness affected infrared absorptivity for clear coatings, but the effect is small over the range of thicknesses between 1.5 and 3.0 mils. Film thickness did not affect infrared absorptivity for coatings containing carbon black because infrared energy appears to be absorbed near the surface of the coating with little penetration.

- Gloss was not an important parameter affecting infrared absorption.

- Cured vs. uncured samples had similar absorptivities.

Opportunities for Using IR

The very rapid heating of powder coatings with electric infrared heating provides significant opportunities for productivity gains. Curing times in the range of seconds to several (two to five) minutes are the rule versus convection heating times specified in powder manufacturer's literature of 15 to 25 minutes. The parameters affecting these excellent gains are now better understood. The foundation has been laid for applying the data gathered in Phase Two to determine optimum curing systems for the powder coater.

Introduction

• The Use of Infrared Heat

Industrial use of infrared radiation (IR) heating has been very successful in the drying and curing of a number of products ranging from non woven fabric to coated metal parts. In the past, many of the IR heating applications have utilized gas as an energy source, and thus the infrared radiation used was in the medium to long infrared regions of the spectrum. In recent years, there have been improvements in electric-based IR equipment, particularly in emitter materials and controls. Electric IR provides the capability to adjust the region (short, medium or long wavelength) in which most of the radiation is emitted as well as the amount of radiant energy emitted (flux density). However, methods and equipment for specifying optimal electrical IR heating systems have not been fully developed and utilized.

The optimal utilization of IR is dependent on the spectral characteristics of the material being processed and on how well the spectral output of the IR source matches those of the material to be heated.

• Technology Applications

These characteristics have been recognized as critical to the success of the use of electric infrared heating of powder coatings . For the past five years, marketing personnel of the Southern Company have been encouraging their customers to investigate the use of powder coating as an environmentally friendly substitute to some of their existing wet coatings. As a tool to help their customers in deciding to move to powder, the customer has been provided testing support through Southern's

Technology Application Center (TAC), owned and operated by their Georgia Power Company operating subsidiary.

The TAC was started at Georgia Power to provide commercially available electrotechnologies for use by their manufacturing customers in a "try before you buy" concept. The Center includes powder coating equipment and electric infrared heating capabilities (along with several other electrotechnologies such as induction heating, radio-frequency heating, ultraviolet curing, plasma torches, robotics welding and cutting, etc.). The concept has been to provide a place where a customer's specific application could be evaluated by TAC staff, the customer's staff, and/or a combination of the two, along with equipment vendors and consultants if needed.

• Proper Use of Infrared Heat

Some of the difficulties encountered in the testing of these customer applications led to the research reported in this paper. There were two primary difficulties when tests were made with infrared heating of powder coatings. The first was the type of emitter to use and the second was the inability to specify a flux density (heat per unit area) of radiant heat for a given time that would successfully cure the powder. Another difficulty was the inability to characterize commercially available emitter/emitter systems (reflectors/etc.) so that accurate overall economic operating costs could be calculated between various combinations of emitters and fuel sources (gas and electric).

- ## Project in Two Phases

Phase I of this project has involved the characterization of the IR spectral absorption properties of selected powder coatings on metal substrates and the identification of the important parameters affecting IR absorption by powder coatings. This information has been used along with the normalized emission characteristics of blackbody emitters to calculate the average absorptivity of the powder coatings for various blackbody emitter temperatures. The variation of average absorptivity with blackbody emitter temperature can be used as an indicator of the type emitter (short, medium or long wavelength) best suited for a particular powder coating.

In Phase II, currently being conducted, a method is being developed for measuring the spectral emission of commercially available IR sources. Average absorptivities of the powder coating when matched with a particular IR emitter will be calculated for several emitter temperatures to identify the temperature at which the emitter most effectively heats the powder coating. Also in Phase II, a procedure is being developed for specifying the heat flux required to heat a product in a specified time.

- ## Scope of Study

This study was limited to the following three major groups of polymeric powder coatings used by industry for coating metals:

- Polyester
- Polyurethane
- Epoxy
- Hybrid resins

The variations of absorptivity of powder coatings with infrared wavelength were measured using an FTIR (Fourier transform infrared) spectrophotometer and an integrating sphere. The effects of various parameters on the infrared spectral absorption characteristics of the polymeric powder coatings were investigated. The resins were examined with respect to different processing and material parameters including the gloss, glass plate value, film thickness, and pigment type. These parameters were investigated both before and after curing of the coatings.

Methodology

Introduction to the Theory of Thermal Radiation

Thermal radiation is a mode of heat transfer characterized by energy transport in the form of electromagnetic waves. Thermal radiation is energy emitted by a body solely by virtue of its temperature. Although thermal radiation can be emitted in the ultraviolet and visible regions of the electromagnetic spectrum, thermal radiation is emitted primarily in the infrared region of the spectrum for most industrial heating applications,. Thus when thermal radiation is used to heat material, it is usually called ***infrared heating***.

All bodies emit thermal radiation, but not all bodies emit or absorb the same amount of energy at a given temperature. A body that emits the maximum amount of energy that is thermodynamically possible at a given temperature is called a blackbody. Also, blackbodies absorb all incident radiation. A blackbody is a standard with which all thermal radiators can be compared and with which all absorbing surfaces can be compared.

When a body is heated to a temperature T, energy is emitted from the surface of the body. The energy is distributed across the electromagnetic spectrum over wavelengths ranging from approximately 0.1 microns to 100 microns, depending on T. It should be emphasized that no body, at any wavelength and average temperature, can emit more thermal radiation than a blackbody.

In 1900, Max Planck derived a relationship (Planck's distribution) for the spectral variation of thermal emission of a blackbody at a temperature T. The energy emitted per unit surface area at a given wavelength is called emissive power, $E_{bl}(T)$. The spectral distribution of monochromatic emissive power for a blackbody at various temperatures is illustrated in Figure 1. This figure shows that the energy emitted per unit surface area increases rapidly with increasing T.

The total amount of radiant energy per unit area, $E_b(T)$, emitted from a blackbody at temperature T is referred to as total emissive power and can be calculated by integrating Planck's distribution over all wavelengths. When the integration is carried out, the result is

$$E_b(T) = sT^4 \qquad \text{Equation (1)}$$

which is known as the Stefan–Boltzmann law. The symbol s is the Stefan–Boltzmann constant.

The normalized distribution of energy emitted through the spectrum can be obtained by dividing emissive power at a given wavelength by the total energy emitted by the blackbody. In other words the ratio, $E_{bl}(T)/E_b(T)$, shows how the energy for a given blackbody temperature is distributed throughout the spectrum. The plots of

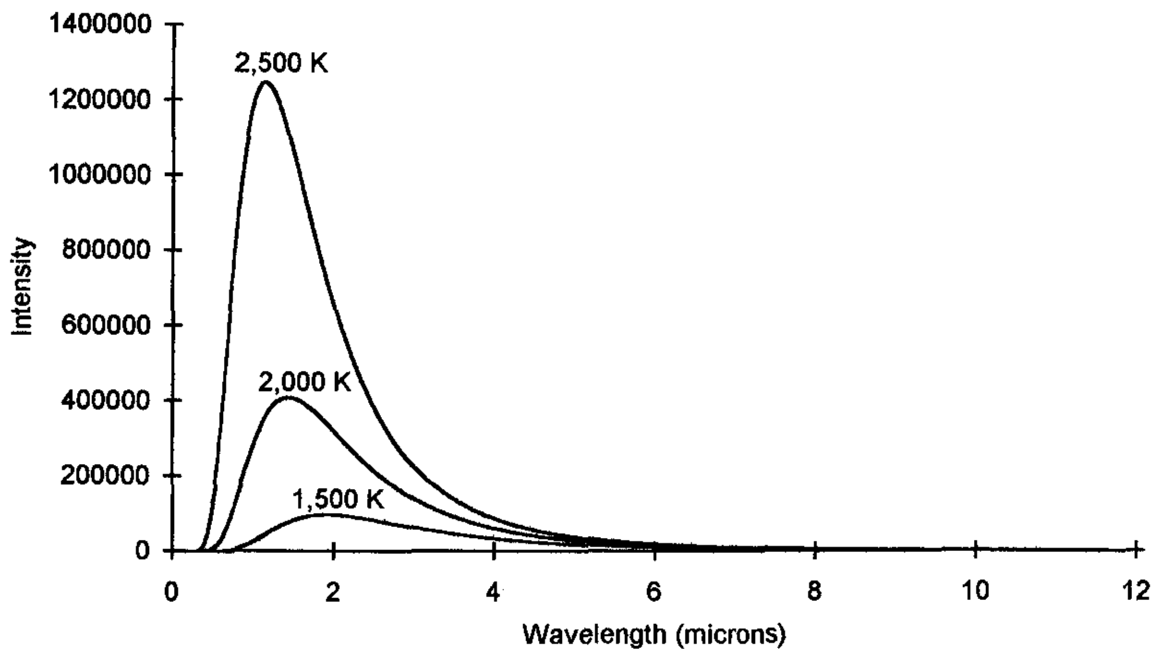

Figure 1. Spectral Distribution of Monochromatic Emissive Power of a Blackbody

$E_{bl}(T)/E_b(T)$ versus Intensity, shown in Figure 2, illustrate how the energy emitted from a blackbody varies with T. At high temperatures, the radiation is concentrated in the shorter wavelength region of the spectrum while at lower temperatures the radiation is spread throughout the spectrum with very little radiation close to the visible region (0.38-0.76 microns).

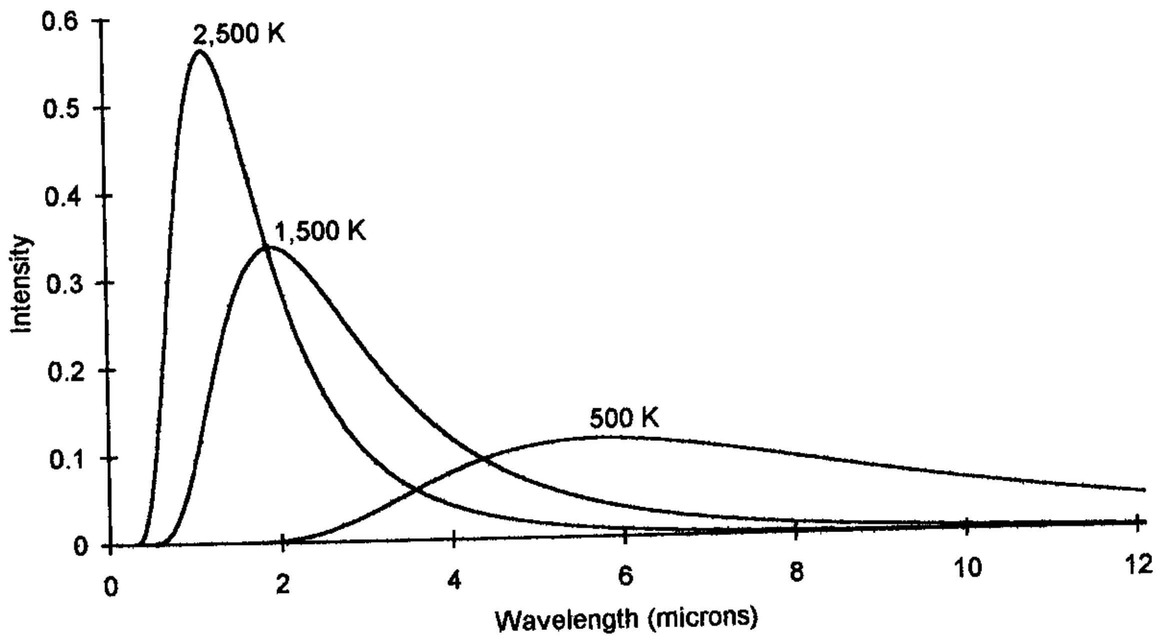

Figure 2. Normalized Blackbody Emission

When radiation is incident on a material, as shown in Figure 3, it can be partially absorbed, partially reflected, and partially transmitted. The relation between the absorbed, reflected, and transmitted energy at a given wavelength is given by Equation number 2:

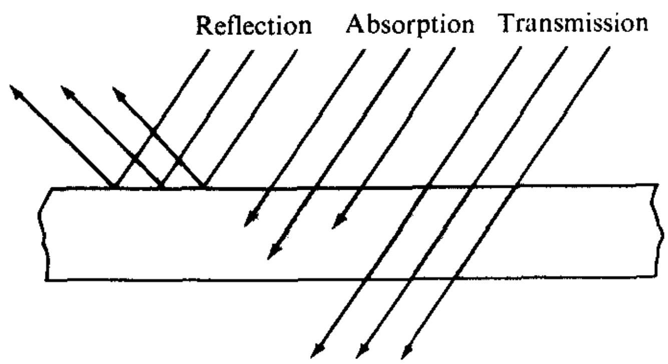

Figure 3. Reflection, Absorption, and Transmission

$$1 = a_l + r_l + t_l \qquad \text{Equation (2)}$$

where:

a_l = absorptivity, the fraction of incident energy at a given wavelength that is absorbed by the body;

r_l = reflectivity, the fraction of incident energy at a given wavelength that is reflected by the body;

t_l = transmissivity, the fraction of incident energy at a given wavelength that is transmitted through the body.

Infrared Emitters

Infrared emitters are usually classified by the wavelength at which maximum intensity occurs. The three classifications for types of emitters used by industry are:

Emitter Type	Wavelength Range (microns)
Short	0.76-2.0
Medium	2.0-4.0
Long	4.0-10+

As illustrated in Figure 2, the shorter wavelength (higher temperature) emitters radiate over a much more narrow wavelength band than the other two emitters. As will be shown later in this report, many powders are not as absorbent in the near-infrared region where these high temperature emitters operate. Lower temperature emitters radiate over a larger region of longer wavelengths. Absorption on IR powders is typically higher in these regions. (The conflicting balance in determining which emitter to use in powder curing often centers on this issue. Although powders may absorb more radiant energy at the longer wave lengths, the infrared flux density and radiant efficiency is considerably less for emitters of this type).

The total amount of radiant energy (q) emitted per unit time by a black body at temperature (T) can be obtained by multiplying $E_b(T)$ given in Equation 1 by emitter area (A).

$$q = sAT^4 \qquad \text{Equation (3)}$$

This equation shows that the power emitted by the radiator (emitter) varies linearly with area but also varies with the fourth power of absolute temperature. Short-wavelength emitters operate at much higher temperatures than the other types, thus the size of the short wavelength emitter can be much smaller. As a result, they have much faster response times than longer wavelength emitters. This is of particular importance for intermittent operations and for manufacturing line stoppage where overheating of the material can be a problem.

The effect of temperature can be seen by comparing two emitters, one at 2500K, and the other at 800K. For the total emission of the emitters to be the same, the area of the low temperature emitter (long wavelength) must be approximately 95 times larger than the high temperature emitter.

Another advantage of short wavelength emitters is that they are capable of producing much higher flux densities than the longer wavelength emitters. They are also more efficient at converting electrical energy into infrared energy, which can be seen using the equation below:

$$P_e = P_{ir} + P_{conv} \quad \text{Equation (4)}$$

The electrical energy dissipated in the emitter, P_e is lost from the emitter primarily by thermal radiation (infrared), P_{ir}, and convection, P_{conv}. Thermal radiation loss is proportional to T^4 while convective losses are proportional to T, the emitter temperature. As the temperature increases, the amount of energy emitted as infrared radiation increases much faster than the energy lost through convection. A direct result of this is that short wavelength emitters are more efficient at converting electrical energy into infrared energy.

In this project, emitters are treated as blackbodies. In many cases, they may not be. However, little information is available in the literature on the emission characteristics of commercial emitters. This is the subject of phase two of this study, currently being conducted at Georgia Tech.

Application of Infrared Theory to Curing of Powder Coatings

Figure 4 shows a typical absorptivity curve for a powder coating. To see how a coating with absorptivity a_l absorbs energy emitted by a blackbody at temperature T, the product of a_l and $E_{bl}(T)/E_b(T)$ can be plotted over the spectrum of wavelengths for which the blackbody is emitting. This is illustrated in Figure 5 for a blackbody temperature of 1500K.

The fraction of the total energy emitted by a blackbody that is incident on the surface having an absorptivity a_l can be calculated by integrating $a_l E_{bl}(T)/E_b(T))$ over all wavelengths. When the integration is carried out, the result is called the average absorptivity of the material for the blackbody emitter at temperature T. Once a_l is measured for a given material, average absorptivity can be calculated for a range of emitter temperatures and plotted to show the effect of emitter temperature on IR absorption, as illustrated in Figure 6. This information is valuable in determining the blackbody temperature best suited for heating a particular powder and for infrared emitter selection.

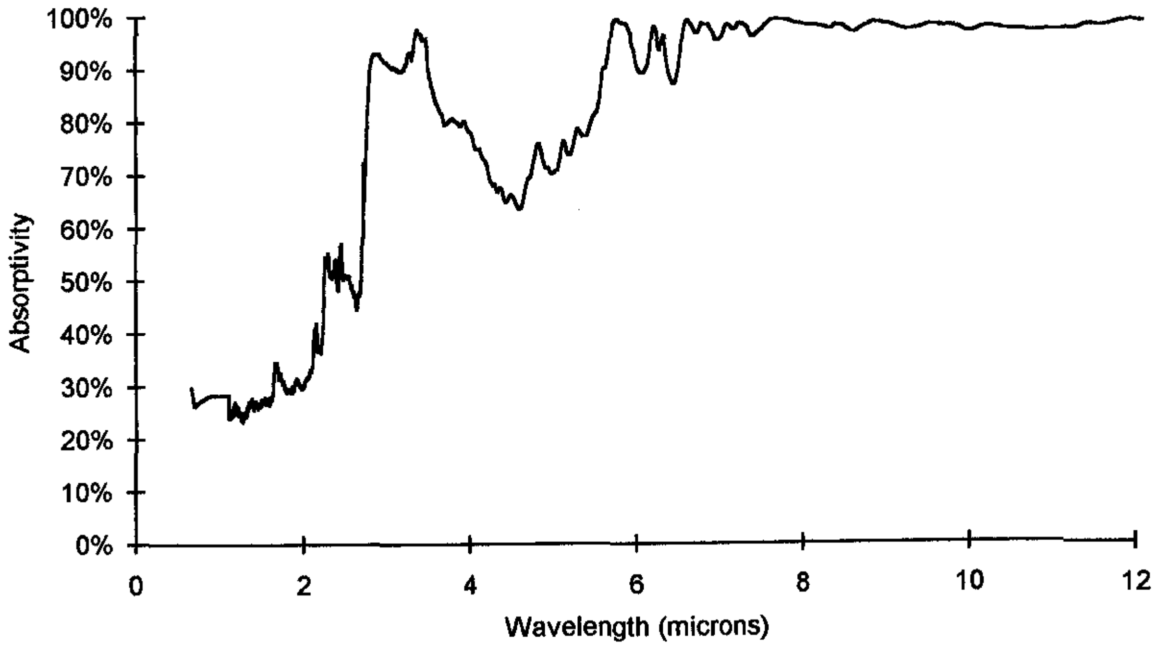

Figure 4. Spectral Absorptivity of a Powder Coating

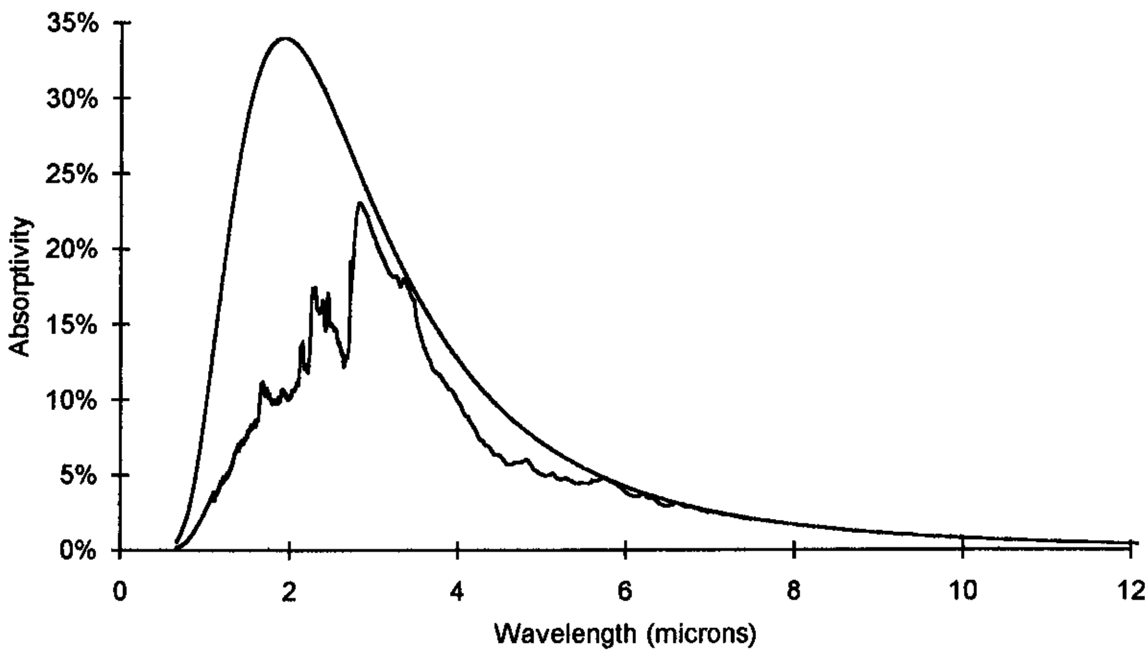

Figure 5. Normalized Black Body Emission and Fraction Absorbed by a Powder Coating

Although the variation of absorptivity with wavelength, a_l, is needed to determine how a material matches a given IR emitter, it is difficult to measure directly. The approach taken in this work has been to measure r_l and t_l and then to use Equation 2 to calculate a_l.

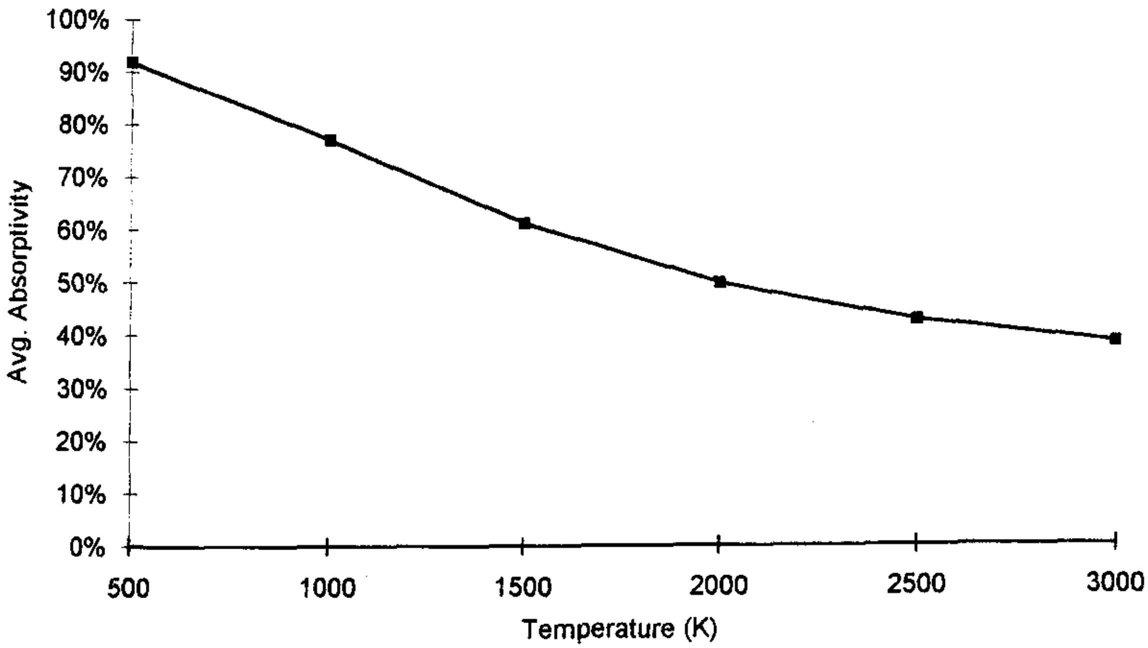

Figure 6. Average Absorptivity versus Blackbody Emitter Temperature

Materials Used

The infrared spectral absorptivities were measured for the three polymeric coating types listed in Tables 1 through 3. For each polymer type, tests were conducted to determine the effect of the following parameters:

- pigment
- film thickness
- level of cure
- particle size
- gloss
- glass plate (flow viscosity)
- stage of cure.

Results

The following results are reported for each of the parameters previously listed. Results are only for the set of test samples used. These samples were from one manufacture of powder coatings. It is unknown how variations in other manufacturer's formulations might affect results.

Gloss and Glass Plate Flow

The term gloss is defined in the visible region of the spectrum and was found to have little effect on infrared absorption Also, glass plate (flow viscosity) did not show any significant effect in the infrared region.

Table 1. Epoxy Powder Coatings Used in Testing

Powder Type & No.	Test No.	Color	Thickness (mls)	Gloss	Glass Plate Value
Epoxy					
881061	A	Dark	1.67	Semi	Low
	B		2.15		
	C		2.01		
881048	A	Dark	1.63	Flat	Low
	B		1.94		
	C		2.63		
881065	A	Dark	2.48	Semi	High
	B		2.22		
	C		1.85		
881271	A	Dark	2.07	High	High
	B		2.15		
	C		1.37		
88990F	A	Dark	1.94	Semi	Unknown
	B		1.80		
	C		3.46		
88990	A	Dark	2.31	Semi	Unknown
	B		2.58		
	C		2.45		
891353	A	Dark	1.35	Flat	High
	B		1.39		
	C		2.76		
891416	A	White	2.61	High	High
	B		1.94		
	C		2.76		
861163	A	Red	1.44	Semi	Unknown
801005	A	Clear	1.47	Semi	Unknown
	B		1.25		
851849	A	Green	1.87	Semi	Unknown

Table 2. Hybrid Powder Coatings Used in Testing

Powder Type & No.	Test No.	Color	Thickness (mls)	Gloss	Glass Plate Value
Hybrid					
881207	A	Dark	1.52	Semi	Unknown
	B		1.05		
	C		0.98		
851733	A	Green	1.67	Semi	Unknown
861223	A	Red	1.92	Semi	Unknown
801067	A	Clear	1.28	Semi	Unknown
	B		1.19		
851879	A	Green	1.41	Semi	Unknown

Table 3 Polyurethane/Polyester Powder Coatings Used in Testing

Powder Type & No.	Test No.	Color	Thickness (mls)	Gloss	Glass Plate Value
Polyurethane					
881203	A	Dark	1.85	High	High
	B		1.65		
	C		1.53		
881276	A	Dark	3.97	Flat	Low
	B		1.49		
	C		1.37		
891433	A	White	2.13	High	High
	B		3.57		
	C		1.20		
801060	A	Clear	1.61	High	High
	B		1.35		
	C		3.18		
	D		3.85		
	E		4.50		
	F		5.20		
	G		0.65		
Polyesters					
801050	A	Clear	1.50	Semi	Unknown
	B		1.16		
861175	A	Red	1.76	Semi	Unknown

Polymer Type

Spectral Absorptivity

The effect of the polymer type (epoxy, polyester, and hybrid) can be seen in Figure 7. These plots are for unpigmented coatings of similar thickness. Although there are local variations, there are very similar patterns of absorption exhibited in the 2 to 10 micron region.

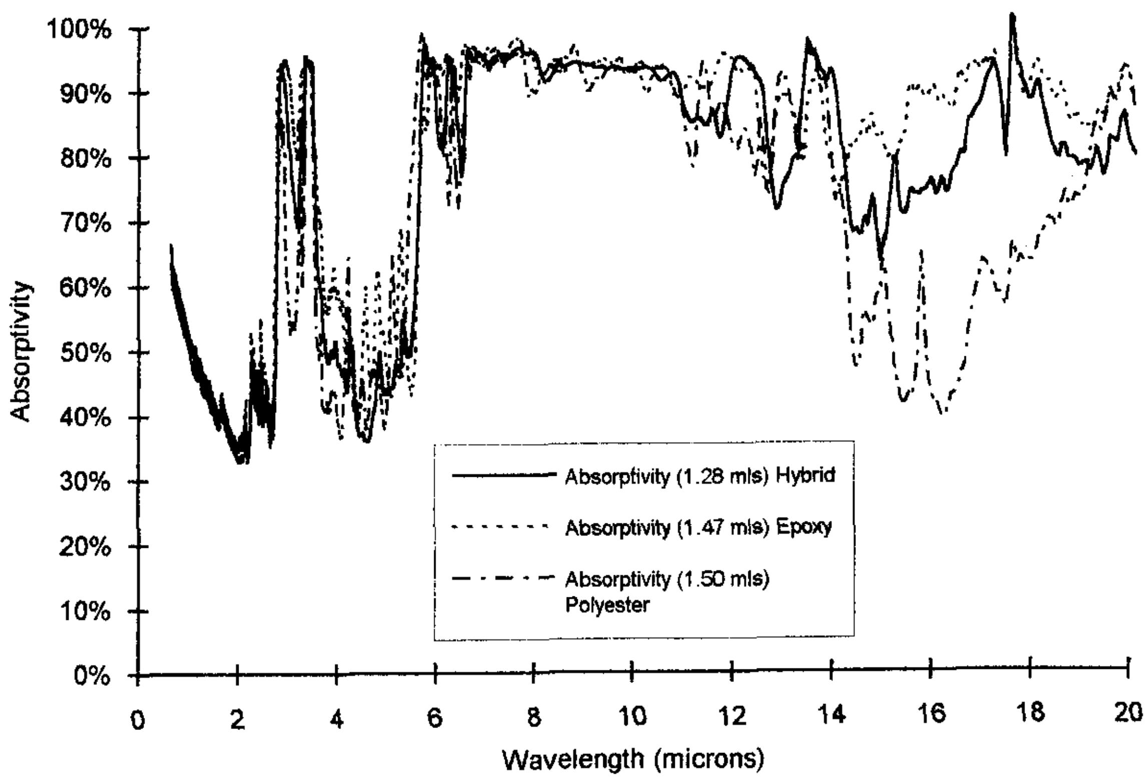

Figure 7: Infrared Spectral Absorptivity of Non pigmented Polymeric Powder Coatings vs. Wavelength. Epoxy 801005, Polyester 801050, Hybrid 801067: Clear, Semi Gloss

Average Absorptivities

The average absorptivities for the non pigmented (clear) coatings are shown in Figure 8. Differences in these three curves are small. Average absorptivities range between 80% for low emitter temperatures (500K) to approximately 50% for the high emitter temperatures. The output of high temperature emitters is mostly in the near infrared region where the spectral absorptivities of the coatings are low. Thus average absorptivities are lower for the high temperature emitters.

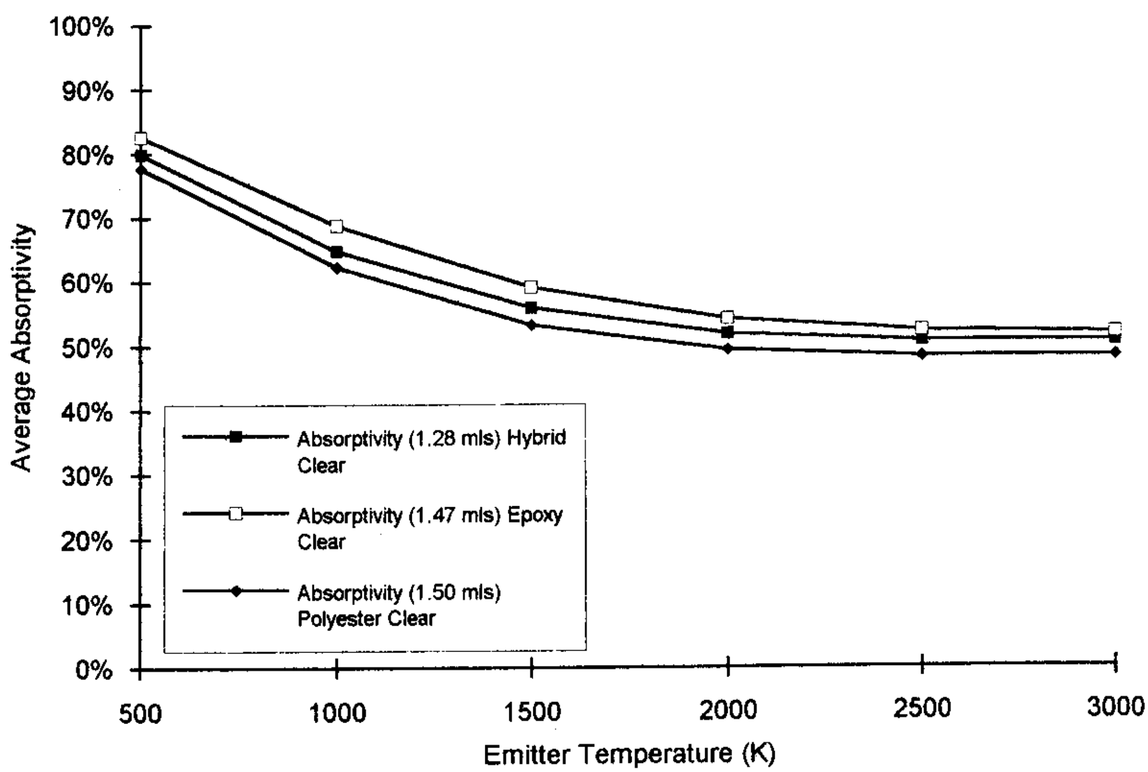

Figure 8: Average Absorptivity of Non pigmented Powder Coatings vs. Black Body Temperature Emitter (Epoxy 801005, Polyester 801050, Hybrid 801067: Clear, Semi Gloss)

Effect of Pigment

Spectral Absorptivity

Spectral absorptivity of the powder coatings used in this study depend greatly on the type of pigments used to color the coatings. The color powders used in this study--green, red, white, and black--have different mixtures of pigments to obtain the desired color. Table 4 lists the colored powders examined in this study and the types of pigment used.

Some Observations:

- The spectral absorptivities of unpigmented powder coatings and red colored powder coatings are similar. This indicates that the pigments used for coloring the red coating interact with the impinging radiation primarily through the visible part of the spectrum.

- Black pigment (carbon black) effectively absorbs greater than ninety percent across the infrared region. This can be seen in Figure 9.

- White pigments, using titanium dioxide, behaved similarly to the unpigmented polymers for wavelengths less than ten microns except in the near (short wavelength) region.. The absorptivities of the white coating falls off significantly at 1.5 microns (i.e., just before the visible region). This can be seen in Figure 10.

Table 4. Type and Amount of Pigment Used to Color Green and Red Powder Coatings Involved in This Research

Color of Coating	Powder No.	Type of Polymer	Pigment Color	Percentage of by weight
Red	861163	Epoxy	white - inorganic red - organic orange - organic	0.40% 4.12% 3.00%
Red	861175	Polyester	red - organic red - organic orange - organic white - inorganic	1.6% 2.8% 0.20% 0.30%
Red	861223	Hybrid	white - inorganic red - organic red - organic	2.24% 2.56% 2.88%
Green	851849	Epoxy	white - inorganic green - inorganic yellow - organic	1.10% 1.40% 1.35%
Green	851789	Polyester	white - inorganic green - inorganic black - organic yellow - organic	2.00% 1.05% 0.05% 3.30%
Green	851733	Hybrid	white - inorganic green - inorganic yellow - organic black - organic	1.79% 0.97% 1.64% 0.60%
Black	see Table 5-1, 5-2, 5-3	All Types	black - organic (carbon black)	approximately 5% or less
White	see Table 5-1, 5-2, 5-3	Polyester, Epoxy	white - inorganic (rutile titanium dioxide)	approximately 5% or less
Clear	see Table 5-1, 5-2, 5-3	All Types	no color	no pigment

- The spectral absorptivities of the green coatings varied with the level of pigment used. The amount of black pigment used in the coating appears to significantly affect the spectral absorptivities.

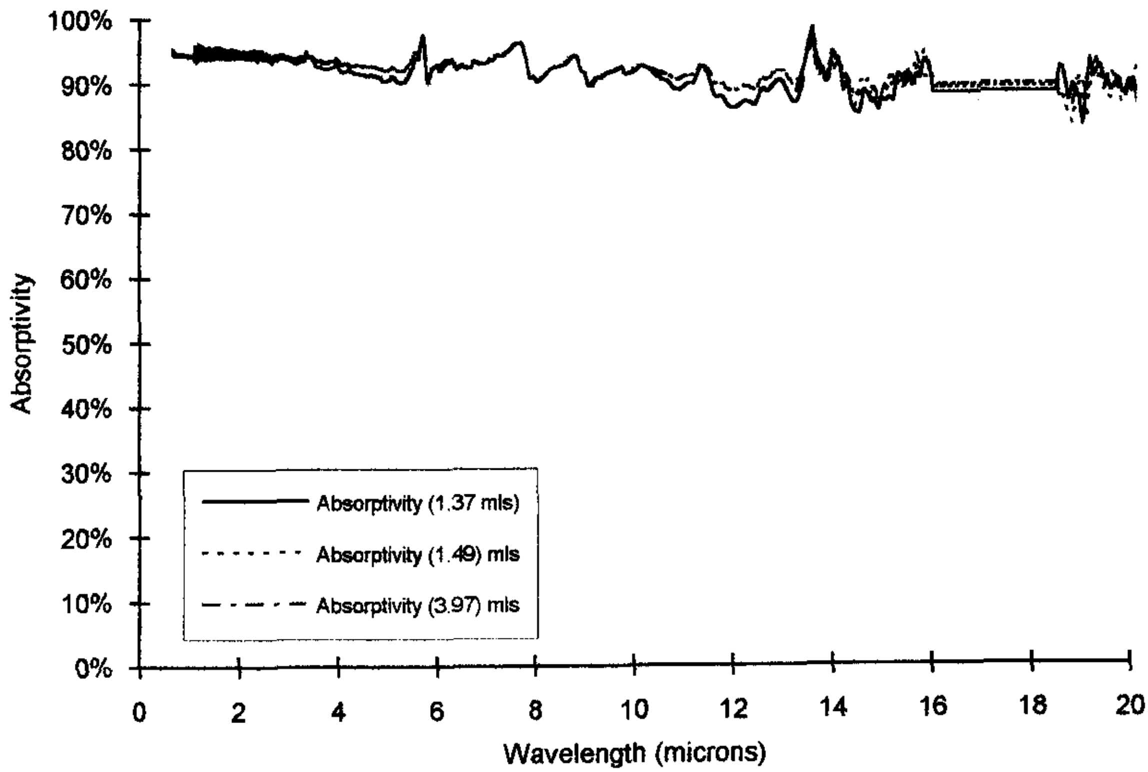

Figure 9: Infrared Spectral Absorptivity of Polyurethane Powder Coating Cured vs. Wavelength (Polyurethane 881276: Dark Color, Flat Gloss, Low Glass Plate).

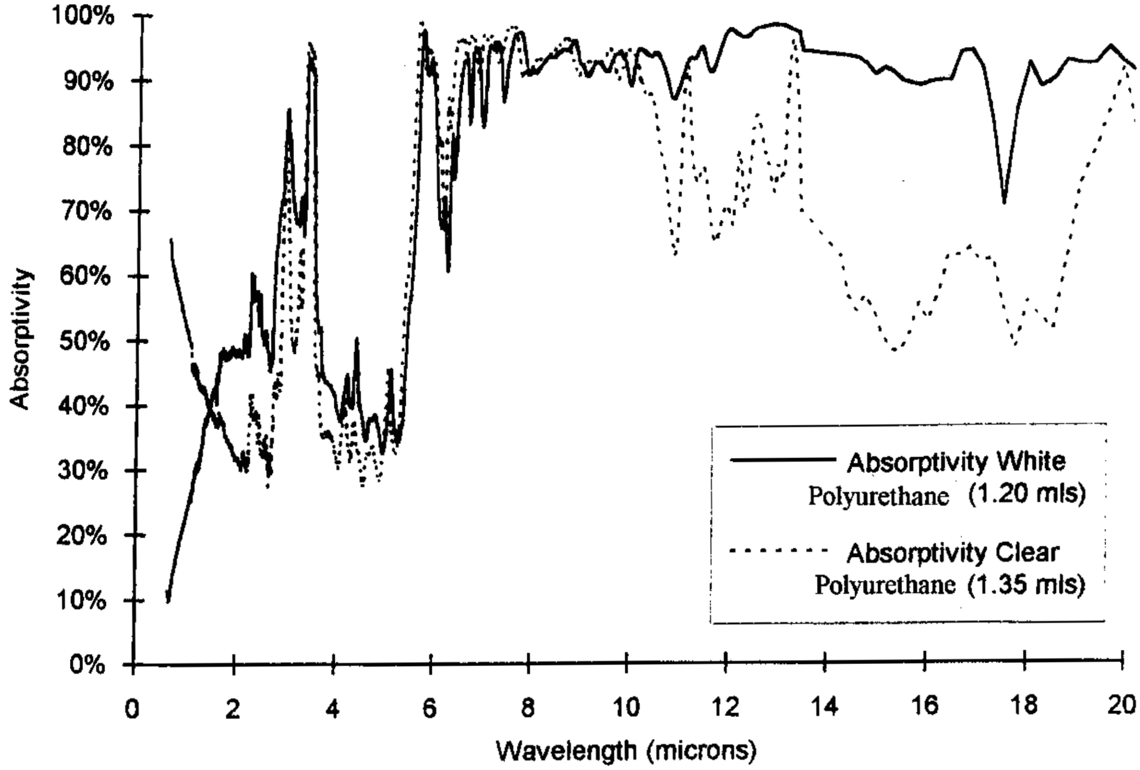

Figure 10: Infrared Spectral Absorptivity of Pigmented and Non pigmented Powder Coatings Cured vs. Wavelength (Polyurethane 801060, 891433: Clear, White, High Gloss, High Glass Plate)

Average Absorptivity

Since pigment can greatly affect spectral absorptivities as discussed in the previous section, it can also greatly affect average absorptivities. The effect depends significantly on the pigment materials used as shown in Figure 11.

Some Observations

- Carbon black had the most significant impact on average absorptivity. Average absorptivities for the three polymeric coatings pigmented with carbon black, with comparable coating thicknesses, have average absorptivities greater than 90%. The emitter temperature has little effect when sufficient carbon black is used since the dark coatings absorb throughout the infrared spectrum.

- Titanium dioxide, used to produce the white coatings, has its major effects in the infrared region near the visible. The spectral absorptivities of the white coatings decrease rapidly as the visible region of the spectrum is approached and are much lower than for unpigmented coatings. Since blackbody emission in the near infrared increases greatly with rising emitter temperature, the titanium dioxide has a larger effect on average absorptivities for high temperature emitters.

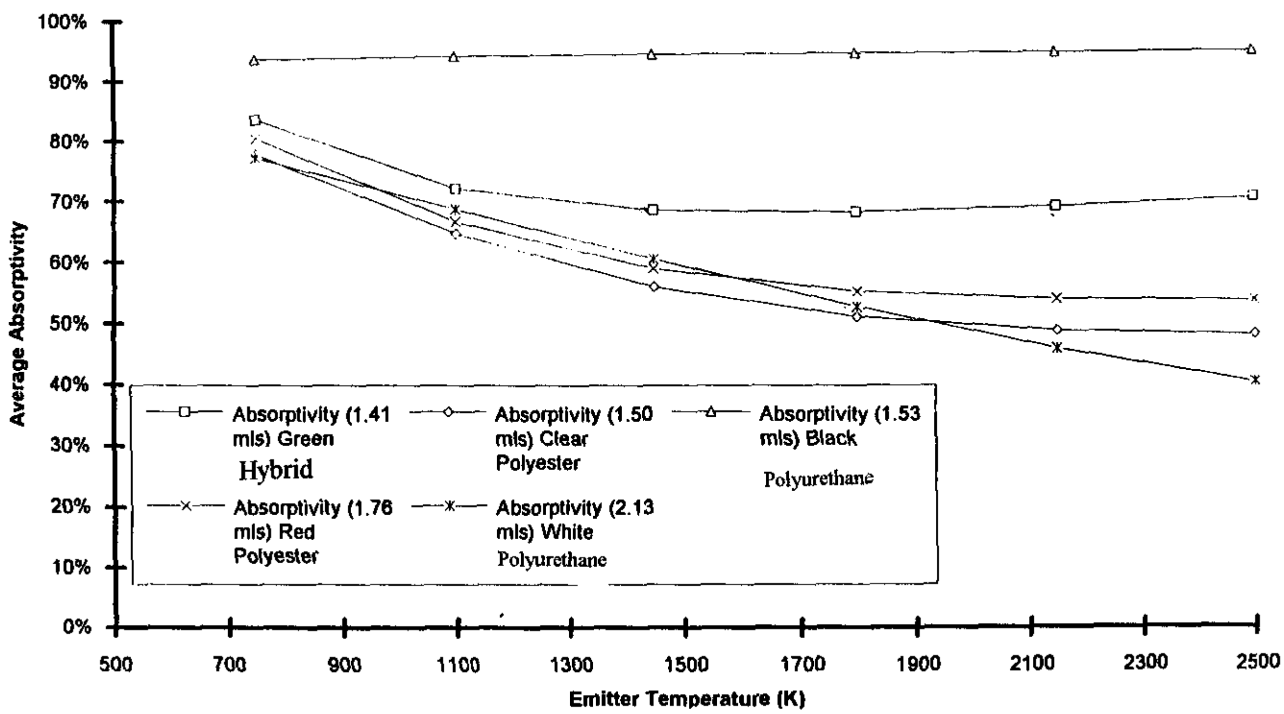

Figure 11: Average Absorptivity of Polyester Pigmented and Non pigmented Powder Coatings vs. Black Body Temperature Emitter. Polyester; 801050, 861175,--Clear,, Red. Hybrid; 851879, Green. Polyurethane; 891433, 881203--White, Black

Effect of Film Thickness

Spectral Absorptivity

Some Observations

- The impact of film thickness can be seen in Figures 12 and 13. For the thickness ranges of 0.65 to 3.18 mils the variation in spectral absorptivity was as much as 30 to 40%, especially in the 3 to 6 micron range.

- For film thicknesses above 3.18 mils, the most pronounced observation is the shift upwards in overall percent absorption of the films.

- The spectral absorptivities of powders containing carbon black varied little with thickness.

- An examination of a white powder coating indicated that its spectral absorption did not vary significantly with coating thickness values between 1.20 mils to 3.57 mils as illustrated in Figure -14. A major effect of titanium dioxide pigment is that it reflects and scatters radiation in the visible region giving hiding power. The reflectivity of coatings containing titanium dioxide is very high in the visible region, since the radiation does not penetrate very far into the coating. Thus, thickness does not have much effect on absorptivity in the visible region through approximately 3 microns. From 3 to 6 microns there are observable differences due to thickness.

Average Absorptivity

The effect of film thickness depends on how far the radiation penetrates the coating. If the film thickness is less than the depth of penetration, increasing the film thickness will affect absorption. Once the film thickness reaches a value where there is little radiation reaching the substrate, increasing film thickness will not affect absorption. Pigments that absorb or scatter radiation reduce penetration depth and thus reduce the critical film thickness where additional thickness has little effect.

Some Observations:

- For the thicknesses studied, all of the average absorptivities for the dark coatings were very high, and film thickness had no effect.

- Since there was no pigment in the clear coatings, the radiation penetrates much deeper in the coating. The effect of film thickness is significant, as can be seen in Figure 15.

- The effect of film thickness for the other coatings should fall between the two limiting cases.

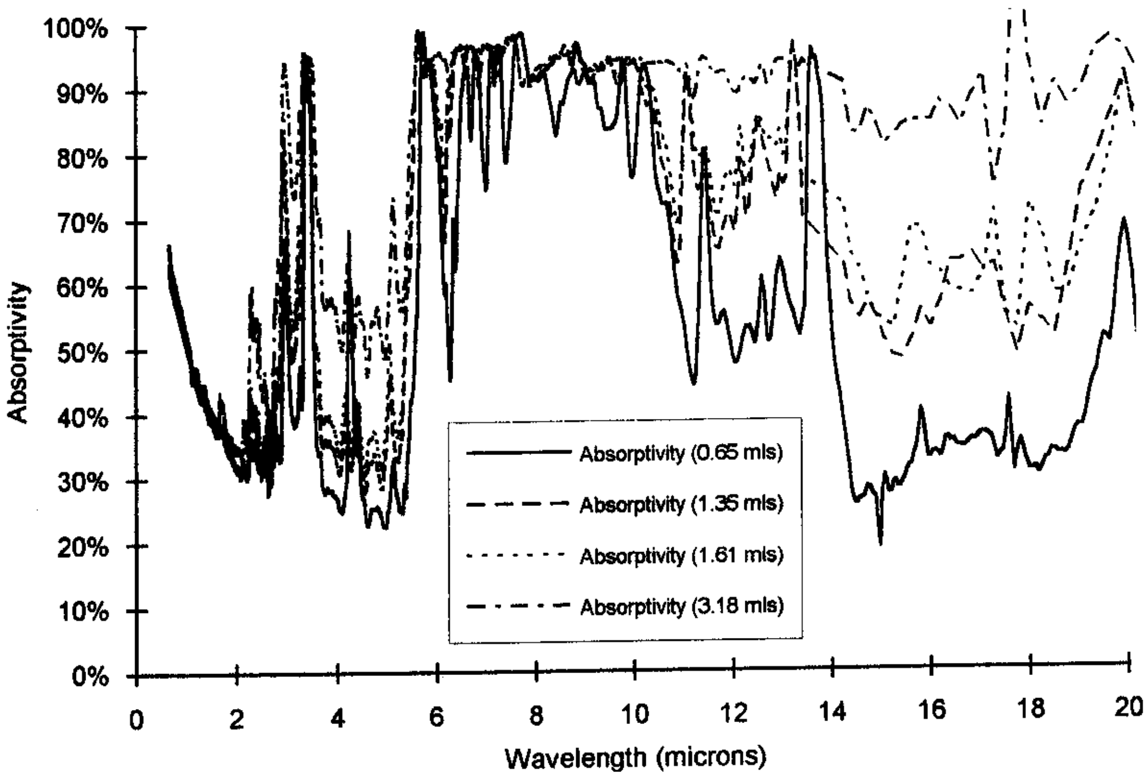

Figure 12: Infrared Spectral Absorptivity of Non pigmented Polymeric Powder Coatings Cured vs. Wavelength (Polyurethane 801060, Clear, High Gloss, High Glass Plate)

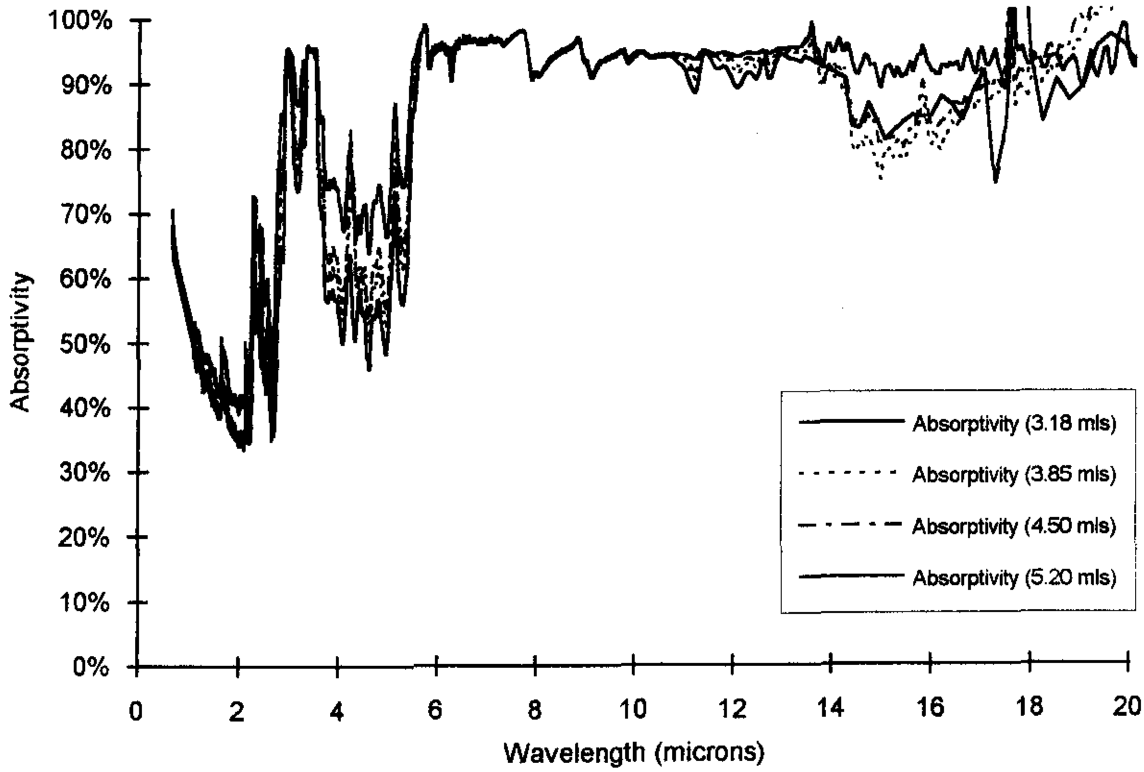

Figure 13: Infrared Spectral Absorptivity of Non pigmented Polymeric Powder Coatings Cured vs. Wavelength (Polyurethane 801060, Clear, High Gloss, High Glass Plate)

Effect of Curing

An example of the effects of curing on the absorptivity of powder coatings is shown in Figure 16. There was a rather pronounced difference in absorptivity between the cured and uncured clear polyurethane coatings in the 3 to 6 micron region. This may be due to curing reactions that change the compounds contained in the coatings sufficiently to affect absorptivity.

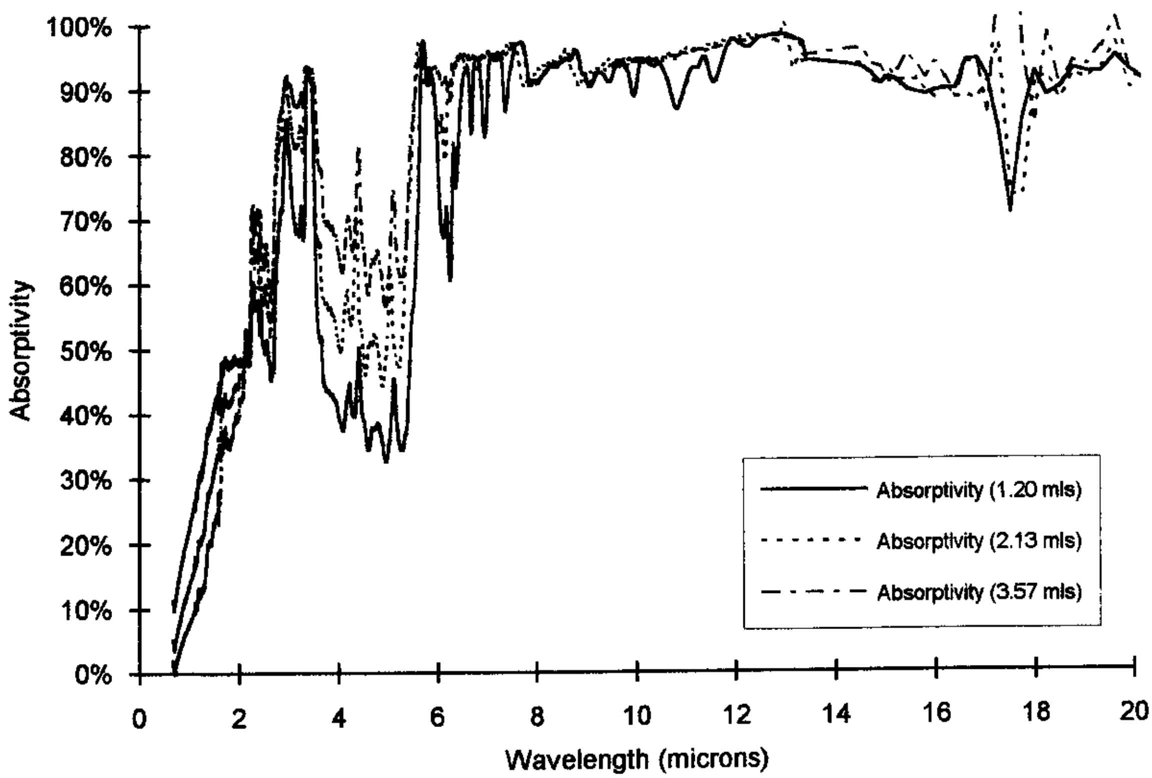

Figure 14: Infrared Spectral Absorptivity of Polyurethane Powder Coating Cured vs. Wavelength (Polyurethane 891433, White, High Gloss, High Glass Plate)

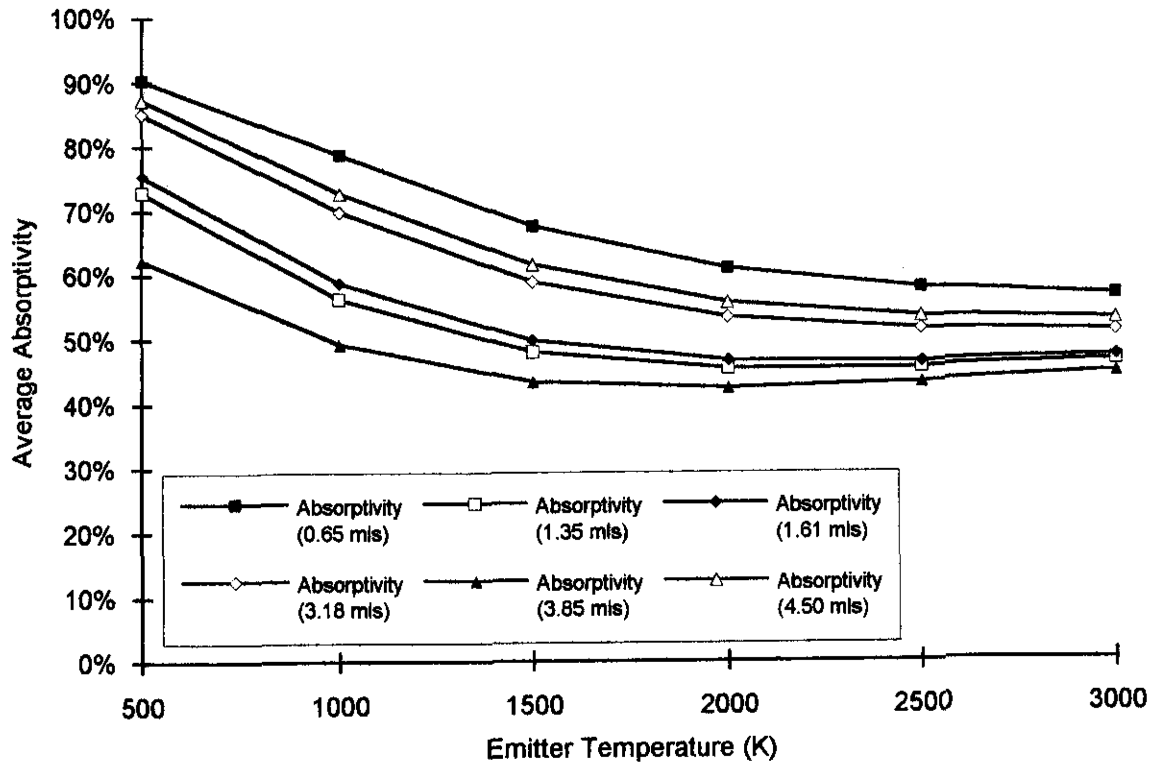

Figure 15: Average Absorptivity of Non pigmented Powder Coating Cured vs. Black Body Temperature Emitter (Polyurethane 801060, Clear, High Gloss)

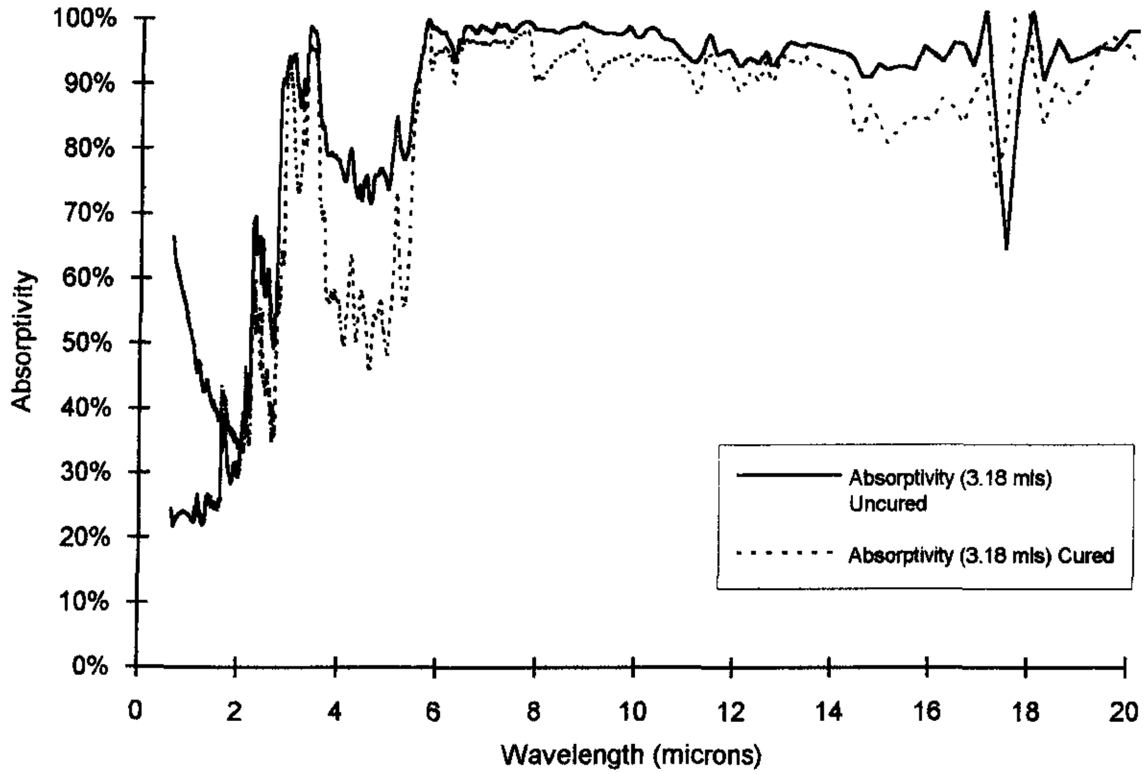

Figure 16: Infrared Spectral Absorptivity of Polyurethane Powder Coatings Uncured and Cured vs. Wavelength (Polyurethane 801060, Clear, High Gloss, High Glass Plate)

Average Absorptivity

The changes in the average absorptivity for the curing of the coatings showed that the effects of curing were small, as illustrated in Figures 17 and 18. The results show for unpigmented coatings that the uncured coating has higher absorptivity at lower temperatures. At 1500K, there is a crossover in the curves and the cured coating has a higher average absorptivity. This behavior is mirrored in the white coatings but the crossover point is at 1000K.

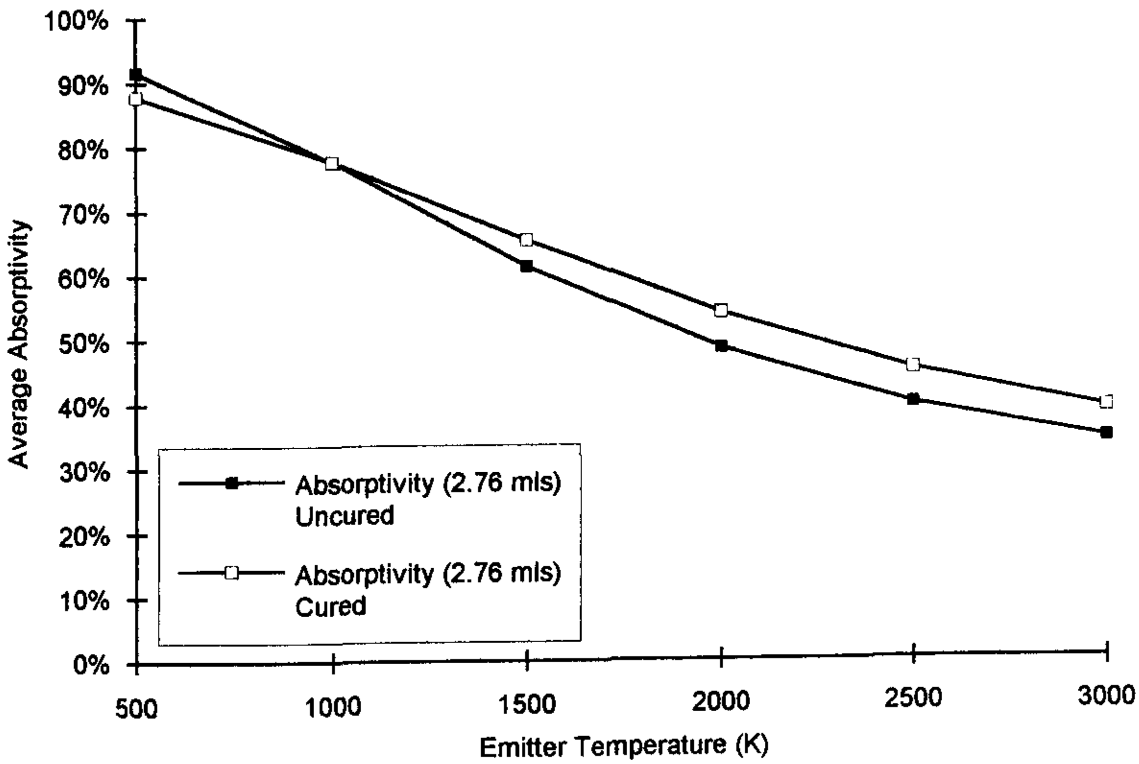

Figure 17: Average Absorptivity of Epoxy Powder Coatings Uncured and Cured vs. Black Body Temperature Emitter (Epoxy 891353, White, Flat Gloss, High Glass Plate).

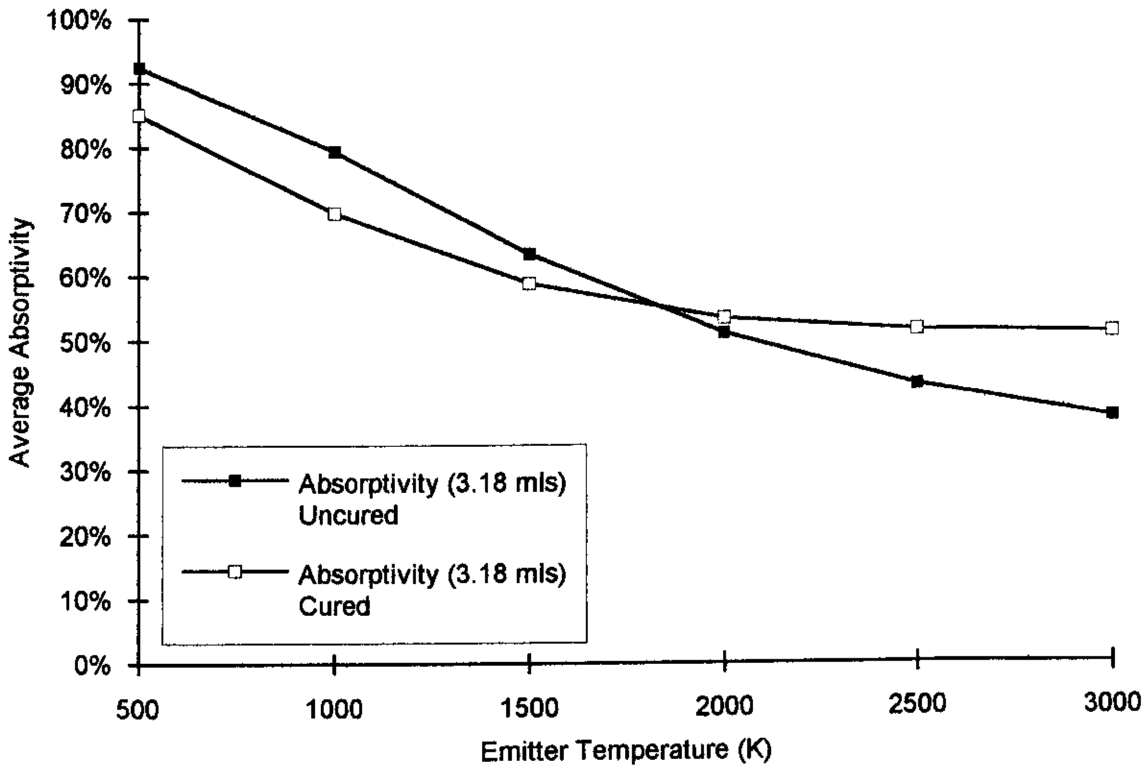

Figure 18: Average Absorptivity of Non pigmented Polyurethane Powder Coatings Uncured and Cured vs. Black Body Temperature Emitter (Polyurethane 801060, Clear, High Gloss).

Effect of Other Parameters

The effects of surface gloss and particle size of the powder coatings were examined. There appeared to be no effect on the normalized absorptivity of the powder coatings. The fact that gloss is defined in the visible region does not precipitate interpretation of this data in the infrared region. Further testing with other pigments would have to be performed to determine possible effects of this parameter.

CONCLUSIONS

- The type of polymer used for the resin in the powder coatings did not affect the overall absorptivities of the powder coatings. There were local differences due to the chemical make-up of the different components that make-up the polymers but trends were similar. Relatively high spectral absorptivity was found in the wavelength range of six microns to twelve microns with lower levels in the far infrared. The energy emitted by an electric infrared emitter falls off beyond twelve microns so that the variations in the far infrared were not that significant.

- Pigment appeared to have the greatest effect on the infrared spectral and average absorptivity of the powder coatings tested. The data showed that the role of carbon black in the infrared region was nearly complete absorption. Therefore, the type and temperature of the emitter did not have an effect on the average absorptivity of these powder coatings. The other pigmented and unpigmented coatings had lower average absorptivities when matched with high emitter temperatures. The effect of varying the amount of carbon black used as a pigment in the green coatings showed that even amounts as small as 0.05% can increase the absorptivity of the coating. The variation in the absorptivity for green epoxy, hybrid, and polyester illustrated this point.

- The effect of film thickness on spectral and average absorptivities depends on the pigment present in the coating. When carbon black was present in amounts greater than 0.6%, all of the samples were highly absorbent, and film thickness had little effect. For the unpigmented coatings, spectral and average absorptivities generally increase with increasing film thickness, but the effect is not large over the film thickness used commercially.

- The titanium dioxide used for pigmenting white powder coatings causes scattering in the visible region and it was found to continue in the near infrared. From 1.8 microns to the visible, the white powder coating's spectral absorptivity decreased toward zero. This indicated that the role of titanium dioxide in the near infrared region was to scatter radiation. The thicker the coating the more scattering it was capable of in the near infrared regions. This was illustrated by the crossover of the spectral absorptivity values of the thicker white epoxy coatings. The thin coating had a higher spectral absorptivity than the thicker one.

- The gloss and glass plate (flow viscosity) value were parameters that did not have a significant effect on the absorptivity characteristics of the coatings.

- The effect of the variation of the powder coating particle size could not be determined from this research because the carbon black in the coatings absorbed completely across the infrared region for the only samples for which we had definite, known particle size differences.

RECOMMENDATIONS

- Further spectroscopic examination of the other individual components (filler, binder, and polymeric resin) that make up a powder coating is needed. The average absorptivities of each of the individual components could be determined and could enhance in the manufacture of coatings that have optimal absorption throughout the infrared region.

- The characterization of pigments in the infrared region would increase the understanding of the effects of the pigment particles on the absorptivity characteristics of the powder coatings during curing. Examination of briquettes of individual pigments through the infrared region would provide a library of the types used and the potential for determining the effect on the curing of the coating before manufacture.

- The effect of different particle sizes of the powder coatings should be examined in greater detail to see if there are any significant effects..

Biographical Information

W.E. Pasley is a consultant with the Technology Applications Center (TAC) in Atlanta, Georgia. Mr. Pasley has 28 years experience in the fields of electric utility marketing, engineering, and research. His primary focus at the TAC is assisting manufacturers in developing new techniques to use in their manufacturing processes.

Mr. Pasley is an electrical engineering graduate from the Georgia Institute of Technology. He is currently pursuing a Masters degree in Technology Management.