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Effects of the Addition of Binder on the Packing Characteristics of Pigment Particles

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EFFECTS OF THE ADDITION OF BINDER ON THE PACKING CHARACTERISTICS OF PIGMENT PARTICLES

by

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EFFECTS OF THE ADDITION OF BINDER ON THE PACKING CHARACTERISTICS OF PIGMENT PARTICLES

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Western Michigan University, 1988

This study describes in a quantitative manner the relationships between coating structure and optical properties. Scattering coefficient, gloss and pore volume were measured after applying different blends of polystyrene spheres using various amounts of binder to transparent Mylar film. The coatings were prepared using four proportions of two sizes of polystyrene spheres and varying amount of two binders, starch and latex respectively. Optical properties of coatings were related to changes in coating structure. A scanning electron microscope was used to observe the structure and to facilitate void size measurement. The void size distribution correlated very well with the scattering and gloss values. Micrographs of the coating surface showed an apparent increase in pigment particle size at low levels of binder addition. The coatings with latex had higher gloss than with starch..

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CHAPTER I

INTRODUCTION

A paper coating is a composite material comprised of pigment, binder, and air. Important properties, including opacity, pick resistance, and ink receptivity, are complex functions of the properties of the components, their volume fractions, their sizes and shapes, and their structural arrangements. The manner in which pigment particles are packed and the distribution of binder and air spaces around them affect the properties of coatings.

Over the years, a considerable amount of research has been devoted to the field of paper coating. Most of this work, however, has been aimed at establishing relationships between coating process parameters (color composition and rheology, application method, substrate properties, drying conditions and finishing, etc.) and the properties of coated paper.

Many studies have been performed to examine the relationship between different coating variables but the complexity of the system makes it difficult to make definite conclusions. This study will try to explain how the addition of binder affects the packing characteristics

of pigment particles and, thereby, pore size, pore volume, and scattering coefficient.

Evaluating the changes in packing characteristics of particles by the addition of binder is very complicated in a real coating system. To effectively explore the interactions of particles the system must be greatly simplified. By eliminating all other variables any change in the structure of the coating could be directly related to the binder. This study will create a simple model system and explore factors that contribute to the optical properties of the coating. This study differs from the past studies because it is designed to examine only one aspect of packing, the effect of the addition of binder.

In order to eliminate any variation in base stock smoothness and porosity, Mylar (a polyester film) will be used instead of paper. It is very difficult to control the characteristics of natural pigments. For this reason synthetic polystyrene spheres will be utilized. With this type of synthetic pigment one has good control over the shape, size and chemical composition.

CHAPTER II

REVIEW OF LITERATURE

Introduction

Early studies of coating properties assumed that the structural arrangement was unaffected by the presence of the binder (1). According to Nadelman and Baldauf (2) coating adhesives are those materials which cause coating pigments to be bound to each other and to adhere to the substrate. The function of adhesives in fluid or semi-fluid coating colors is to help carry pigments in a dispersed condition and to govern or influence the flow behavior of a coating mixture. The term binder is used widely as a synonym for adhesive in paper coatings.

When studying the optical properties of paper coatings, the light-scattering efficiency of the pigment particles is important. The light-scattering depends on many factors: (a) particle size, (b) shape, (c) orientation, (d) size distribution of the pigment, (e) the difference between the refractive index of the pigment and binder, and (f) the distance between pigment particles in the coating. That distance is obviously a function of the pigment packing characteristics of the coating.

Packing Characteristics of Pigments

Borch and Lepoutre (3) in their study of light reflectance of spherical pigment particles in paper coatings, found that for each type of pigment there was an optimum size for maximum light scattering depending on the refractive index and wavelength of light. Many studies indicate that pigment particle size is most important for the scattering of light. However, more recent studies indicate that it is the packing of particles and subsequent pore size in the coating which is more important than the particle size itself.

Climpson and Taylor (4) determined that there was a strong correlation between pore size and scattering coefficient. They found that pore size ranging from 0.3 um to 0.9 um in diameter contributed significantly to light scattering of pigment coatings.

Alince and Lepoutre (5) studied the packing characteristics of binder-free clay, plastic pigments, and mixtures of clay and plastic pigments. They measured the light-scattering coefficient and porosity of these films. From the optical point of view it is often preferable to consider the pigmented coating as a dispersion of microvoids in a solid matrix. They concluded that the microvoids are the scattering species and the light-scattering efficiency depends on the number as well as the size of the voids. They found that the light scattering of

coating formulated from two different pigments depart from the value calculated assuming a proportional contribution, i.e., using the additivity rule ($S = S1.W1 + S2.W2$) where W is the weight fraction and S is the light-scattering coefficient.

Childs (6) describes the packing of unconstrained homogeneous spherical particles. He demonstrated that the particles pack in a very orderly fashion as long as no external forces are exerted on the particles. Particles scatter light at the air solid interfaces. Packing in flocculated systems gives more air surfaces than in well dispersed systems. Accordingly, in flocculated systems there should be more air surface to scatter the light, which could give higher scattering in dried films.

Cook (7) measured the pore size distribution, gloss and scattering coefficient for different sizes of (polystyrene spheres) plastic pigment particles. He found that the void volume even in the case of different particle sizes was approximately the same. With the large particles, the void volume was made up of a few large pores, while the smaller particles create the void volume with many small pores. The void volume that resulted from a mixture of two different-sized particles was primarily a function of the size ratio of the pigment particles used.

Effects of Binder on Coating Structure

The first attempts to describe the structure of paper coatings seem to date back to the 1950's. At that time paper coating scientists were particularly interested in the adhesive demand of pigment systems. "They were intrigued by the fact that very fine clay with a high specific surface area required no more binder than the coarser grades with less surface area to achieve the same pick resistance. It was usually accepted that specific surface area governed adhesive demand" (1).

Cobb (8) studied the pigment adhesive structure in the light of the work in similar fields, including soil and paint technology because the determination of voids was known to be of importance in these other fields. She used water, a strongly polar liquid with a high surface tension, and kerosene, a nonpolar liquid with a low surface tension, to measure the percent voids in packed pigment structure. She found that the percent voids measured with kerosene were 1.15 times the percent voids measured with water for the same packed pigment structure. In this study relating percent voids to the casein requirement, she demonstrated that relationship between the two can be expressed by the equation:

$$R = K\left(\frac{L}{L+V}\right) - C$$

where:

R = casein requirement in cc. per 100 cc. pigment

L = test liquid to fill voids in 100 grams pigment

V = volume in cc. of 100 gram pigment

K = a constant = 0.914 ; water as test liquid

C = a constant = 21.2 ; water as test liquid

Cobb (8) demonstrated that the coating adhesive demand of a pigment was entirely independent of its specific surface and particle size and depended upon the percent voids in the packed pigment structure.

Burke, Garey and Leekley (9) studied starch-clay films, PVA-clay films, and latex-clay films on a non-porous foil base to determine if the role of binder in a clay coating was actually simply the filling of space between the jammed particles of pigment (as had previously been assumed). They showed, "Small quantities of starch added expand the structure, and decrease film density. When more starch was added, at about 12-15 percent starch on weight of clay, film density passes through a minimum, then increases as the voids begin to fill with the binder".

Garey (10) proposed that the slow addition of protein allows the adhesive to gradually coat the particle creating a new type of surface on the clay (and other pigments).

Burke (11) in his study investigating the role of

adhesive in the structure of pigment-adhesive films, found that a latex present alone expands the film but this expansion increases monotonically with binder content. The first of these effects is evident at the low binder contents and the second is most apparent at the high binder levels as shown in Figure 1.

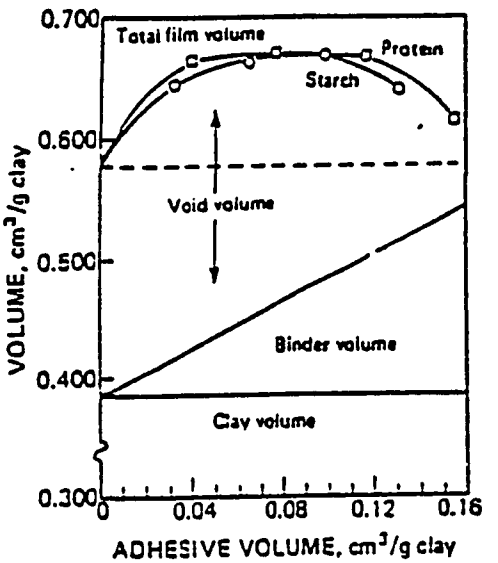

Figure 1. Effect of Increasing Adhesive Volume, Based on Weight of Clay, on Total Film Volume (11).

Grafton (12) attempted to follow what happens to the structure of clay coatings when a binder was added by determining the changes in the void volume and void size distribution as measured by mercury porosimeter. He showed that the soluble binder did not simply fill the voids present in 100 percent clay film, as had previously been assumed, but caused an expansion of the clay lattice.

Since the binder is added before film formation, it is perhaps better to regard the binder as preventing the clay particles from packing as closely upon drying as they would in its absence. The increase in void volume was accompanied by an increase in void size. Burke, Garey and Leekley (9) also observed that a styrene-butadiene latex caused a small but continuous "expansion of the coating film" as its level was increased.

Coating binder plays an important role in the establishment of the porous characteristics of the coating. Kaliski (13) and Trader (14) measured the scattering properties and the pore volumes of coatings containing adhesive applied to a black glass substrate. Kaliski (13) found that the scattering coefficient first increased or stayed constant, depending on the clay, and then decreased as the starch was added. There was a general agreement between the void volume and scattering coefficient at greater starch additions in that both decreased. These results were in general agreement with the porosimetry data of Grafton (12) who found void volume and size to increase at first and then decrease as the starch was added.

Linear correlations between scattering coefficient and void volume at high adhesive (starch) addition was also found in the work of Robinson and Linke (15). They did not measure coating porosity but calculated it from

the values of the centrifuged sediment volume of pigments, assuming that the binder filled the voids of a structure controlled solely by the natural packing of the pigment alone.

Trader (14) in his studies relating coating structure and coating performance found coating properties were more dependent on binder than on clay as long as the clay was dispersed to its lowest viscosity before binder addition. He found that the addition of binder caused formation of flocs or aggregates which increased or decreased scattering power depending upon the starting particle size distribution. Addition of binder then, effectively caused a shift in particle size distribution in the coarser direction which decreased gloss as if the clay had been a coarser clay to start with and no binder had been added. The effect of increase in pigment particle size and binder addition on gloss and scattering coefficient of coatings is shown in Figures 2 and 3.

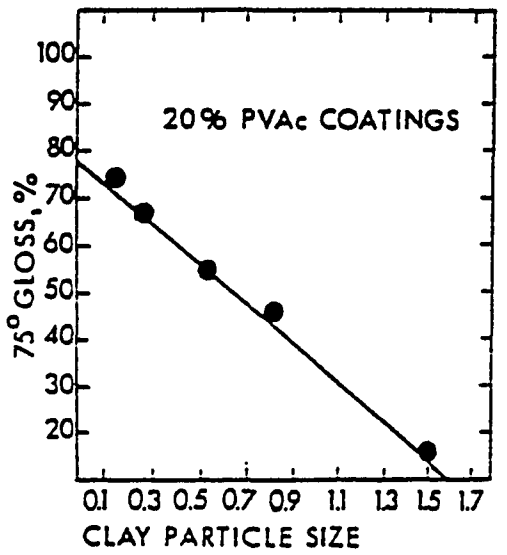

Figure 2. The Relationship Between 75 Degree Gloss and Clay Particle Size (14).

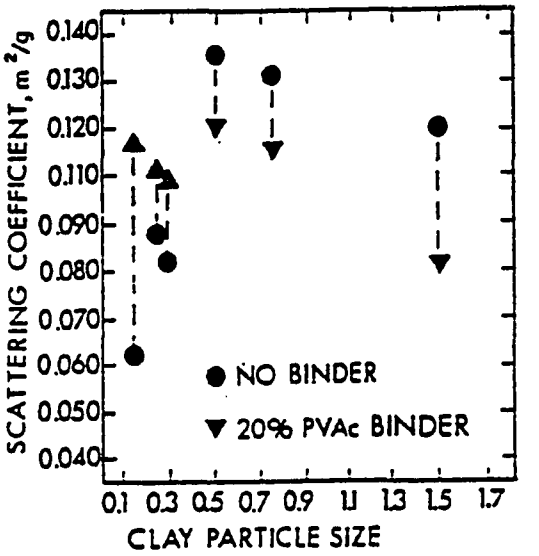

Figure 3. The Relationship Between Scattering Coefficient and Clay Particle Size (14).

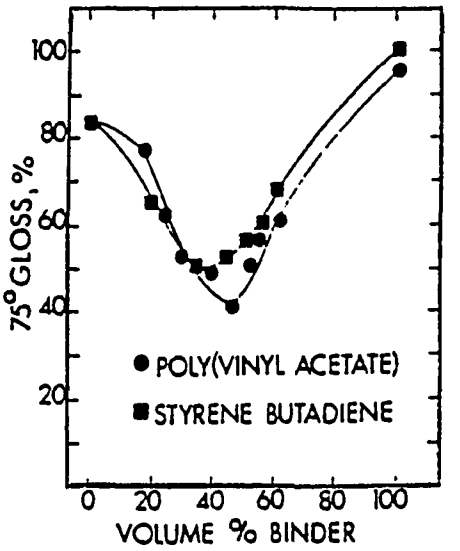

Figure 4. Values of 75 Degree Gloss as a Function of Binder Concentration (14).

Figure 4 shows that the gloss of coatings decreased with the addition of binders and the minimum occurred between 30 to 40 percent by volume binder concentration (based on critical pigment volume concentration). After this minimum, gloss increased rapidly until the binder concentration reached 100 percent. Trader (14) also found that coating porosity remained constant up to 10 pph latex addition and then decreased.

Garey, Leekley, and Hultman (16) studied the effects of mixed binder systems on the film volume and pore size distribution of isolated clay coatings on a nonporous substrate.

> Starch or protein can affect the structure of clay coating in two ways. The clay-binder film is originally expanded by a layer of the adhesive that adsorbs on each pigment particle and that prevents interparticle contact upon drying. The film may also be compacted by the shrinkage of binder as the concentration of the aqueous phase increases due to loss of water, especially during the later stages of evaporation. (P. 81)

Climpson and Taylor (4) developed a method for deriving the pore size distribution of clay coatings from measurements made on ultrathin cross sections. This method gave a distribution of the internal dimension of the pores which was appropriate to the interpretation of the light scattering properties of the coatings. The experiment showed that mercury porosimeter was not capable of giving such a result. "Although mercury porosimeter has been widely used in the study of kaolinite systems, it

is generally accepted that distribution of pore entrance diameter is obtained which can be very different from the true internal pore dimensions".

Kline (17) in his study of adhesive pigment interaction found that the latex-pigment systems do not fit the starch-pigment interaction theories. Dalal and Kline (18) studied starch-clay coatings to establish the relationships between the degree of dispersion of pigment particles in a coating color and the scattering and relative pore volume properties of dried film produced. They found, "At low levels of binder (starch) addition, the better dispersion produced reduced scatter; but as the starch level was increased, the dispersion effect was masked by the starch filling in voids between the particles".

According to Lepoutre (1) soluble binders are believed to form an adsorbed layer around clay particles, thereby increasing their interparticle distance. Additional binder simply accumulates in the interparticle voids, without otherwise affecting the structure. In his study of optical properties and structure of clay-latex coatings Lepoutre (1) measured coating thickness, scattering coefficient, and compared freeze-fractured cross-sections of the coating at small increments of binder level. He concluded that the addition of latex to a well-dispersed clay causes changes in the surface and

bulk structure of the coatings, resulting in a change in optical properties.

After a study of synthetic binders to correlate the optical properties and coating structure, Lepoutre and Rezanowich (19) proposed that the solid particles in the latex may interfere with the close packing of the clay particles. They concluded that the addition of a latex to a well-dispersed clay causes changes in the surface and bulk structure of the coating, resulting in changes in optical properties.

Sasagawa, Tsuji and Hirai (20) in their study of latex properties on paper coating structure, concluded that Tg (glass transition temperature) and gel content of the latex had a great influence on latex migration and film formation even if coated papers were prepared under the same conditions of color solid content and drying temperature. They also suggested that the factors other than Tg and gel content of latex (such as particle size and distribution and interaction between latex particles and pigments) should be taken into consideration.

Paper Coating Adhesives

A number of materials are available as binders for pigment coating. These can be divided into two major classifications, soluble and synthetic polymers. Two types of soluble binders are commercially available in dry condition: carbohydrates such as modified starches and derivatives of starch and cellulose, as well as proteinaceous materials exemplified by soy protein. Synthetic binders are commonly used in the form of latexes such as styrene-butadienes, acrylics, butadiene-acrylonitriles and vinyl acetates.

Starch is the most widely used paper coating binder. It represents approximately 60 percent of the total coating binder used in United States. Most starches contain two related chemical substances, amylose and amylopectin, which are polymers of anhydro-glucose units. Both compounds consist of pyranose rings held together by alpha glucosidic linkages. These linkages permit flexibility to the starch molecules, enabling them to coil and twist.

The amylose fraction has a greater pigment binding strength than the amylopectin (branched chain) fraction, but has a greater tendency to increase in viscosity and yield value with time. When the amylose fraction is modified to lower viscosity, it tends to lose strength much more rapidly than the amylopectin fraction. For this

reason, it is desirable to use starches containing a minimum of amylose. The composition of most starches used for paper coating is 74-78 % amylopectin and 22-26 % amylose. For this study we will use hydroxy-ethylated starch. Ethylated starch is a good film former, resistant to amylose formation, has good binding ability, and is commonly used in paper coatings as a pigment binder.

Latexes are colloidal dispersions of synthetic polymers in water. Latexes are incorporated into formulations to improve the performance of the coating color and/or to impart special characteristics to the finished coating. The styrene-butadiene polymers are good film formers and are widely used as binders in pigment coating. Probably the most significant change in performance of latex occurred in the late 1950's with the addition of vinyl acid to the polymer chain. This change has a very beneficial effect on the performance of the latex, not only the final coated product, but also in the wet coating formulation. For this study we will use styrene butadiene latex binder.

Measurements of Packing

Void Volume

Leskinen (21) measured the hydraulic circular diameter of the pores using mercury porosimeter. She measured the porosity in binary mixture of spherical particles and concluded that the structure also affects the strength properties of coatings in which single and conjugated pores are of importance. The absorption properties are influenced only by the conjugated pores.

Gary, Leekley, Hultman and Nagel (22) measured the pore volume using mercury intrusion method and gas drive method to determine their suitability for use on pigment coatings. Both methods expressed pore size as the effective cylindrical diameter. They found, "The calculation of pore size distribution from gas flow data depends on highly idealized models which leave the validity of the distribution in considerable doubt." In the mercury porosimeter, "Because the path of mercury entering in the voids is not known, it is not possible to state the extent to which the pores are accessible from the coating surface."

Lepoutre and Rezanowich (19) used an oil absorption method to measure the porosity of coatings by gently applying a high vacuum oil of known density over the surface of the coating and allowing it to penetrate.

Porosity (volume of oil absorbed divided by the total volume of the coating) was then simply calculated from the known density of oil, pigment and binder. Because of the limitations in the use of mercury porosimeter in paper coatings, the oil absorption method will be used to measure pore volume.

Scattering Coefficient

Brightness and opacity are two of the most important optical characteristics used to define the optical properties of coatings. The interrelation of brightness (reflectivity) and opacity and their dependence upon more fundamental factors have been studied extensively. Clark and Ramsay (23) presented a method based on Kubelka-Munk equations for predicting the brightness and opacity of coated sheets. They found, "The predicted and measured values were almost identical and well within the experimental error of measuring standard brightness and Tappi opacity".

The equations developed by Kubelka and Munk are particularly useful in mathematically analyzing the aggregate values of brightness and opacity (24). Derivation of these equation was presented by Steele (25). Due to the complexity of the expressions, these direct solutions are entirely impractical for practical work. Therefore, these equations were transformed by means of

hyperbolic functions into expressions which are more rapidly solved. Using this expression, the amount of labor involved in calculating the points for the curve is greatly reduced. Starr and Young (26) acknowledged the limitations involved in the determination and use of Kubelka-Munk constants and based on these equations developed the Variable Rg method to measure the scattering coefficient (S) and absorption coefficient (K). Therefore Variable Rg method will be used in this study to measure light-scattering of coatings.

Void Size Distribution

Void size distribution is among one of the most important factors influencing the structure of coatings. Attempts have been made to accurately measure this. Lord and Willis (27) calculated the mean pore diameter of the air bubble in aerated concrete. While originally developed for study of concrete, the method is applicable to any system containing spherical dispersoids. Climpson and Taylor (4) measured the pore size distribution using a transmission electron microscope and the then processed the plates obtained on an image analyzing computer. They showed that the data for pore size distribution with this method were in better correlation with scattering coefficient than data obtained with mercury intrusion.

Summary

This review of the literature not only shows general concurrence that there is some form of pigment-binder interaction but also some disagreement as to the nature of the interaction. Cobb (8) demonstrated that coating adhesive demand of a pigment is entirely independent of its specific surface and particle size and depends upon the percent voids in the packed pigment.

Kaliski (12) observed that the scattering coefficient first increased or stayed constant, depending on the clay, and then decreased as the starch level was increased. These results were in general agreement with the porosity data of Grafton (11) who found void volume and size to increased at first and then decreased as the starch was added. He showed that a soluble binder did not simply fill the voids present in a 100 percent clay film but caused an expansion of the clay lattice.

Linear correlations between the scattering coefficient and void volume at high adhesive (starch) level is also found in the work of Robinson and Linke (14). Lepoutre (1) explained the expansion of the clay lattice as binder forming an adsorbed layer around the pigment particles, thereby increasing the interparticle distance in the clay-starch coating.

The basic disagreement is whether the binder is filling the voids by being trapped in the interparticle

spaces or forming an adsorbed layer around the pigment particles, thereby increasing the interparticle distance. More likely, both mechanisms are occurring simultaneously depending upon the conditions. It is important to know why starch and latex behave in different manners. Knowledge of particular characteristics which are responsible for such behavior should be of value in the selection of a binder.

CHAPTER III

PROPOSAL

This experiment is designed to study the effect of the binder on coating structure. All other variables which could influence the coating structure are to be eliminated through careful experimental design. By eliminating all other variables, any changes in coating structure should be directly related to the type or quantity of binder used. A model system can be prepared using polystyrene spheres whose void volume and relative void size can be predicted. Therefore, measuring these results should allow conclusions to be drawn concerning the behavior of the binder.

If the addition of binder opens up the structure and increases pore size or void volume then it has relevance with the theory that binder forms an adsorbed layer around the pigment particles thereby increasing the interparticle distance. If the void size is reduced by close packing of pigments after the binder is introduced then it can be concluded that the binder is filling the voids or open spaces between the pigment particles without otherwise affecting the structure of the coating.

In order to eliminate any variation other than binder, care has been taken to design the experiment. The paper surface has irregularities in the structure and variable liquid absorption properties therefore it would be very difficult to identify if the changes in the structure of coating surface are because of the coating film or the base stock. To eliminate the variation in base stock Mylar was used instead of paper. It is very difficult to control the size and shape of natural pigments, therefore to eliminate these variations, polystyrene spheres were used.

Based on Cook's work the pigment blends will be selected to study the effect of the addition of binder on optical properties such as opacity and scattering of light as well as the void structure of the film produced.

CHAPTER IV

EXPERIMENTAL APPROACH AND RESEARCH DESIGN

Coating Preparation

For this study, polystyrene spheres (plastic pigments) were used in place of natural pigments. These plastic pigments are uniform, hard, light weight, spherical, polystyrene polymer particles. This material is synthetic, enabling control over the size, shape, and weight. The polystyrene sphere also offers control over electrical charge, surface activity, compatibility, solubility and fusion temperature. The specific plastic pigments used in this experiment were Lytron 2705 (0.67 um particle diameter), Lytron 2503 (0.40 um particle diameter), Lytron 2203 (0.20 um particle diameter), and Lytron 2101 (0.12 um particle diameter). All pigments had a specific gravity of 1.05 gs/cu.cm. These particles are also nonfilm-forming, hydrophobic and carried an anionic charge.

The plastic pigments come already dispersed in water at 50 % solids, eliminating variations due to dispersing a coating system. However, with the pigments at only 50 % solids, the final coating had a very low solids level.

low solids level. This made it difficult to control coat weight with the Mayer rod. The only viable solution was to make up many samples, and then choose those samples with the most desirable coat weights.

To decide what pigment blends should be used, coatings were made without introducing binder. The blends used are shown in Table 1. They were 0.67 um and 0.40 um, 0.67 um and 0.20 um, and 0.67 um and 0.12 um diameter particles in the proportion 0-100, 5-95 , 10-90, 15-85, 20-80, 40-60, 60-40, 80-20, 100-0 percent respectively. These pigment blends and proportions were based on Cook's thesis (7).

Table 1

Scattering Coefficient of Pigments

S.No.	Pigment Blend	Size Ratio	Scattering Coefficient
1.	Blend "A"	100% (0.67 um)	0.182
2.	Blend "B"	90% (0.67 um) 10% (0.20 um)	0.145
3.	Blend "C"	80% (0.67 um) 20% (0.20 um)	0.125
4.	Blend "D"	60% (0.67 um) 40% (0.20 um)	0.108

Four coatings were selected having a pore size large enough to scatter light (A), second and third (B) & (C) barely large enough pore size to scatter light and fourth

(D) having pores too small to scatter light as shown above in Table 1.

Coating Application

The desired amount of each pigment was mixed and the desired amount of binder was added to the blend. With each pigment blend both starch and styrene-butadiene were added as binders. For this study we used starch (Penford Gum 280) starch and latex binder (Dow 620 A) latex binder. The coating mixtures were dispersed using a slow mixer ensuring that there was no air entrained in the coating. The substrate used was Dupont 4000 Mylar film with a weight of 72 gs/cu.cm. Mylar is a clear plastic film made from polyethylene terephthalate and is also virtually impermeable to the liquid phase of most chemicals and reagents. The substrate was cut into 8x12 inch square rectangles and then mounted on a draw-down board.

The draw-downs were prepared using a number fourteen Mayer rod. After the coating was applied, the Mylar was transferred to a cutting board. On the cutting board, two inch diameter circles were cut from the sheet using an arc punch. The mylar was cut while the coating was still wet because the coating was so brittle when it dried that it could not be cut without causing it to flake off. After the circles were cut, they were allowed to dry at room temperature. Once dry, they were placed in a conditioning

room and conditioned overnight at 50 % relative humidity and 25 C. After the coatings had been applied, dried and conditioned, ten samples with uniform coat weight and good surface were selected for each coating formulation to be tested.

Testing

Determination of Coat Weight

An accurate weight for each circle was measured for the determination of coat weight. The weight of the uncoated Mylar had already been determined, allowing one to subtract that weight from the weight of the coated circle to get a measurement of the amount of coating applied. Coat weight was calculated as shown below.

$$CW = (TW - MW) \times 493.38$$

Where: CW = Coat Weight (g/sq.m.)

TW = Total Weight (g)

MW = Weight of Mylar (g)

Determination of Scattering Coefficient

A Technidyne brightness tester was used to obtain the reflectance values of each coating over two different backings, white (having 72.9 % brightness) and black (having 3.68 % brightness). Once the coat weight and the reflectance of the coating over both black and white

backings were known, the scattering coefficient was calculated.

The scattering coefficient was calculated using the Variable Rg method (Detailed derivation of the formula used is given in Appendix A) using the following equations.

$$Ro = (Rw - Rgw)/(1 - Rgw * (1/Ri + Ri - Rw) \quad .....(A)$$

$$Ro = (Rb - Rgb)/(1 - Rgb * (1/Ri + Ri - Rb) \quad .....(B)$$

From equation (A) and (B) we have

$$Ri = \frac{- b - [b^{**}2 - 4 * (a^{**}2)]^{**} 0.5}{(2 * a)}$$

where:

$a = (Rb * Rgw - Rw * Rgb)$

$b = (Rb + Rgw) * (Rw*Rgb-1) - (Rw+Rgb) * (Rb*Rgw-1)$

Then:

$$S = \frac{1}{Cw * [(1/Ri)-Ri]} * \ln \frac{(1 - Ro*Ri)}{(1 - Ro/Ri)}$$

where:

Cw = Coat Weight (g/sq.m.)

Rb = Reflectance of coating with black backing (%)

Rw = Reflectance of coating with white backing (%)

Rgb = Reflectance of uncoated mylar with black backing (%)

Rgw = Reflectance of uncoated mylar with white backing (%)

Ri = Brightness (Reflectivity) of coating

S = Scattering Coefficient

For each coating slurry, ten circles were cut and measured, giving a total of ten values of scattering coefficient for each coating. These ten values were averaged to give a final scattering coefficient, and a standard deviation was determined in order to examine the variability of the results.

Determination of Pore Volume

Five of the above circles were used for the determination of the pore volume. A high-vacuum oil of known density (0.8567 gs/cu. cm. at 25 ^{o}C) was applied to the surface and allowed to penetrate. When the coating became uniformly translucent, the excess oil was removed by patting the surface with tissue paper until the gloss of the coated surface decreased, but stopped before the coating began to lose its translucency. The amount of absorbed oil was calculated by subtracting the previously determined weight of coating from the weight of coating saturated with oil. The percent volume occupied by the oil could then be calculated by dividing the weight of the oil by the density of the oil. The pore volume of the coating was calculated using the following equation.

$$PV = \frac{(O/SGo) * 100}{[(O/SGo) + (P/SGp) + (B/SGb)]} \quad (3)$$

where:

PV = Pore Volume (%)

P = Weight of pigment (g)

B = Weight of binder (g)

O = Weight of oil absorbed (g)

SGp = Specific Gravity of the pigment (g/cc)

SGb = Specific Gravity of the binder (g/cc)

SGo = Specific Gravity of the oil (g/cc)

Determination of Gloss

The gloss of the coatings was measured with a Gardner (Glossguard II) gloss meter. The device uses the standard 75^{o} angle of incidence as prescribed by TAPPI standards. A number of measurements was taken for each sample and the average gloss of three readings on one circle was recorded. Then the average gloss of five circles was calculated and the standard deviation of the gloss for that coating was determined.

Determination of Void Size Distribution

SEM micrographs of the coatings were prepared at 6 K magnification. The negatives of these micrographs were projected and the size of the voids was measured using a scale based on the size of the polystyrene spheres. The

void size distribution for 100 sq. um. area were then calculated for all coatings.

Data Processing and Analysis

Measurements for the determination of scattering coefficient, gloss and pore volume were taken and calculations were performed using the methods previously described. For ease of calculation, all data were entered into the mainframe VAX computer at Western Michigan University or an IBM micro-computer. The scattering coefficient calculations were made using a FORTRAN program. The pore volume and gloss were calculated using Lotus 123. The analysis of variance for the data obtained from these experiments for the scattering of light, gloss and pore volume was performed using the SAS statistical program on the mainframe computer.

The statistical model used for this analysis was three factor analysis of variance, split-plot design. The treatment for pigment blend was whole-plot treatment, for the binder type it was split-plot treatment, and for the amount of binder it was split-plot treatment nested in type of binder. The interactions between pigment blend, type of binder, and between the increments of binder added were taken into the consideration.

CHAPTER V

RESULTS AND DISCUSSION

The scattering coefficient of the mixture of pigment particles was measured varying the ratio of small particles to large particles. The plot of scattering coefficient versus pigment size ratio is shown in Figure 5. Error bars are equal to one standard deviation.

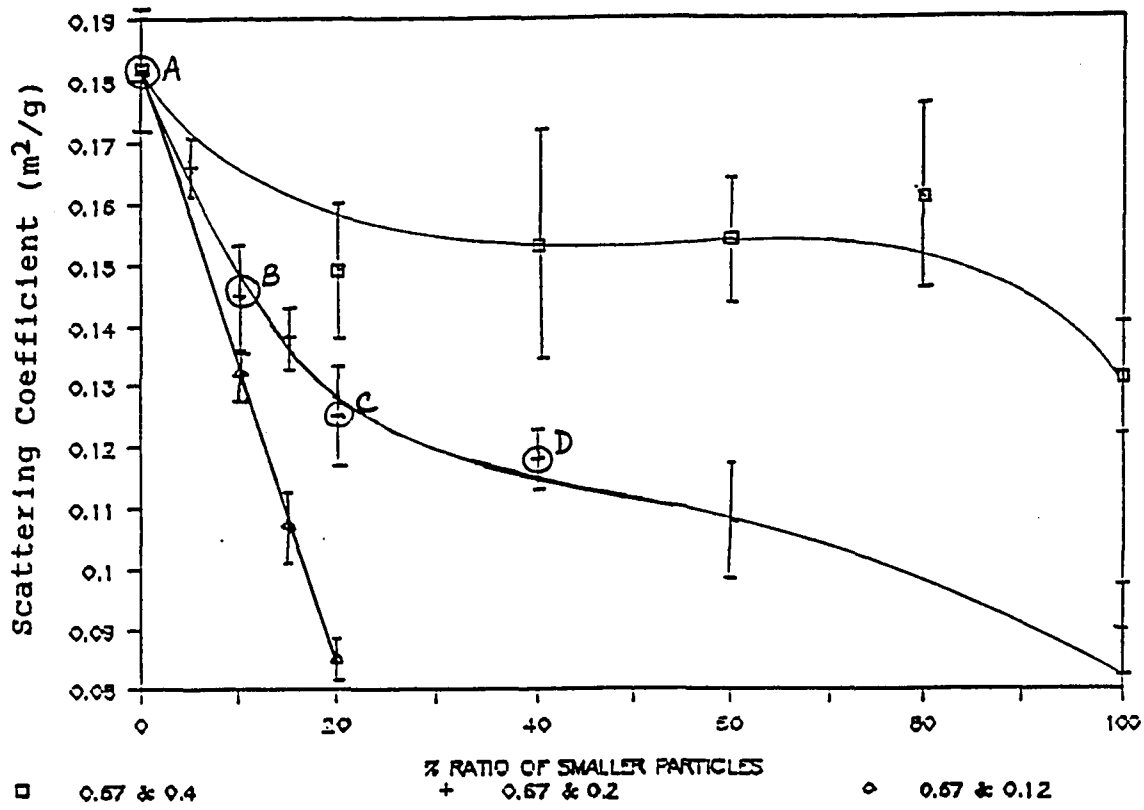

Figure 5. Scattering Coefficient Vs. Particle Size Ratio.

The highest scattering coefficient was achieved with a monodispersion of the 0.67 um particles and the minimum scattering coefficient was achieved with a monodispersion of the 0.20 um particles. The scattering coefficient dropped rapidly in coatings containing binary mixture (Figure 5) when as low as 5 % of the large particles were replaced with smaller particles. Even though the coatings still contained 95 % of what is defined as an optically efficient particle size, a high degree of light scattering could not be maintained. After this initial drop the scattering coefficient dropped slowly.

These data confirm Cook's conclusions (7) that the particle size is not the major contributor to the scattering of light. If the scattering coefficient was exclusively dependent on the pigment particle size, one would expect to see a linear drop in the scattering coefficient as the less optically efficient particles replaced more optically efficient particles.

Based on these data four pigment blends were selected for this study in order to produce coatings with a variety of pore sizes. The binder was then introduced into these blends at various proportions. The starch and latex binders used in this study had different specific gravities. The relative volumes of pigments and binders are more important than weights when studying the structure of coatings. Therefore, to maintain the same

structure of coatings. Therefore, to maintain the same volume for both binders it was important to use volume fraction rather than weight fraction.

Scattering Coefficient

Starch as a Binder

The data for the scattering coefficient for the Blends A, B, C, and D are summarized in Table 2 and Figure 6. The data clearly show that the scattering decreased with the increased amount of binder in all four blends. But in case of blends B and C there was a slight

Table 2

Scattering Coefficient of Coatings With Starch

Percent Binder	Pigment Blend A	B	C	D
0.00	0.182	0.145	0.125	0.117
0.66	0.178	0.148	0.123	0.108
1.32	0.161	0.146	0.128	0.114
1.99	0.158	0.151	0.124	0.113
3.97	0.164	0.132	0.132	0.112
5.96	0.145	0.138	0.120	0.111
9.93	0.127	0.110	0.100	0.091

(A=100 % 0.67, B=90 % 0.67 and 10 % 0.2, C=80 % 0.67 and 20 % 0.2, D=60 % 0.67 and 40 % 0.2 microns particles)

increase in scattering coefficient before it started to decrease. This shows evidence for the assumption, as indicated in the review of the literature, that the soluble binder formed an adsorbed layer around the pigment rather than filling the voids at lower concentration.

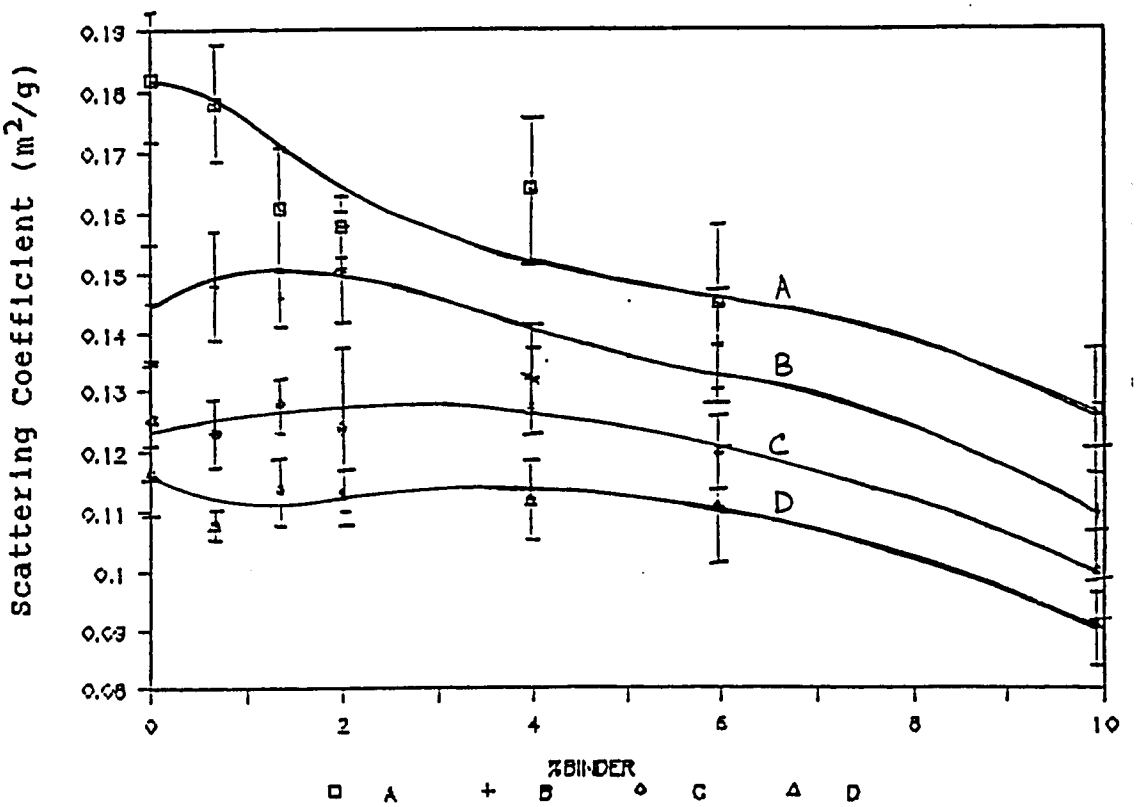

Figure 6. Scattering Coefficient Vs. Amount of Starch.

For the comparison of the scattering coefficients of the coatings with starch the data are plotted in Figure 6. The plot shows that there is an increase in scattering coefficient of coatings with blends B and C at low level of binder concentration.

Latex as a Binder

The data for the scattering coefficient of the coatings with latex are shown in Table 3 and Figure 7. These data show the same general effect. The scattering coefficient of the coatings with blend A decreased with the addition of latex as the binder while the scattering coefficient of pigment blends B and C increased at lower concentrations and then decreased as more binder was added.

Table 3

Scattering Coefficient of Coatings With Latex

Percent Binder	Pigment Blend A	B	C	D
0	0.182	0.145	0.125	0.117
1	0.173	0.150	0.124	0.111
2	0.161	0.144	0.135	0.114
3	0.161	0.147	0.130	0.116
6	0.131	0.119	0.109	0.104
9	0.116	0.105	0.103	0.101

(A=100 % 0.67, B=90 % 0.67 and 10 % 0.2, C=80 % 0.67 and 20 % 0.2, D=60 % 0.67 and 40 % 0.2 microns particles)

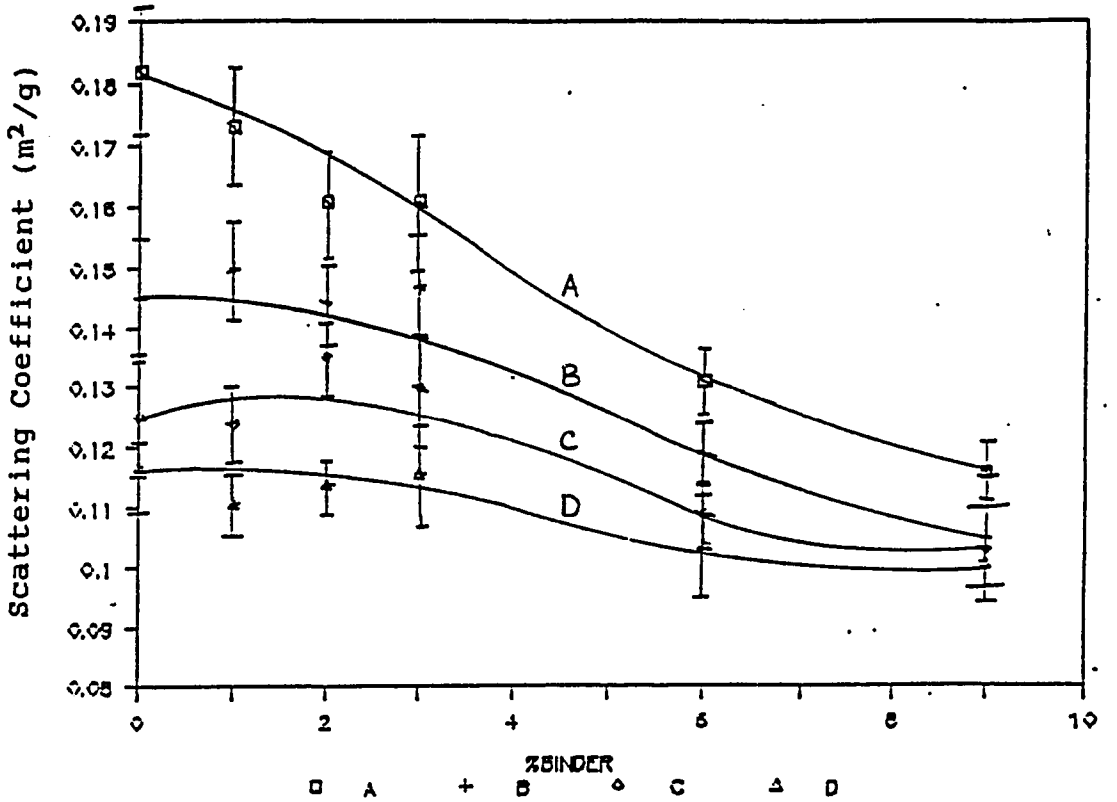

Figure 7. Scattering Coefficient Vs. Amount of Latex.

These plots show evidence of the change in bulk structure of coating by the addition of binder as suggested by the literature. The light-scattering increased at low level of binder due to an expansion in structure and decreased at higher level of binder indicating a shift in pore size from optically efficient pores to smaller pores. These results could result from binder adsorption at low levels and void filling at higher levels.

Summary of Scattering Coefficient

The results are plotted for comparison of scattering coefficient of coating with starch and latex in Figures 8, 9, 10 and 11 for blends A, B, C and D. The difference between the scattering coefficient of coatings with starch and latex with blend A is greater than B, C, and D at higher level of binder as shown in Figure 8 below.

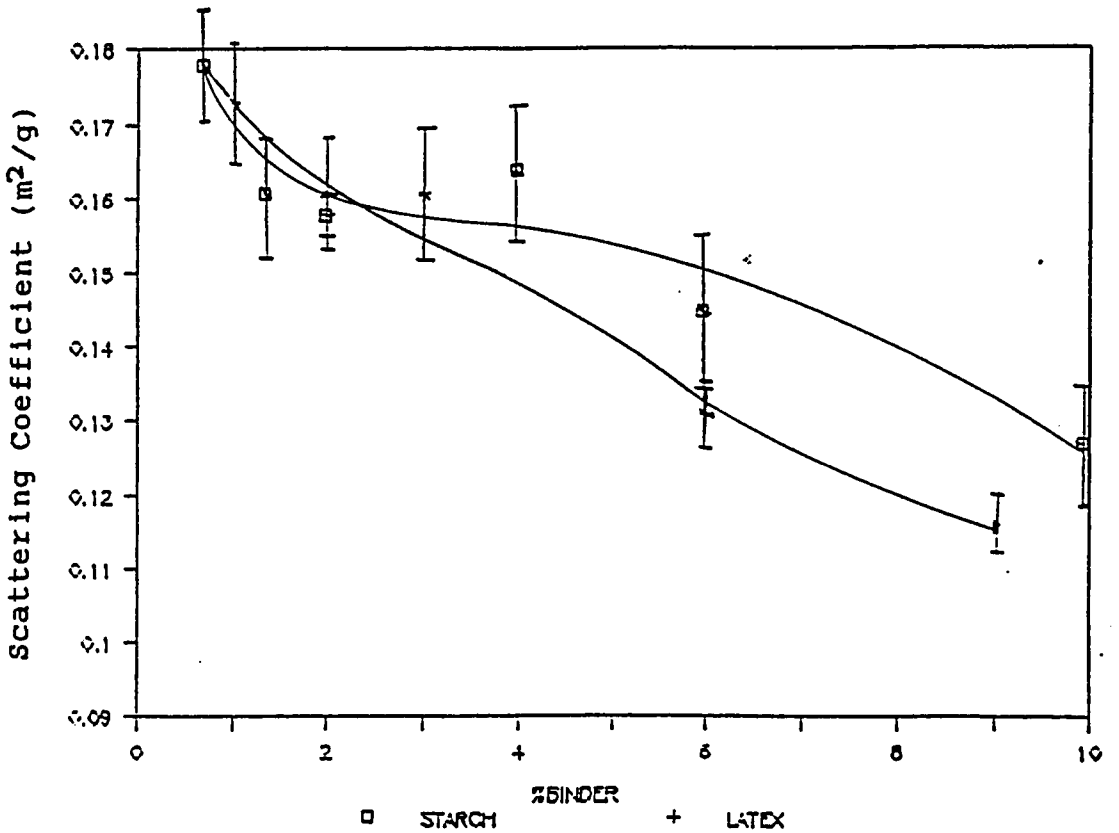

Figure 8. Scattering Coefficient Vs. Amount of Binder With Blend "A."

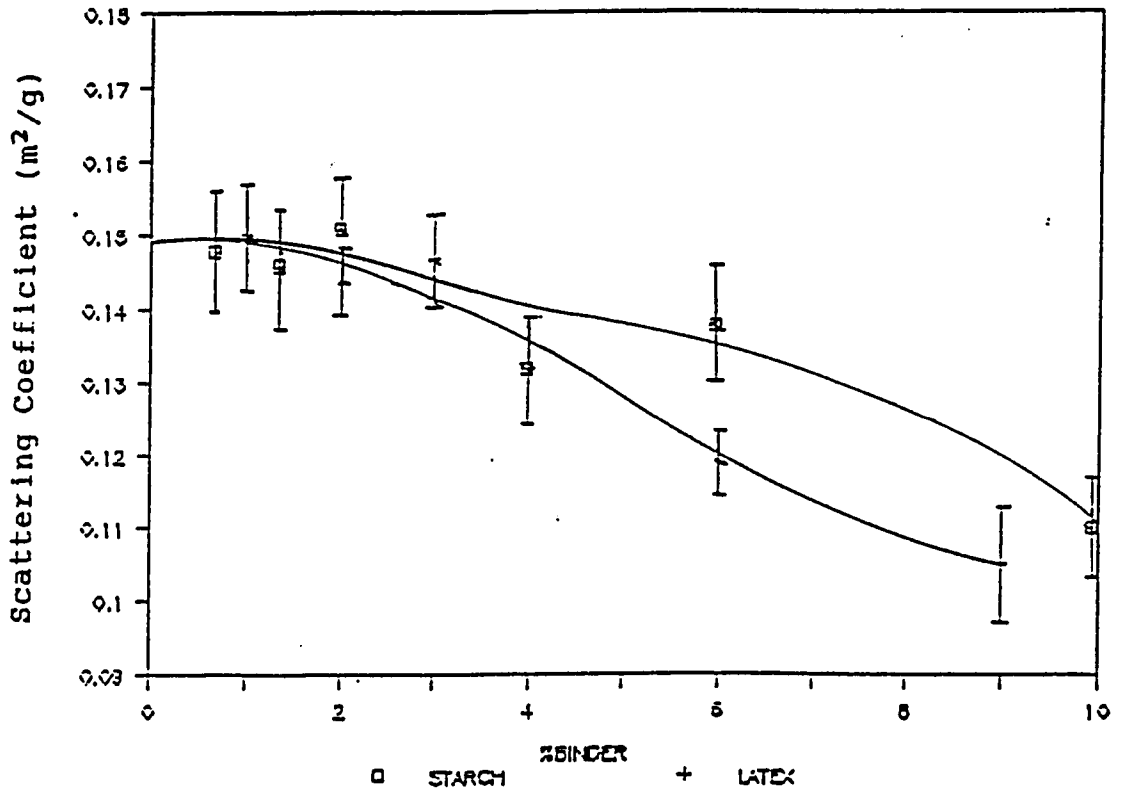

Figure 9. Scattering Coefficient Vs. Amount of Binder With Blend "B."

In Figure 9 the scattering of coating with latex drops rapidly as the binder level is increased. Coatings with starch in this case had a fairly linear drop in scattering following a little increase at 2 % starch which again indicated the change in pore size.

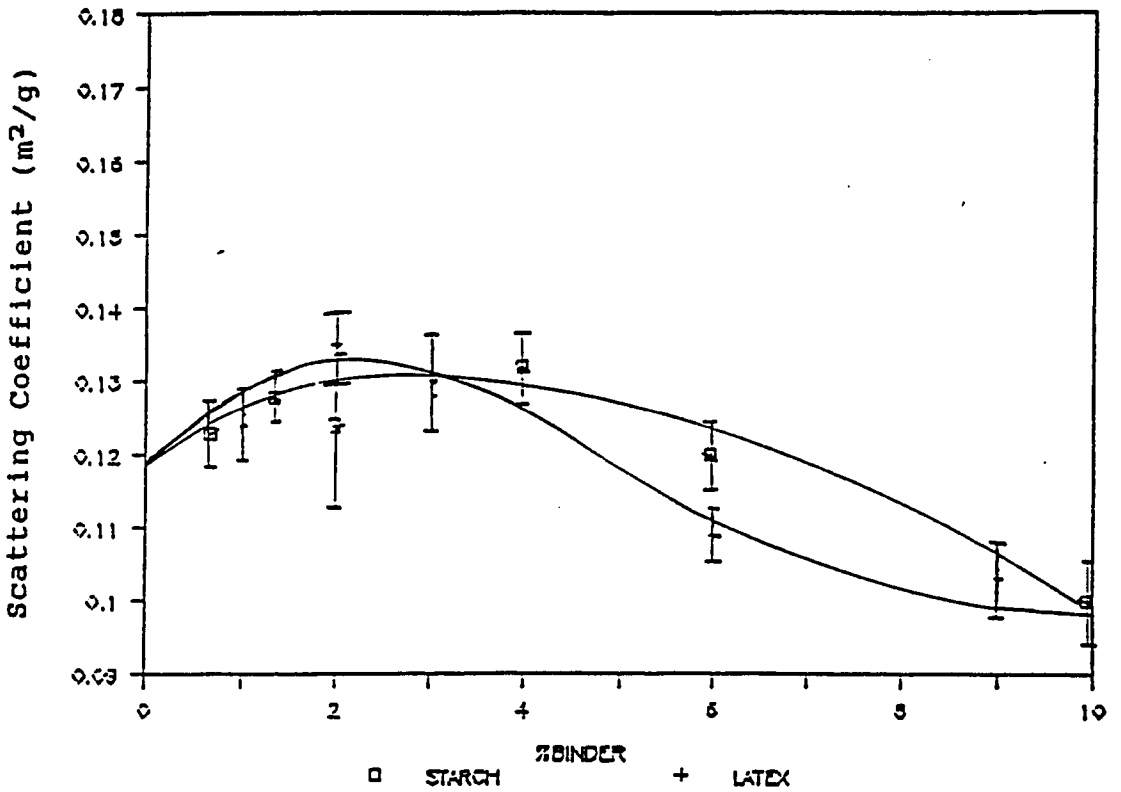

Figure 10. Scattering Coefficient Vs. Amount of Binder With Blend "C."

In Figure 10 the scattering coefficient of coating with blend C and latex increased until 2 % binder and then decreased as binder concentration was increased. With starch the change in scattering was relatively less, indicating that there was no change in the number of optically efficient pores. This indicates an initial increase in pore size due to increased pigment spacing, followed by filling of voids.

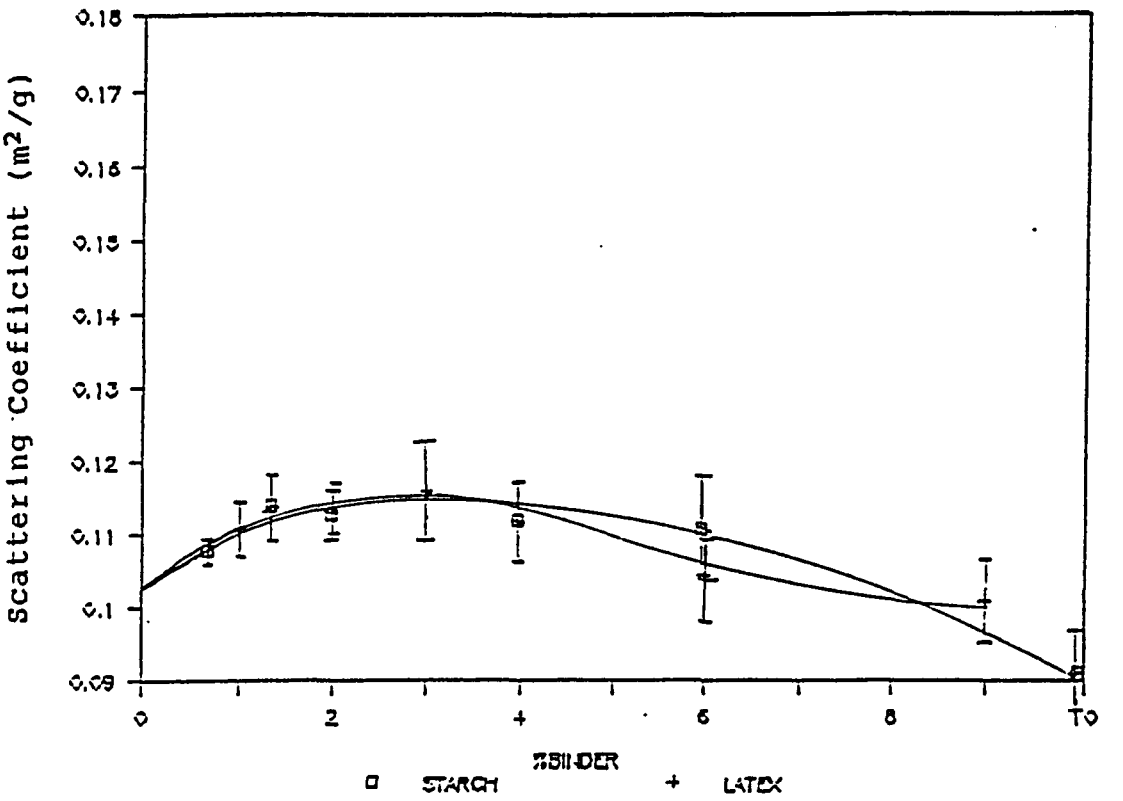

Figure 11. Scattering Coefficient Vs. Amount of Binder With Blend "D."

In the blend D, (Figure 11), scattering coefficient showed an increase with both binders before it started to decrease. There was no significant difference between the scattering coefficients of coatings with starch and latex as the error bars (equal to one standard deviation) are drawn.

The amount of light scattering can be related to the total number of pores of effective size. Coatings which do not possess pores at or above this size scatter little light. The criteria for the development of good light

scattering is just the opposite of that for good gloss development. The light scattering of pigments (without binder) decreases as the particle size decreases but the gloss increases with the decrease in particle size.

It is quite conceivable that when the original porosity of a pigment blend is altered by the addition of binder, the light scattering coefficient changes, despite the fact that the pigment particle size remains constant as stated by Alince and Lepoutre (5).

Coatings which had large enough pores to scatter light experienced a loss in scattering with addition of binder. The loss was greatest with the initial addition and less at additions above two percent. The coatings with low levels of binder showed a slight increase in scatter followed by a decrease. The decrease in scattering coefficient indicates that the binder is filling the voids at high level of binder. These data indicate that the binder is causing an expansion of pore size. The increase in pore size could be explained by the binder coating the particles and causing an increase in effective pore size because of the increased particle size.

Pore Volume

Starch as a Binder

The data for the pore volume are given in Table 4 and Figure 12. These pore volume data indicate that pore volume dropped when smaller particles were increased which explains the drop in scattering coefficient with the increase in smaller particles.

Table 4

Pore Volume of the Coatings With Starch

Percent Binder	Pigment Blend A	B	C	D
0.66	36.5	32.9	34.2	27.5
1.32	38.9	35.4	31.9	36.4
1.99	34.6	34.0	28.9	32.9
3.97	34.2	28.6	34.7	35.7
5.96	34.4	33.7	27.3	25.8
9.93	28.8	24.2	37.4	21.4

(A=100 % 0.67, B=90 % 0.67 and 10 % 0.2, C=80 % 0.67 and 20 % 0.2, D=60 % 0.67 and 40 % 0.2 microns particles)

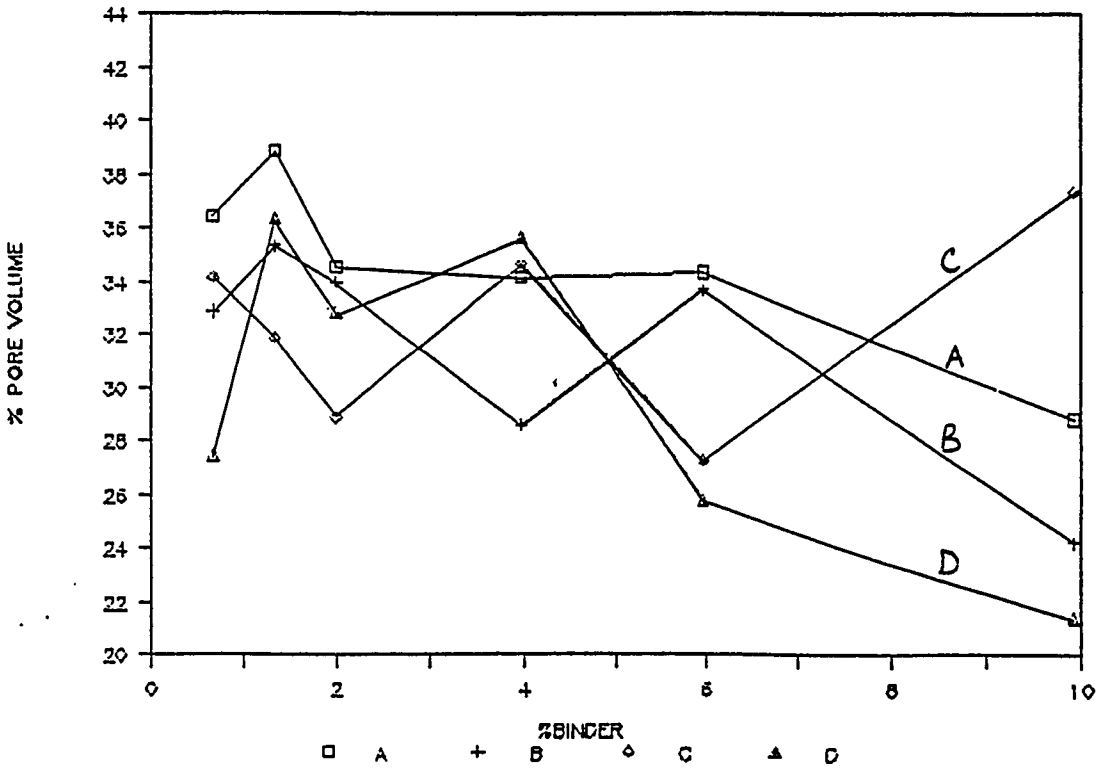

Figure 12. Pore Volume Vs. Amount of Starch.

The pore volume with blend A, B and blend D decreased with the increased addition of binder but there was an initial increase in pore volume at 1.32 % starch. The trend was not the same for the coatings with blend C. The scattered data points for the pore volume made it difficult to make definite conclusions based on these data.

Latex as a Binder

The data for the pore volume of coating are shown in Table 5 and Figure 13. The pore volume deceased as the particle size was decreased. Pore volume also decreased with the increased binder concentration.

Table 5

Pore Volume of the Coatings With Latex

Percent Binder	Pigment Blend A	B	C	D
1	34.2	29.9	33.3	34.3
2	42.7	36.1	33.1	27.5
3	34.0	34.0	36.8	36.1
6	34.4	26.7	30.9	27.6
9	29.9	27.8	23.5	27.6

(A=100 % 0.67, B=90 % 0.67 and 10 % 0.2, C=80 % 0.67 and 20 % 0.2, D=60 % 0.67 and 40 % 0.2 microns particles)

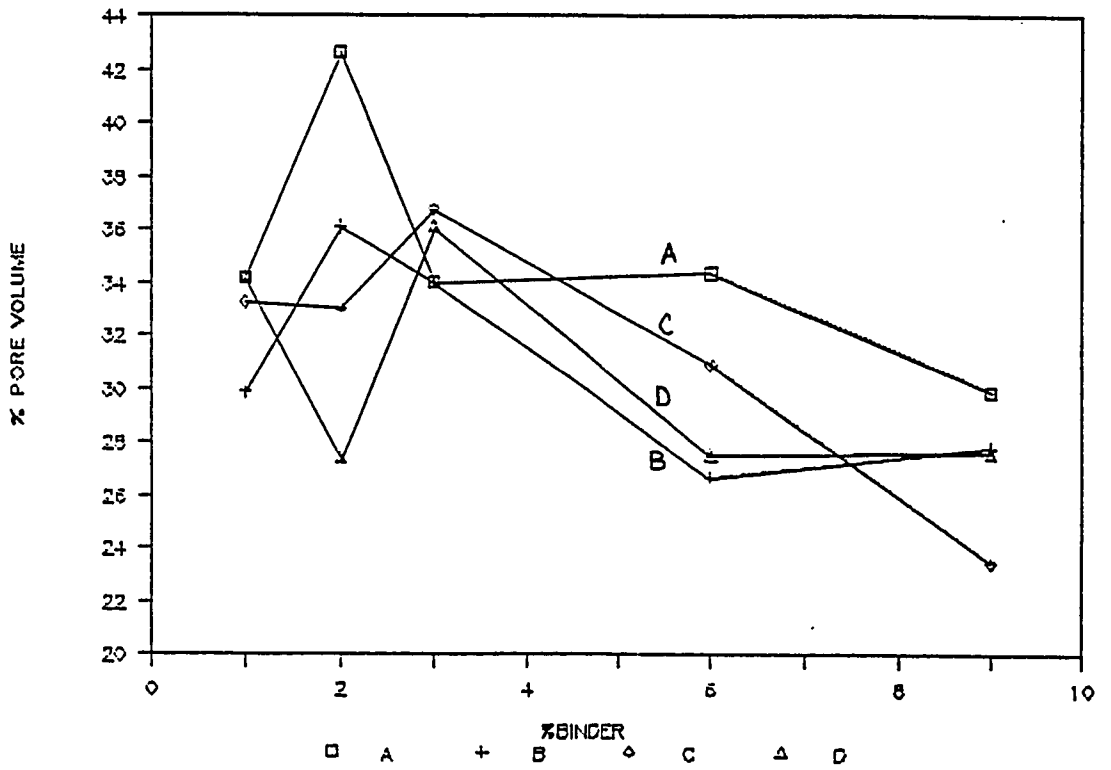

Figure 13. Pore Volume Vs. Amount of Latex

The pore volume data show a high degree of scatter, but still indicate a slight trend towards a decrease in pore volume with the addition of binder. There is a possibility that the voids are being filled but also that voids are being created by the adsorption of binder around the pigment particles at the same time. Therefore the relative pore volume remained constant even with the change in pore size distribution which led to the change in scattering coefficient.

Summary of Pore Volume

These data showed no significant difference in pore volume between the coatings with starch and latex. However, since scattering coefficient data showed a difference, one must conclude that there was a shift in relative pore sizes, i.e, reduction in the pores larger than 0.3 um and increase in pores smaller than 0.3 um. The pore volume decreased with the increase in binder concentration in coatings with starch and latex.

Gloss

Starch as a Binder

The data for the gloss of coating with starch are given in Table 6 and Figure 14. The gloss value of the coatings generally decreased with increased concentration of binder.

Table 6

Gloss of the Coatings With Starch

Percent Binder	Pigment Blend A	B	C	D
0.66	61.0	61.7	68.3	74.4
1.32	57.6	61.7	66.6	69.9
1.99	58.1	59.4	64.9	66.3
3.97	56.9	57.9	61.3	65.2
5.96	55.7	56.5	57.9	61.3
9.93	50.9	52.3	53.0	57.6

(A=100 % 0.67, B=90 % 0.67 and 10 % 0.2, C=80 % 0.67 and 20 % 0.2, D=60 % 0.67 and 40 % 0.2 microns particles)

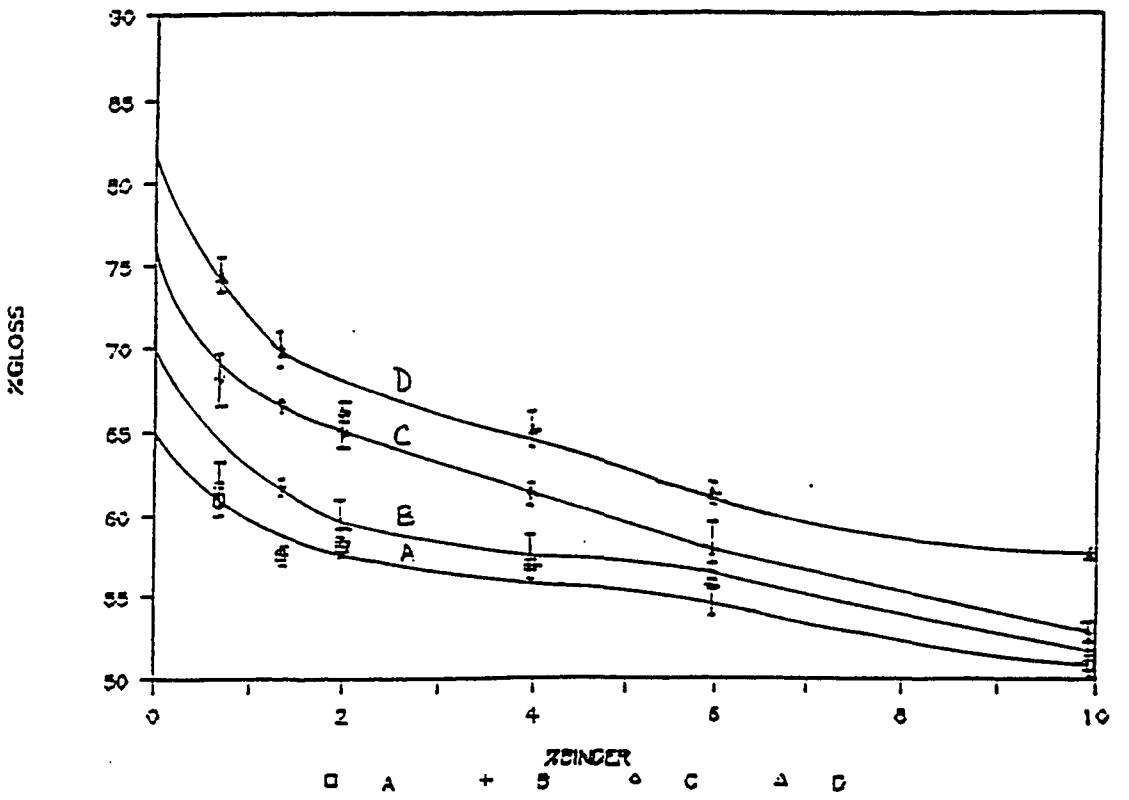

Figure 14. 75 Degree Gloss Vs. Amount of Starch.

The data and Figure show that gloss decreased rapidly when binder concentration was increased from 0.66-2.0 % and then decreased more slowly at higher levels. The earlier studies (1) and (11) suggested that the soluble binders form an adsorbed layer of binder around the pigment particles to cause an expansion in pigment system at low levels of binder.

Latex as a Binder

The data for gloss of coatings with latex are summarized in Table 7. The data show that the gloss of coating was increased when the amount of smaller particles increased as from blend A to blend D.

Table 7

Gloss of the Coatings With Latex

Percent Binder	Pigment Blend A	B	C	D
1	63.8	70.1	78.5	83.0
2	62.7	69.9	78.2	84.0
3	64.0	68.8	76.6	80.7
6	58.2	61.2	58.1	65.3
9	52.8	54.6	52.9	58.2

(A=100 % 0.67, B=90 % 0.67 and 10 % 0.2, C=80 % 0.67 and 20 % 0.2, D=60 % 0.67 and 40 % 0.2 microns particles)

The highest gloss was obtained from the coatings with blend D and the lowest gloss was obtained from coatings with blend A. Watanabe and Lepoutre (28) showed 75^{o} gloss to decrease rapidly with surface irregularities larger than 0.2 um. The gloss of the coating with latex did not rapidly decrease as in the coatings with starch. This could be due to the shrinkage in binder upon drying.

Since gloss goes down, one must conclude otherwise; perhaps binder: (a) causes flocculated clusters to form, (b) causes attachment points during drying to resist tight packing, or (c) increases viscosity of continuous phase to resist tight packing.

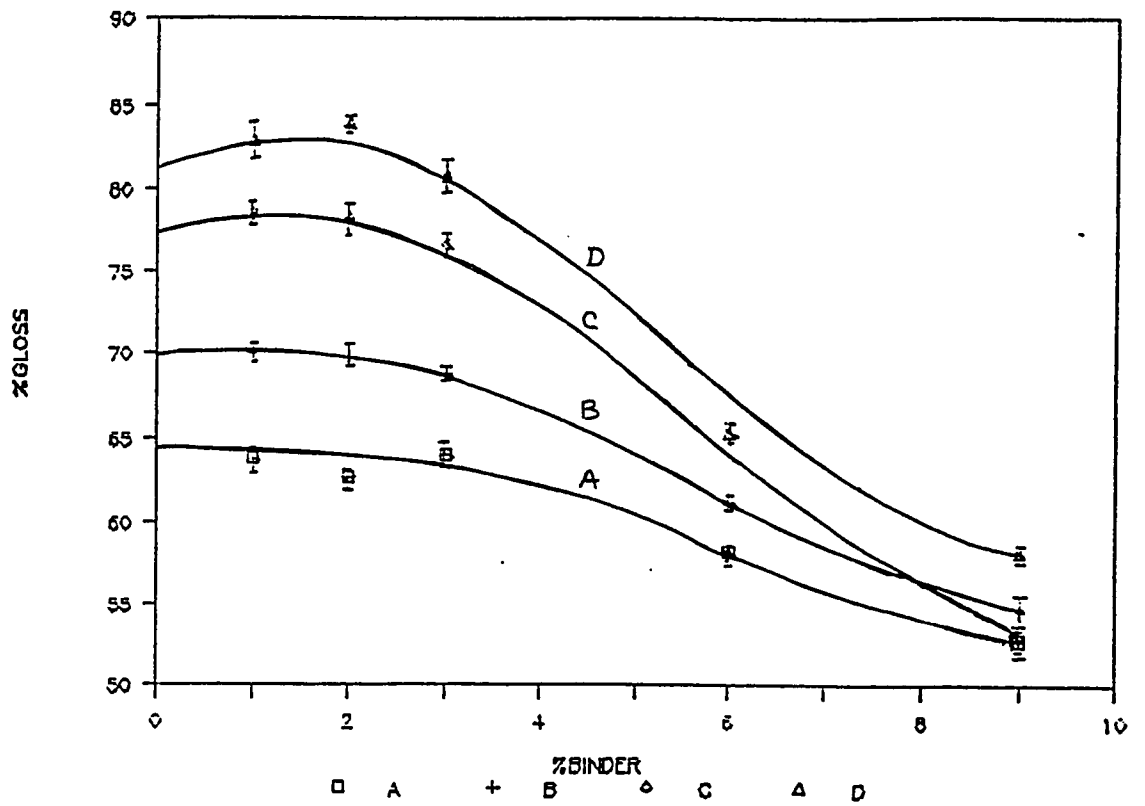

Figure 15. 75 Degree Gloss Vs. Amount of Latex.

As shown in Figure 15, the gloss of coating with latex decreased rapidly as the binder was increased from 3 to 6 %. But these coatings did not show an immediate change in the surface structure as in case of coatings with starch.

Summary of Gloss

The data for gloss are plotted in Figures 16, 17, 18, and 19 to compare the gloss of the coating with starch and latex. The plots clearly show that coatings with latex had higher gloss than coatings with starch.

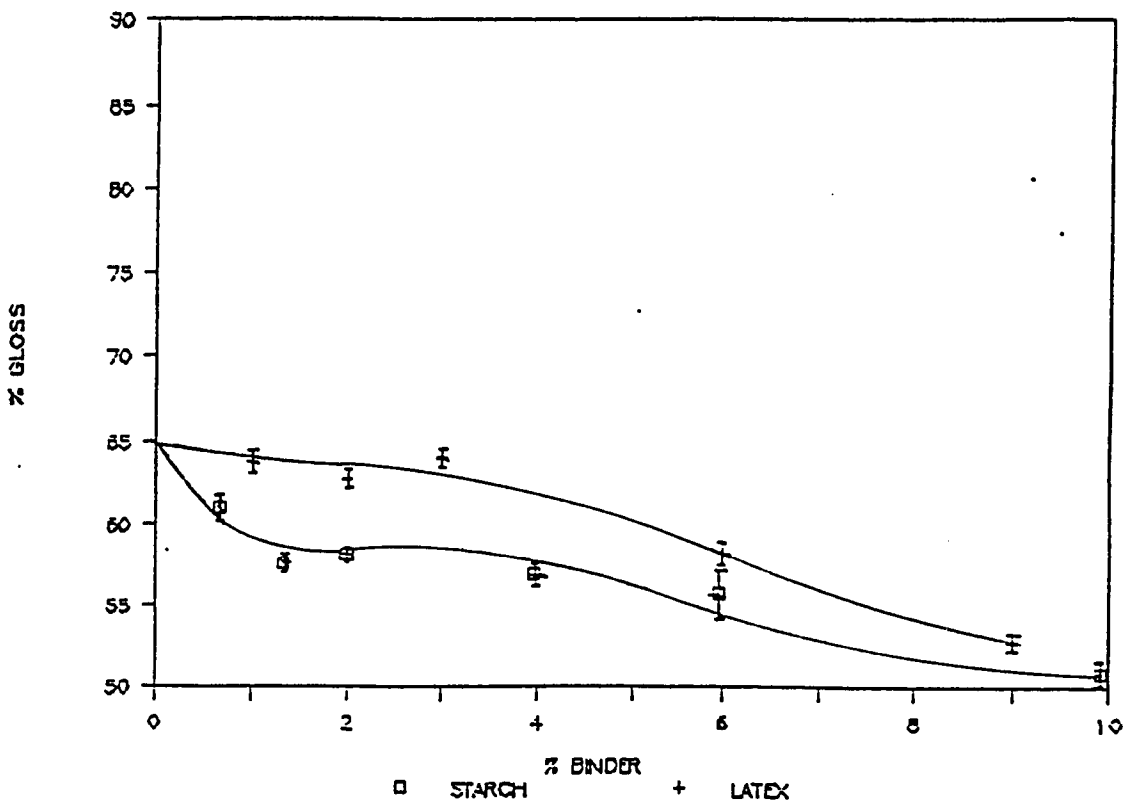

Figure 16. 75 Degree Gloss Vs. Binder with Blend "A."

The data for gloss of coatings with blend A are plotted in Figure 16. The difference in gloss of coatings with starch and latex decreased with the increased binder concentration. However, the difference between the two binders was minimum in blend A.

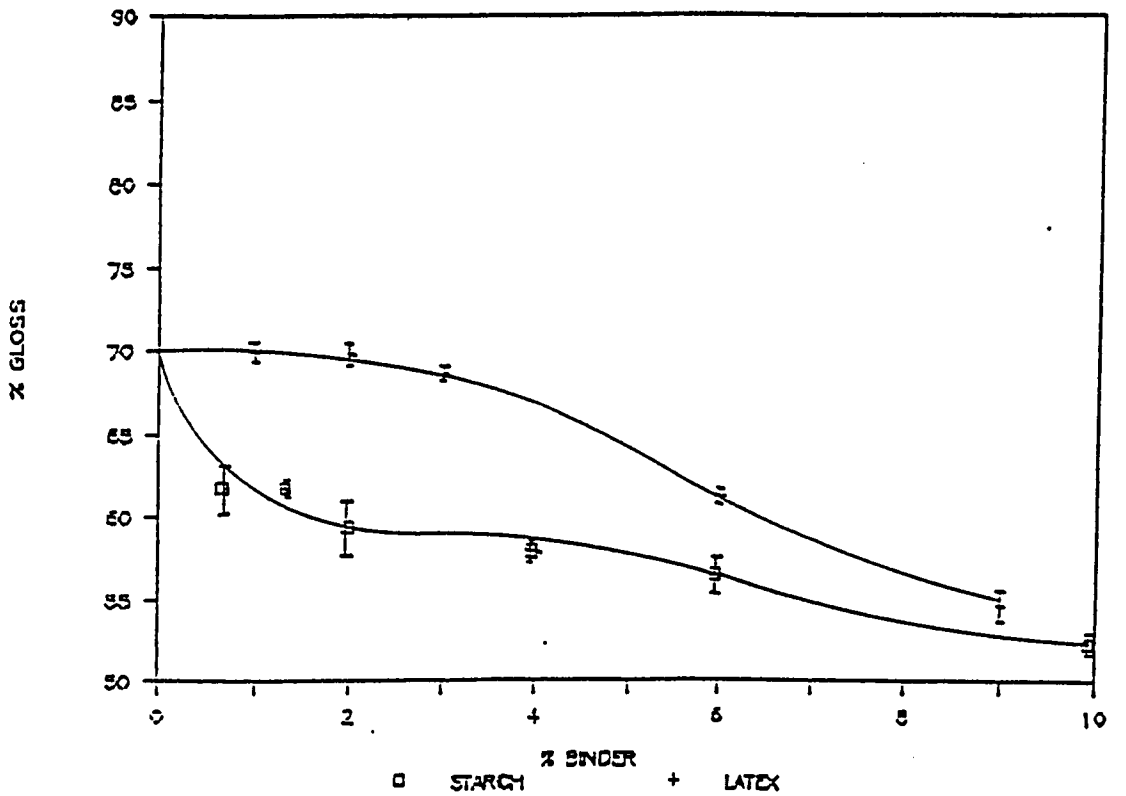

Figure 17. 75 Degree Gloss Vs. Binder with Blend "B."

It is shown in Figure 17 that starch and latex had different effects on the gloss of coating. The gloss of coatings is greater with latex than with starch. This could be because of the fact that starch shrinks more than latex upon drying (29) or some other reason. Since the shrinkage in the coating film was not measured in this study it would not be possible to draw conclusions to explain what is actually causing this difference in behaviour of starch and latex.

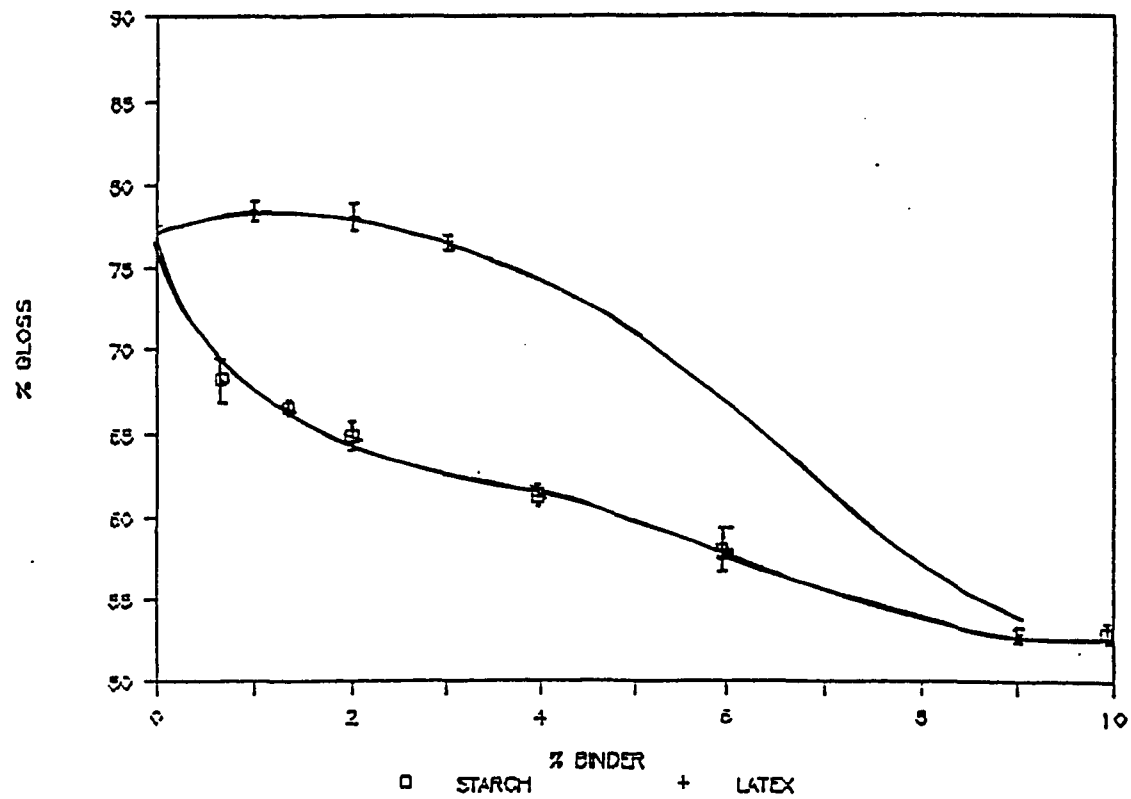

Figure 18. 75 Degree Gloss Vs. Binder with Blend "C."

In Figure 18, the gloss of coatings with starch decreased rapidly at low binder concentration and then decreased at a nearly constant rate but the gloss of coatings with latex showed a more rapid decrease above the six percent binder level.

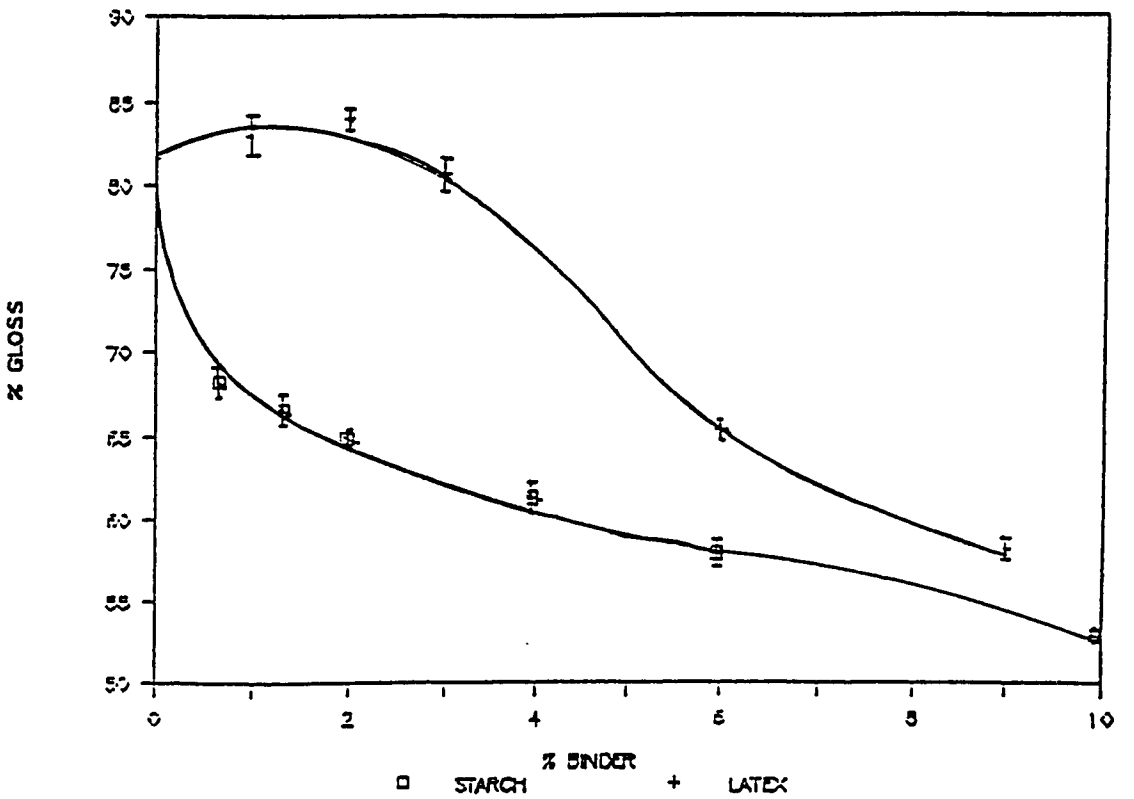

Figure 19. 75 Degree Gloss Vs. Binder with Blend "D."

In Figure 19, the gloss of the coatings with starch in blend D shows a fast drop with increase in binder concentration while the latex did not show a similar trend. The difference between the gloss values of the coatings with starch and latex increased as the ratio of smaller particles increased and this difference was greatest with blend D.

The results of these experiments show that the coating was glossier with the small particles and that the gloss of surface decreased as the apparent particle size increased. The large particles created larger voids on the surface. In the case of blends B, C, and D, when the smaller particles are able to fill the voids created by the larger particles, packing efficiency was improved. With improved packing, the particles fit more tightly together, helping to eliminate surface disruptions, creating a smoother surface, which promotes the development of gloss. The gloss was highest with blend D which had 40 % smaller particles. The gloss of coating decreased with the increase in binder concentration. This decrease in gloss can be explained with the increased interparticle distance because of the binder forming an adsorbed layer around the pigment particles.

In this study it was observed that the gloss of coatings with latex was much higher than coatings with starch at all levels of binder. This difference between starch and latex could be because of many reasons and one of them could be the shrinkage of starch and latex upon drying. But, based on this study, it would be difficult to draw any conclusions as to what is causing this change in gloss of coatings with starch and binder. This difference between the two binders increased as the pigment particles size of the pigment blend decreased.

Void Size Distribution

Starch as a binder

Micrographs of coatings with starch and various pigment blends were made using a scanning electron microscope and are shown in Figures 20 through 29.

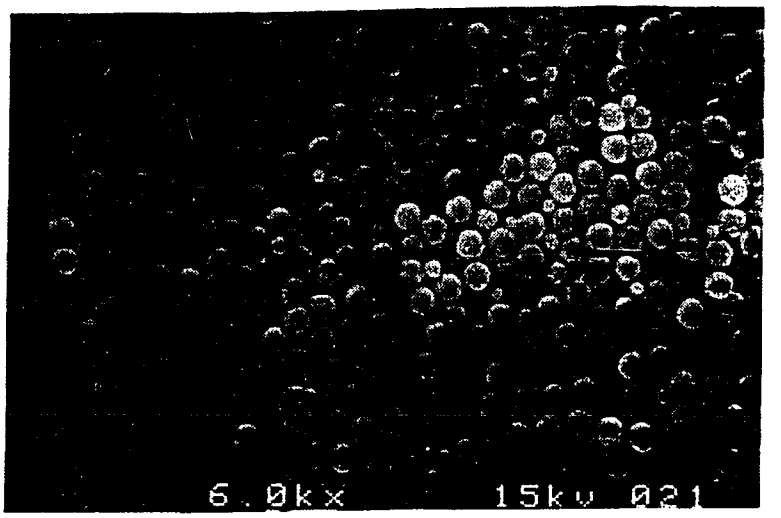

Figure 20. Micrograph of Coating With 0.66 Percent Starch and Blend "A."

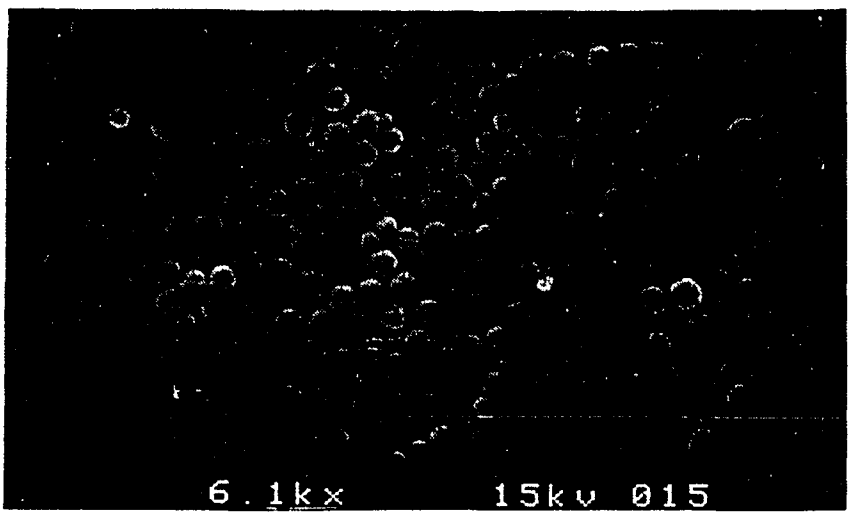

Figure 21. Micrograph of Coating With 2 Percent Starch and Blend "A."

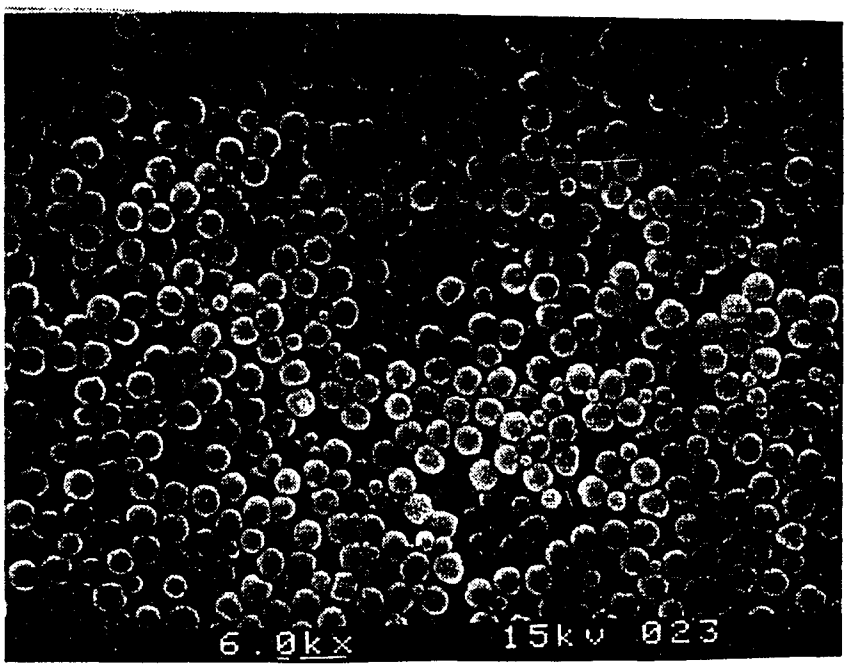

Figure 22. Micrograph of Coating With 6 Percent Starch and Blend "A."

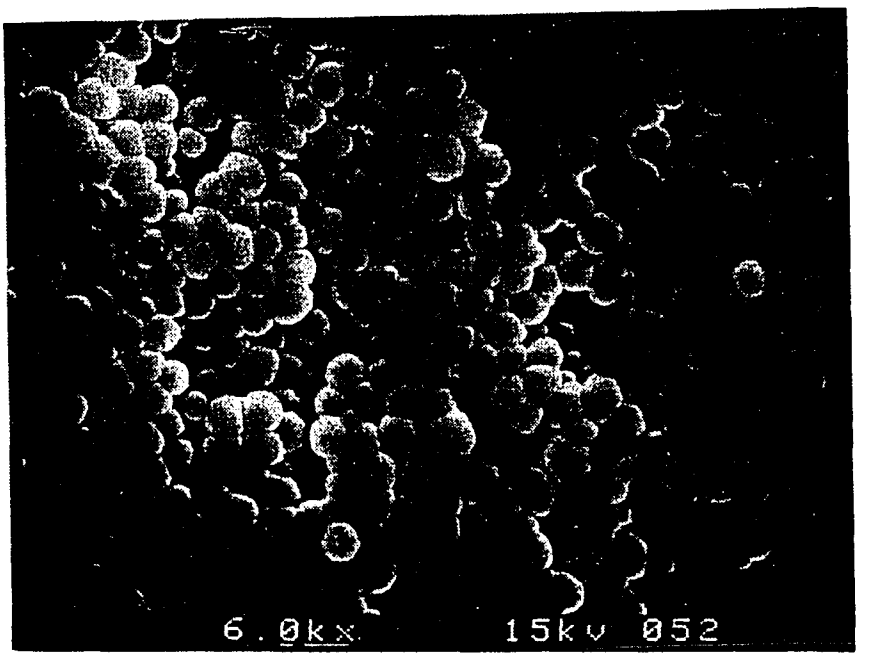

Figure 23. Micrograph of Coating With 9 Percent Starch and Blend "A."

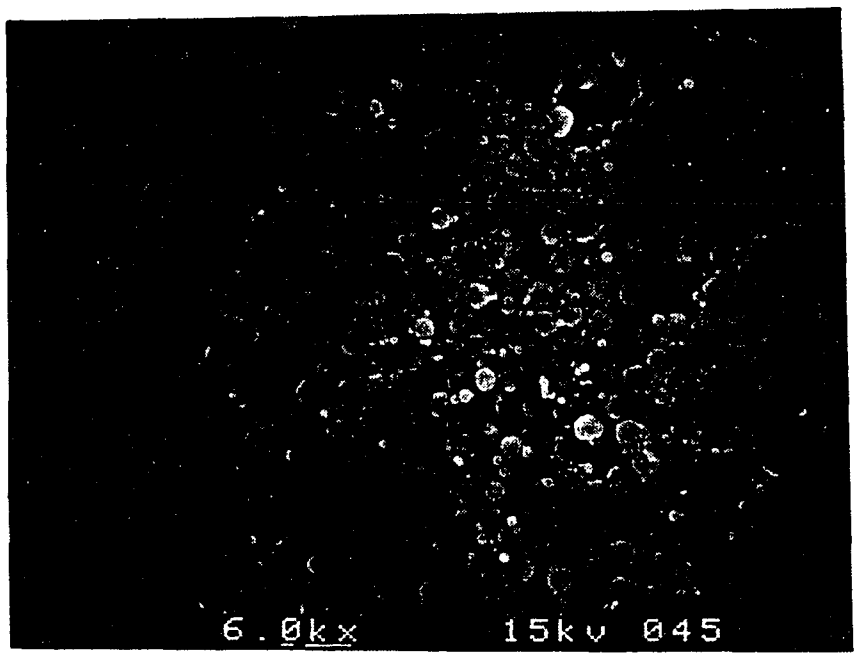

Figure 24. Micrograph of Coating With 0.66 Percent Starch and Blend "C."

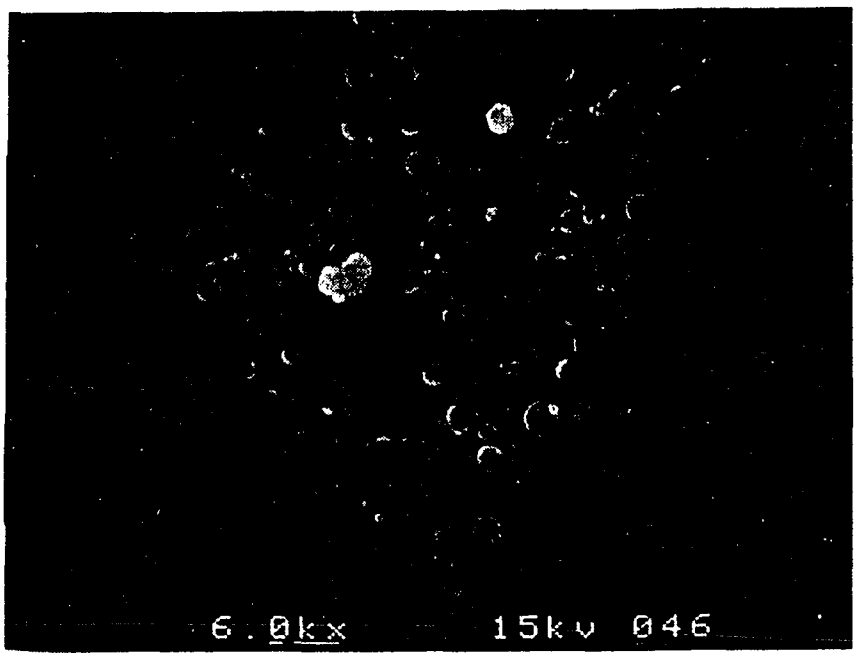

Figure 25. Micrograph of Coating With 2 Percent Starch and Blend "C."

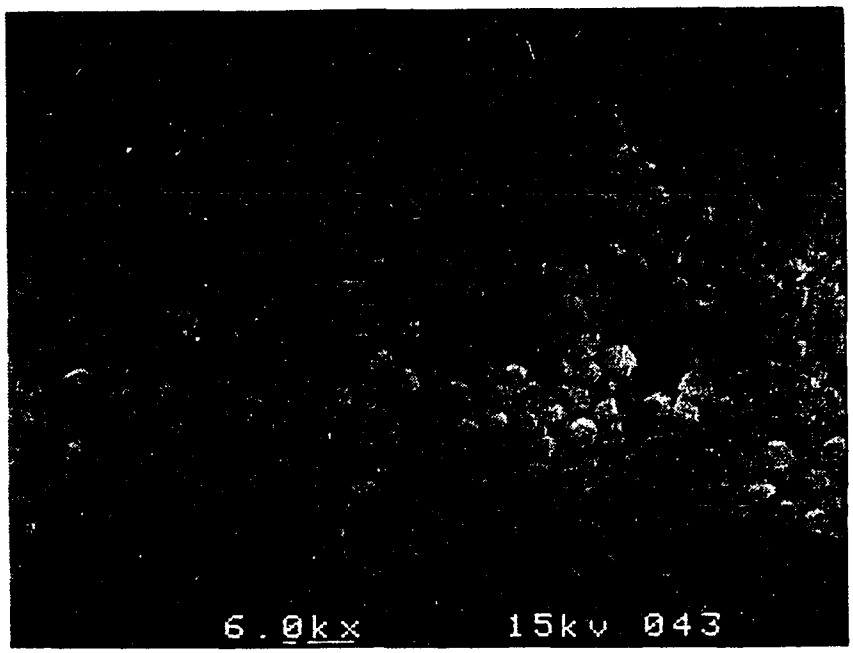

Figure 26. Micrograph of Coating With 6 Percent Starch and Blend "C."

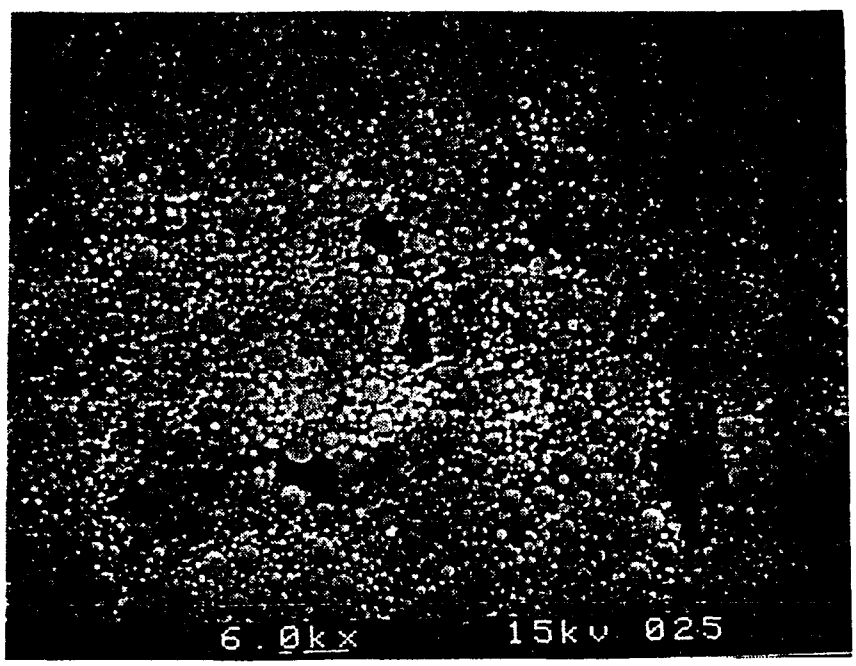

Figure 27. Micrograph of Coating With 0.66 Percent Starch and Blend "D."

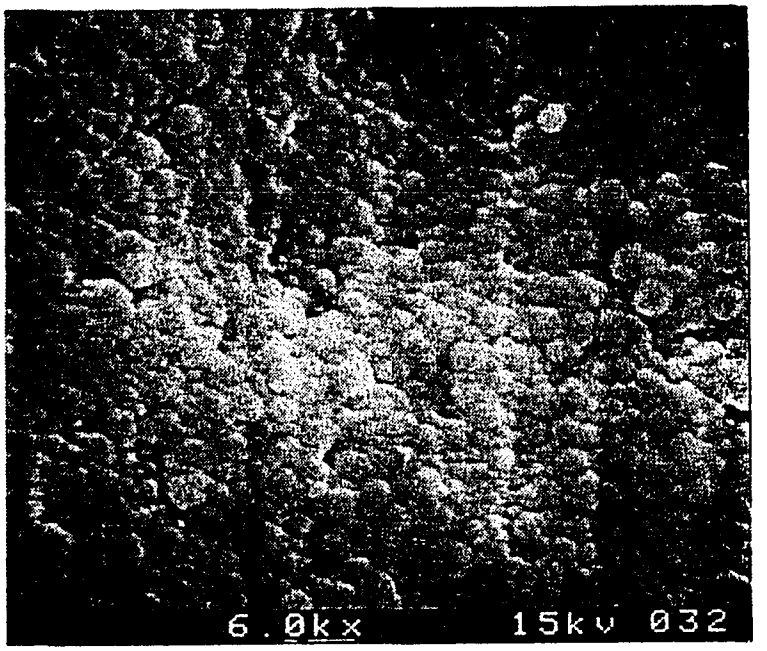

Figure 28. Micrograph of Coating With 2 Percent Starch and Blend "D."

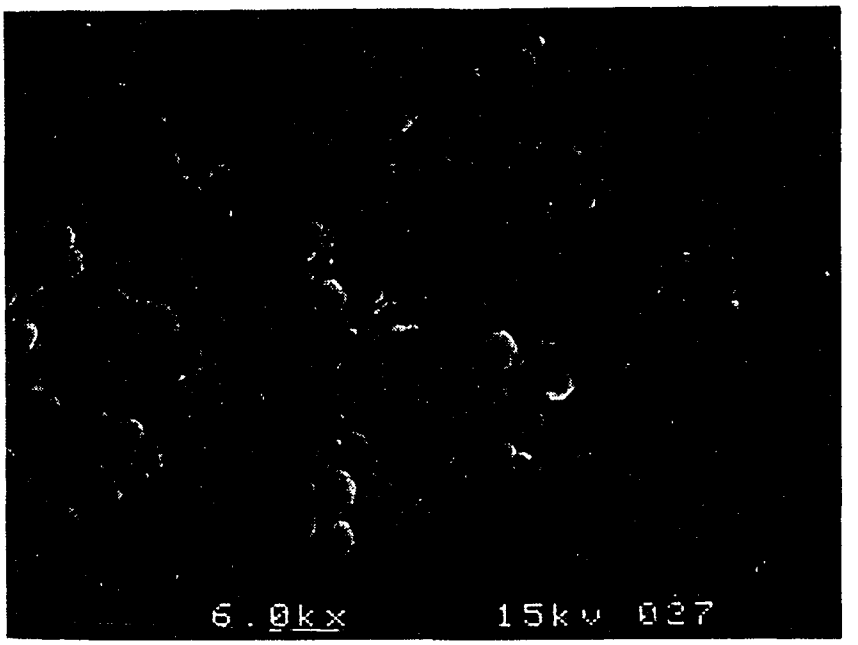

Figure 29. Micrograph of Coating With 6 Percent Starch and Blend "D."

From the comparison of coating structure as shown in the micrographs, it was observed that in coatings with blend A the size of the particles appears to increase at the first stage when the starch was added. With blend A, void filling can be seen to take place when the binder was increased from 6 % to 9 % concentration.

With blend C the behavior of starch was different because of the 20 percent smaller particles present. Void filling takes place at a lower level as can be seen from Figure 24 through 26. Similar results were observed with blend D. The surface of the coating appears to be more uniform with the binary mixture of pigments.

Table 8

Pore Size Distribution for the Coatings with Starch

Pigment Blend	Pore Size Distribution (um)	Starch (%) 1	2	6
		(Number of Pores)		
A	0.0 - 0.10	0	0	29
	0.1 - 0.19	34	29	44
	0.2 - 0.29	11	18	21
	> 0.30	32	27	17
C	0.0 - 0.10	58	108	92
	0.1 - 0.19	37	29	18
	0.2 - 0.29	7	6	3
	> 0.30	26	24	4
D	0.0 - 0.10	200	0	0
	0.1 - 0.19	27	4	4
	0.2 - 0.29	6	2	6
	> 0.30	7	0	2

Void size distribution for these coatings was measured and the results are given in Table 8. The data also show similar effects to the scattering and void volume data. As the starch volume was increased from one to six parts, the number of pores larger than 0.3 um was reduced as were the scattering coefficient and void volume.

Latex as a Binder

The micrograph of coatings with latex and various pigment blends were developed using scanning electron microscope and are shown here in Figures 30 through 37.

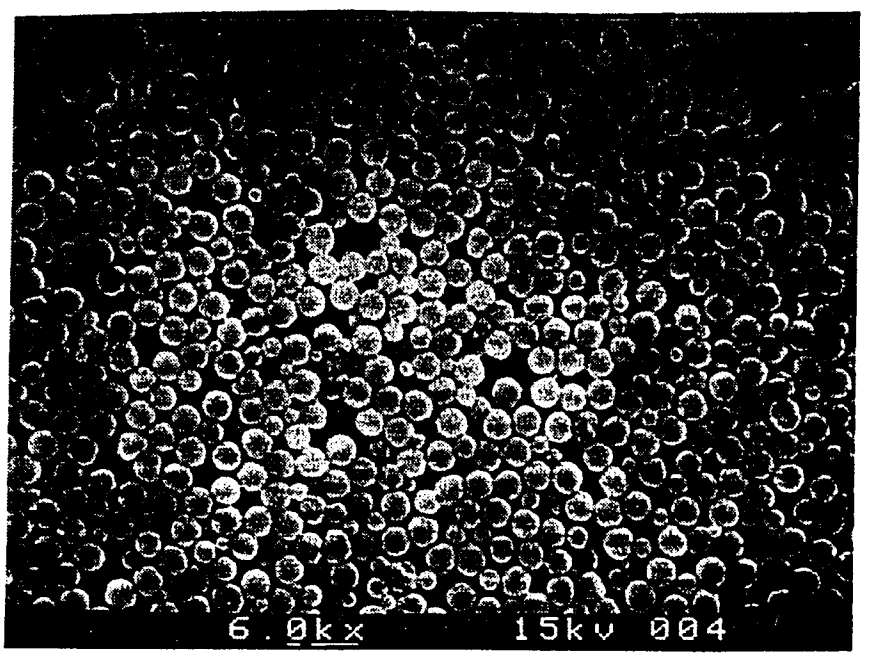

Figure 30. Micrograph of Coating with 1 Percent Latex and Blend "A."

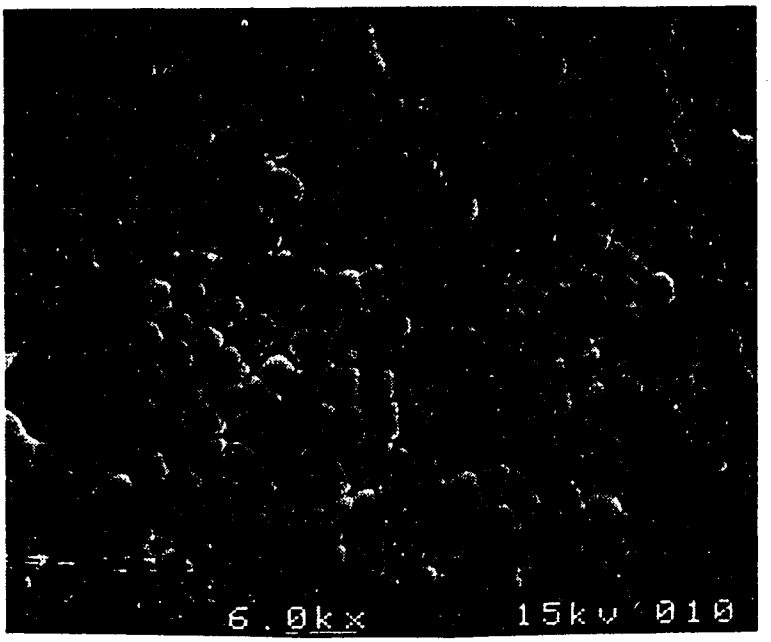

Figure 31. Micrograph of Coating With 3 Percent Latex and Blend "A."

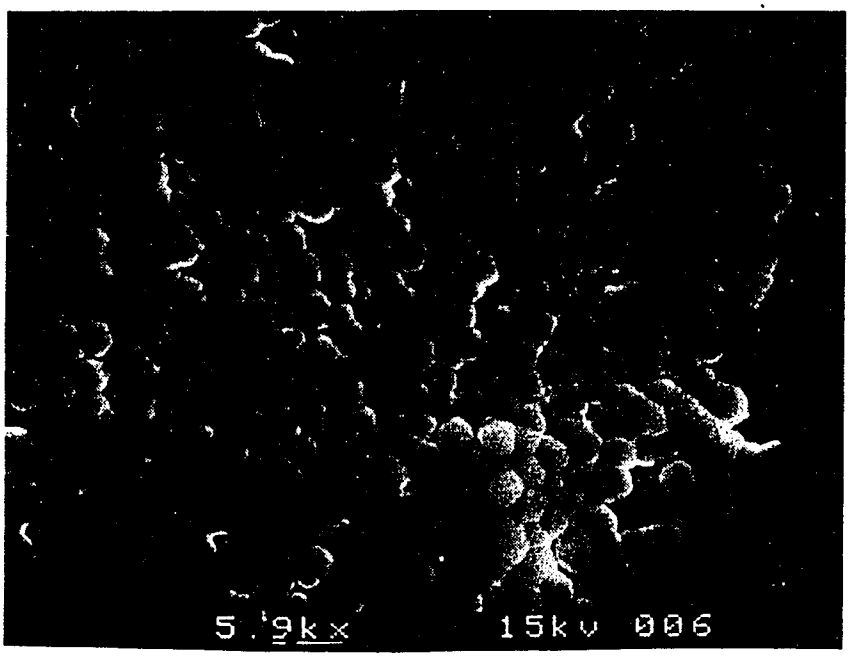

Figure 32. Micrograph of Coating With 6 Percent Latex and Blend "A."

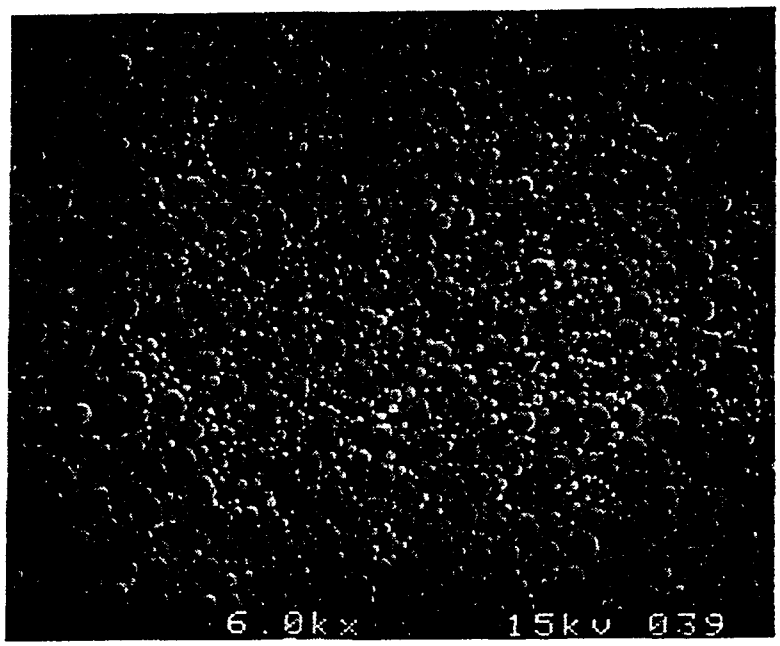

Figure 33. Micrograph of Coating With 1 Percent Latex and Blend "C."

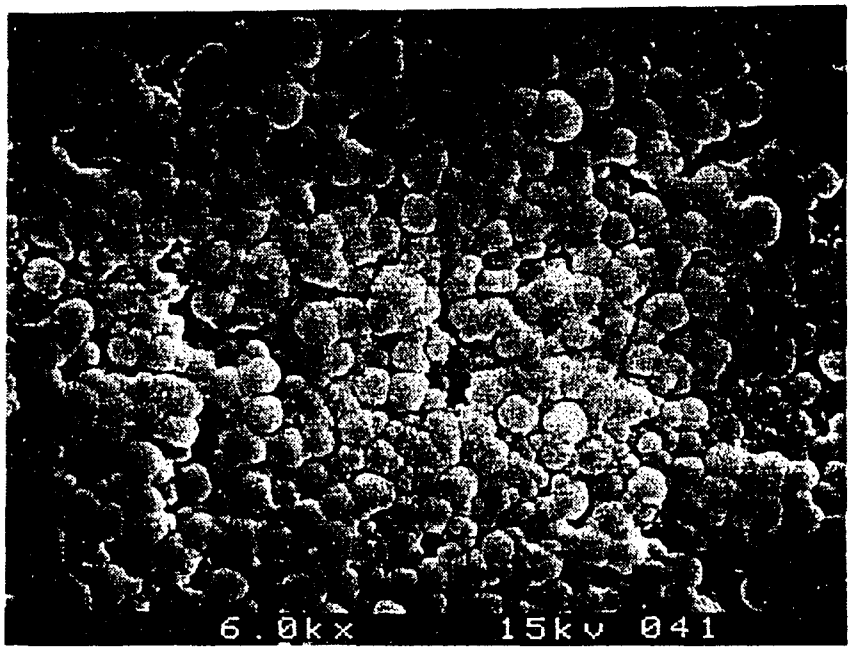

Figure 34. Micrograph of Coating With 6 Percent Latex and Blend "C."

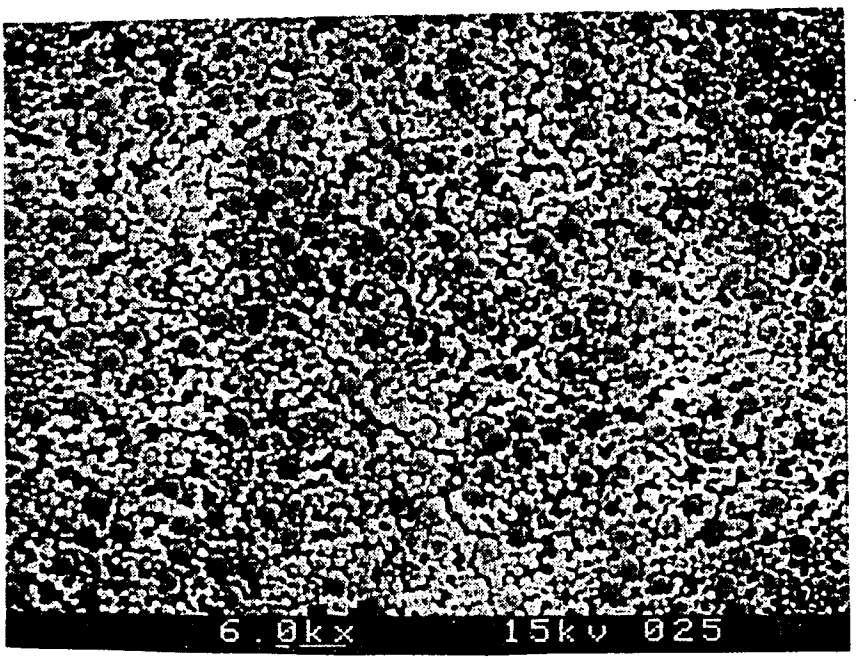

Figure 35. Micrograph of Coating With 1 Percent Latex and Blend "D."

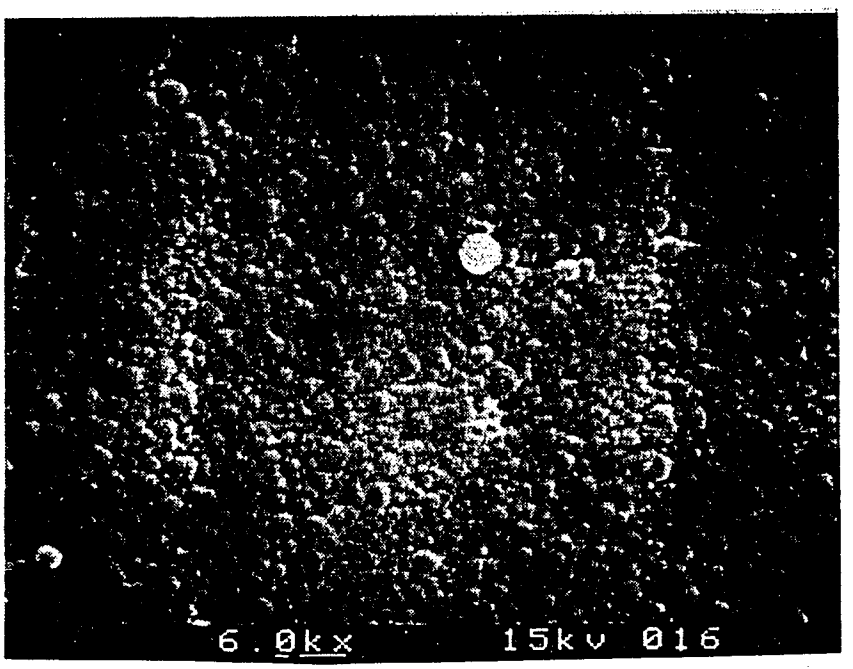

Figure 36. Micrograph of Coating With 3 Percent Latex and Blend "D."

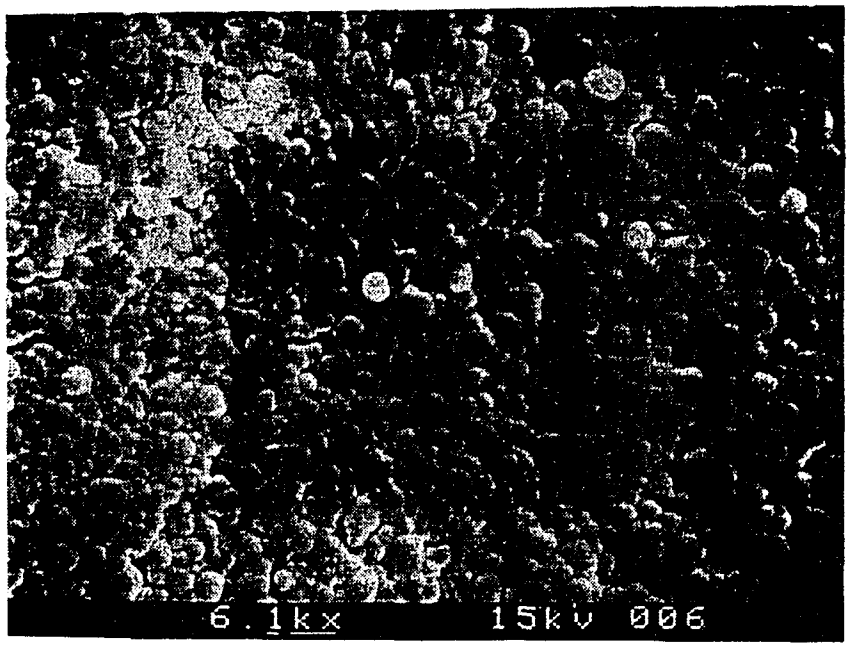

Figure 37. Micrograph of Coating With 6 Percent Latex and Blend "D."

Table 9

Pore Size Distribution for the Coatings with Latex

Pigment Blend	Pore Size Distribution (um)	Latex (%) 1	3	6
		(Number of Pores)		
A	0.0 - 0.10	0	68	96
	0.1 - 0.19	34	24	13
	0.2 - 0.29	13	5	3
	> 0.30	9	3	0
C	0.0 - 0.10	78	94	116
	0.1 - 0.19	37	22	17
	0.2 - 0.29	19	12	4
	> 0.30	12	9	4
D	0.0 - 0.10	90	46	28
	0.1 - 0.19	28	4	5
	0.2 - 0.29	13	0	0
	> 0.30	30	0	1

Void size distribution for these coatings were measured and the results are given in Table 9. The data for void sizes show that the number of optically efficient pores (larger than 0.3 um) was reduced with increased binder concentrations.

The micrographs show an apparent in the size of the particles when the starch and latex were added. For the coatings with blend A and latex, void filling occurred when the binder concentration was increased from 3 to 6 %. With blend D, void filling started at as low as 3 % binder. This could be due to the presence of of the smaller voids created by 40 % smaller particles as can be seen in Figures 35 through 37. The surface of the coatings appeared to be more uniform and smoother with binary mixture of pigments. In other words voids filling shifted to low binder level when the smaller particles increased.

The scattering coefficient first increased and then decreased at high binder concentration. The pore size data confirm the scattering coefficient data in that the starch had higher scattering at 6 % in binder in blends A and C but not in D. The void size analysis shows more optically active pores with starch in blend A and C but not with D.

CHAPTER VI

CONCLUSIONS

1. This study confirmed that the presence, amount and type of binder definitely affect the packing of pigment particles and optical properties of coatings.

2. In some coatings there was evidence of an increase in scattering coefficient due to the expansion of coatings that was confirmed by void size measurements made on the SEM photomicrograph pictures.

3. Void filling and adsorption of binder appear to occur simultaneously. Depending on the conditions, the relative amount of each and its importance seem to shift. (a) Micrographs of the coating surface showed an apparent increase in pigment particle size at low levels of binder addition. This provides evidence that the binder adsorption mechanism was prevalent at low levels of binder. (b) Void size data show a decrease in pore size at high binder levels of addition, which indicated the void filling mechanism was prevalent at high levels of binder. (c) The amount of binder required to cause a large decrease in scattering coefficient decreased as the particle size of the pigment blend decreased. This gives evidence that the void filling becomes prevalent at lower

binder concentrations with smaller pigment particle size.

4. The coatings with latex had higher gloss than with starch. The difference between these two binders increased as the pigment particle size of the pigment blend decreased. The gloss data seem to be contrary to the pore size distribution data. As the pores are filled, one would expect the gloss to increase but instead it is seem to decrease. Since gloss is a surface phenomena, not void structure, the binders must have some other effect on the surface which the measurement made in this study failed to identify.

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APPENDICES

Appendix A

Derivation of the Formula used for the Scattering Coefficient of Coating

Derivation of the formula used for calculation of the scattering of coatings

Based on the work of Starr and Young (23) and Steele (22) the Variable Rg method was used for the calculations. When a beam of light is incident upon a sheet of paper or other material, three things will happen to the beam; it will be reflected, absorbed and transmitted. Just how much of these three things will take place is dependent upon the material itself as well as the nature of incident light.

If we consider what happens to a beam of light of intensity Io as it passed through a sheet of paper of thickness X, considering that the sheet is homogeneous.

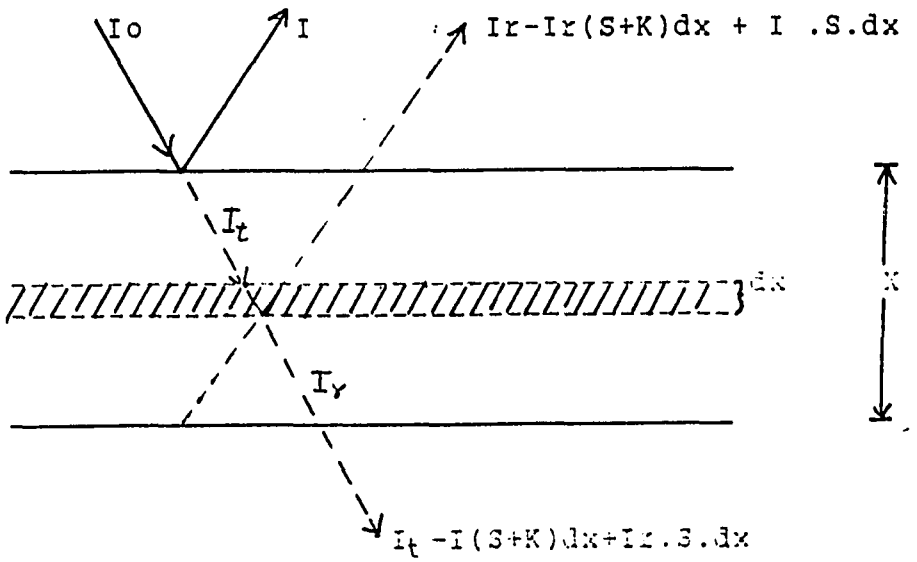

Figure 1. Scattering of Light

Where I is the reflection of light from the surface of the paper, I_t is the transmitted light, and Ir is the

reflection from the bottom layers. Let us suppose that paper has scattering coefficient equal to S and absorption coefficient equal to K.

Considering a small thickness of sheet, dx

I will be decreased by $I_t.(S+K)dx$

I will be increased by Ir.Sdx and

I will be decreased by Ir.(S+K)dx

I will be increased by $I_t.Sdx$

Therefore expressing the change in the intensity as differential algebraic sum we obtain

$$-dI_t = -(S+K)I_t.dx + S.Ir.dx \quad (1)$$

$$dIr = -(S+K)Ir.dx + S.I_t.dx \quad (2)$$

if we divide the two equaitons by It and Ir respectively and add, we obtain

$$-\frac{dIt}{It} + \frac{dIr}{Ir} = d \ln \frac{Ir}{It} = -2(S+K)dx + S*(\frac{It}{Ir} + \frac{Ir}{It})*dx \quad (3)$$

Now if we define the reflectance R of the sheet of paper as

R = I/Io we can then define r, the reflectance of the layer dx, as $r = Ir/I_t$.

Substituting these in equation (3) we obtain

$$dr = [-2(S+K).r + Sr\ ]dx$$

on integration with the limits from 0 to X thickness of the sheet we obtain

$$\int_{R'}^{R} \frac{dr}{R - 2[(S+K)/s] + 1} = S\int_{0}^{X} 1.dx \quad (4)$$

where R is the reflectance of the sheet, R' is the reflectance of the material right behind the sheet, and X is the thickness of the sheet of paper.

In case of brightness we measure the reflectance of sheets which is thick enough to represent an infinitely thick pad of paper. In this case X = infinity and R = R'= Ri (i=infinity). Therefore here Ri becomes the brightness of paper. Substituting these values of X and R in the equation (4) and solving for Ri we obtain

$$Ri = 1 + \frac{K}{S} - \sqrt{\frac{K}{S} + \frac{2K}{S}} \qquad (5)$$

But for the case where R = R' and X is less than infinity, the solution of these equations is as follows

$$R = \frac{R' \sinh (y-z) + \sinh z}{-R' \sinh z + \sinh (y+z)} \qquad (6)$$

where $R = e^{-Y}$ and $z = sx \sinh y$

Integration is as follows:

$$\int_{Rg}^{R} \frac{dR}{r - 2[(S+K)/S].r+1} = S \int_{0}^{X} 1.dx$$

Let $(S+K)/S = a$

$$\int_{Rg}^{R} \frac{dr}{(r^2-2ar+1)} = s \int_{0}^{X} 1.dx$$

$$\int_{Rg}^{R} \frac{dr}{(r-a)^2-(a^2-1)^2} = s \int_{0}^{X} 1.dx$$

Let $(a^2-1) = b$

Then:

$$\int_{Rg}^{R} \frac{dr}{(r-a)^2 - b^2} = s \int_{0}^{X} 1.dx$$

Now:

$$\frac{1}{2b} \ln \left[\frac{r - (a+b)}{r - (a-b)} \right]_{Rg}^{R} = s.x$$

or:

$$\ln \frac{[R - (a+b)]}{[R - (a-b)]} - \ln \frac{[Rg - (a+b)]}{[Rg - (a-b)]} = 2bsx$$

or:

$$2bsx = \ln \frac{[R - (a+b)]}{[R - (a-b)]} * \frac{[Rg - (a-b)]}{[Rg - (a+b)]}$$

In case of R = Ri and Rg = Ro

Substituting values of a and b we get

$$sx = \frac{\ln [(1-RoR)/(1-Ro/Ri)]}{(1-Ri)^2/Ri}$$

Let Rg be the reflection of the backing material

$$R_{Rg} = \frac{(1/Ri)[Rg - (1/Ri)] - R\{Rg - (1/Ri)\} e^{2bSX}}{[Rg - Ri] - [Rg - (1/Ri)] \cdot e^{2bSX}}$$

or:

$$R_{Rg} = \frac{(1/Ri)[Rg - (1/Ri)] - R\{Rg - (1/Ri)\}}{[Rg - Ri] - [Rg - (1/R)]} \qquad (7)$$

Let Rg = 0

$$Ro = \frac{(1/Ri)^2 - Ri(-1/Ri)}{(-Ri) - (-1/Ri)} \qquad (8)$$

Now on solving equation (7) and (8) for e^{2bSX}, we get

$$Ro = \frac{(R - Rg)}{[1-Rg((1/Ri) + Ri - R)]} \quad (9)$$

Now as we will be using black and white backing for calculation here. Let us assume:

R_{Rg} = Rb for black backing

R_{Rg} = Rw for white backing

Substituting these in equation (9) respectively, we obtain:

$$Ro = \frac{(RB - RgB)}{[1 - Rgb\ ((1/Ri) + Ri - Rb)]} \quad (10)$$

$$Ro = \frac{(Rw - Rgw)}{[1 - Rgw\ ((1/Ri) + Ri - Rw)]} \quad (11)$$

From equation (9) and (10), on solving these for Ri we get:

$$a\ Ri^2 + bRi + c = 0$$

Where $a = (Rb.Rgw - Rw.Rgb) = c$ (12)

and $b = [(Rb + Rgw) * (Rw.Rgb-1)] - [(Rw + Rgb)*(Rb.Rgw-1)]$ (13)

Therefore, Reflectivity or Brightness is:

$$R = \frac{-b +/- \sqrt{b^2 - 4ac}}{2a} \quad (14)$$

On solving equaiton (4), we get:

$$sx = \frac{\ln [(1-Ro.Ri)/(1-Ro/Ri)]}{(1-Ri)^2/Ri} \quad (15)$$

Or:

$$s = \frac{1}{x} * \frac{\ln [(1-Ro.Ri)/(1-Ro/Ri)]}{(1-Ri)^2/Ri} \quad (16)$$

Where R is the brightness of coating and s is the scattering coefficient.

Appendix B

Program for Calculation of Scattering Coefficient Using FORTRAN Program

```
      CHARACTER *1 ANSWER
      REAL RW, RB, RGB, RGW, RO, RI, A, B, S ,X
      TYPE *
      TYPE *, 'ENTER RGW'
      READ *   RGW
      TYPE *, 'ENTER RGB'
      READ *,  RGB
2     TYPE *, 'ENTER RW'
      READ *   RW
      TYPE *, 'ENTER RB'
      READ *,  RB
      TYPE *, 'ENTER X'
      READ *, X
      A= (RB*RGW)-(RW*RGB-1)
      B= (RB+RGW)*(RW*RGB-1)-(RW+RGB)*(RB*RGW-1)
      RI=(-B-SQRT(B**2-4*A*A))/(2*A)
      RD=(RW-RGW)/(1-RGW*(1/RI+RI-RW))
      S=(1/((1/RI-RI)*X))*ALOG((1-RO*RI)/(1-RO/RT))
      TYPE *
      TYPE *, 'A=', A
      TYPE *
      TYPE *, 'B=', B
      TYPE *
      TYPE *, 'RI=', RI
      TYPE *
      TYPE *, 'RO=', RO
      TYPE *
      TYPE *, 'S=', S
      TYPE *
      TYPE *
      GO TO 2
      END
```

Appendix C

Calculation of Scattering Coefficient

Calculation of Scattering Coefficient

$$Ri = \frac{-b - [b^{**}2 - 4 * (a^{**}2)]^{**} 0.5}{(2 * a)}$$

where:

$$a = (Rb * Rgw - Rw * Rgb)$$

$$b = (Rb + Rgw) * (Rw*Rgb - 1) - (Rw + Rgb) * (Rb*Rgw - 1)$$

$$S = \frac{1}{CW * [(1/Ri) - Ri]} * \ln \frac{(1 - Ro*Ri)}{(1 - Ro/Ri)}$$

where:

CW = Coat Weight (g/sq.m.)

Rb = Reflectance of coating with black backing (%)

Rw = Reflectance of coating with white backing (%)

Rgb = Reflectance of uncoated mylar with black backing (%) = 3.7

Rgw = Reflectance of uncoated mylar with white backing (%) = 72.9

Ri = Brightness (Reflectivity) of coating

S = Scattering Coefficient

Table 1. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.40 um Particles

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.4		g/sq.m.	%	%	
100%	0%	1	15.8	78.7	69.7	0.1670
		2	23.7	80.3	75.3	0.1616
		3	13.8	79.0	70.7	0.2026
		4	15.8	78.6	70.3	0.1749
		5	13.8	78.5	68.9	0.1825
		6	13.8	79.2	70.9	0.2038
		7	15.8	79.3	70.8	0.1759
		8	13.8	78.4	69.1	0.1857
		9	13.8	79.0	70.2	0.1955
		10	15.8	78.9	70.2	0.1715
			Average			0.1820
			Standard Deviation			0.0146

Table 2. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.40 um Particles

Particle size (um) 0.67	0.4	#	Coat Wt. g/sq.m.	Rw %	Rb %	Scattering Coeff.
80%	20%	1	15.8	79.4	68.9	0.1541
		2	17.8	79.3	68.1	0.1306
		3	15.8	79.1	67.6	0.1436
		4	15.8	79.7	69.1	0.1545
		5	15.8	79.2	67.5	0.1423
		6	17.8	79.6	69.7	0.1431
		7	15.8	79.5	69.2	0.1566
		8	17.8	79.5	69.5	0.1417
		9	13.8	79.4	68.6	0.1732
		10	15.8	79.3	68.7	0.1527
			Average			0.1492
			Standard Deviation			0.0116

Table 3. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.40 um Particles

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.4		g/sq.m.	%	%	
60%	40%	1	17.8	79.1	69.7	0.1458
		2	17.8	79.6	70.1	0.1469
		3	13.8	79.2	68.5	0.1733
		4	15.8	79.1	68.6	0.1529
		5	15.8	79.3	68.4	0.1499
		6	17.8	79.3	69.5	0.1428
		7	13.8	79.4	70.8	0.2006
		8	15.8	78.9	67.0	0.1394
		9	17.8	79.0	68.6	0.1362
		10	17.8	79.4	69.8	0.1451
			Average			0.1533
			Standard Deviation			0.0194

Table 4. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.40 um Particles

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.4		g/sq.m.	%	%	
40%	60%	1	15.8	78.9	68.8	0.1560
		2	15.8	79.1	67.3	0.1410
		3	13.8	78.6	65.2	0.1451
		4	15.8	79.4	68.5	0.1503
		5	13.8	79.1	67.4	0.1624
		6	15.8	79.2	67.9	0.1458
		7	11.8	78.9	66.1	0.1771
		8	15.8	79.7	69.3	0.1565
		9	15.8	79.0	67.7	0.1450
		10	13.8	79.0	67.5	0.1640
			Average			0.1543
			Standard Deviation			0.0111

Table 5. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.40 um Particles

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.4		g/sq.m.	%	%	
20%	80%	1	13.8	79.9	68.5	0.1692
		2	13.8	79.8	69.1	0.1762
		3	11.8	79.9	67.6	0.1874
		4	13.8	79.8	67.8	0.1627
		5	13.8	79.5	67.7	0.1633
		6	15.8	79.3	66.8	0.1360
		7	17.8	80.1	68.7	0.1319
		8	13.8	79.5	67.3	0.1594
		9	13.8	79.3	67.0	0.1576
		10	13.8	79.9	68.3	0.1671
			Average			0.1610
			Standard Deviation			0.0167

Table 6. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.40 um Particles

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.4		g/sq.m.	%	%	
0%	100%	1	15.8	79.0	67.0	0.1390
		2	13.8	78.7	65.1	0.1438
		3	13.8	77.9	61.5	0.1211
		4	15.8	77.8	64.0	0.1212
		5	13.8	78.1	62.4	0.1263
		6	15.8	77.8	64.0	0.1212
		7	13.8	77.9	62.3	0.1262
		8	13.8	78.5	64.7	0.1415
		9	13.8	78.7	64.9	0.1423
		10	15.8	78.3	65.6	0.1308
			Average			0.1313
			Standard Deviation			0.0094

Table 7. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.20 um Particles

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
80%	20%	1	14.3	77.5	61.8	0.1199
		2	15.3	77.6	62.7	0.1172
		3	15.3	78.0	63.3	0.1198
		4	14.3	78.3	63.0	0.1251
		5	13.8	78.1	63.1	0.1310
		6	13.8	78.7	64.6	0.1399
		7	13.8	78.1	61.6	0.1211
		8	15.3	79.1	66.4	0.1381
		9	14.3	78.1	61.6	0.1169
		10	15.8	78.7	64.3	0.1202
			Average			0.1249
			Standard Deviation			0.0084

Table 8. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.20 um Particles

Particle size (um) 0.67	0.2	#	Coat Wt. g/sq.m.	Rw %	Rb %	Scattering Coeff.
60%	40%	1	12.8	78.6	60.4	0.1214
		2	12.8	78.9	61.8	0.1294
		3	13.3	78.2	60.0	0.1156
		4	13.3	78.2	60.5	0.1185
		5	13.3	77.7	59.5	0.1140
		6	13.3	78.2	59.1	0.1106
		7	11.8	77.4	57.8	0.1190
		8	11.8	77.6	57.6	0.1174
		9	13.8	77.6	60.5	0.1158
		10	13.8	77.6	60.0	0.1129
			Average			0.1175
			Standard Deviation			0.0052

Table 9. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.20 um Particles

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
40%	60%	1	10.3	77.0	56.0	0.1261
		2	10.3	77.6	56.5	0.1276
		3	12.3	77.8	55.7	0.1025
		4	12.3	77.2	55.2	0.1013
		5	12.8	77.5	55.9	0.1000
		6	12.8	77.5	56.9	0.1048
		7	12.8	77.7	56.0	0.1001
		8	12.8	77.7	55.7	0.0987
		9	11.3	77.1	54.9	0.1089
		10	11.3	77.1	54.8	0.1084
			Average			0.1078
			Standard Deviation			0.0105

Table 10. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.20 um Particles

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
0%	100%	1	11.3	76.7	52.2	0.0968
		2	11.3	76.5	52.4	0.0980
		3	13.3	76.8	52.3	0.0825
		4	13.3	76.8	51.9	0.0810
		5	11.3	77.1	52.5	0.0933
		6	11.3	77.3	52.7	0.0938
		7	11.3	76.4	51.0	0.0921
		8	11.3	76.9	51.9	0.0951
		9	12.3	75.7	50.6	0.0841
		10	12.3	76.7	50.5	0.0823
			Average			0.0899
			Standard Deviation			0.0066

Table 11. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.20 um Particles

Particle size (um) 0.67	0.2	#	Coat Wt. g/sq.m.	Rw %	Rb %	Scattering Coeff.
95%	5%	1	14.3	78.4	68.3	0.1698
		2	14.8	78.0	68.0	0.1634
		3	16.8	78.5	70.0	0.1619
		4	14.3	78.5	68.1	0.1670
		5	14.3	78.2	68.6	0.1745
		6	13.3	77.3	66.4	0.1681
		7	14.8	78.3	68.0	0.1616
		8	14.3	78.2	67.9	0.1667
		9	14.8	78.1	67.5	0.1577
		10	13.3	77.8	66.6	0.1673
			Average			0.1658
			Standard Deviation			0.0047

Table 12. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.20 um Particles

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
90%	10%	1	13.8	77.3	65.4	0.1526
		2	13.8	77.0	64.0	0.1419
		3	15.3	77.5	65.7	0.1393
		4	13.3	77.6	65.2	0.1549
		5	15.3	77.4	65.2	0.1357
		6	13.8	77.2	64.4	0.1443
		7	14.3	77.2	64.3	0.1385
		8	13.3	77.0	64.2	0.1488
		9	15.7	77.6	65.3	0.1314
		10	13.3	77.6	65.7	0.1595
			Average			0.1447
			Standard Deviation			0.0090

Table 13. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.20 um Particles

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
85%	15%	1	13.3	76.9	63.3	0.1418
		2	14.8	77.1	63.5	0.1284
		3	13.8	77.4	64.5	0.1443
		4	14.3	77.5	64.1	0.1357
		5	15.3	77.5	65.3	0.1360
		6	14.3	77.7	65.0	0.1420
		7	13.3	77.0	63.1	0.1399
		8	16.8	78.0	66.9	0.1344
		9	15.3	76.9	65.2	0.1378
		10	14.3	77.1	63.9	0.1358
			Average			0.1376
			Standard Deviation			0.0046

Table 14. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.12 um Particles

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.12		g/sq.m.	%	%	
90%	10%	1	14.8	78.4	63.5	0.1239
		2	14.3	77.7	64.0	0.1342
		3	15.3	78.2	65.6	0.1355
		4	15.8	78.4	66.0	0.1336
		5	14.3	77.5	63.9	0.1342
		6	13.8	77.7	63.8	0.1375
		7	13.3	77.8	62.3	0.1311
		8	13.3	77.3	62.1	0.1314
		9	14.3	78.0	63.0	0.1260
		10	13.8	77.9	62.9	0.1302
			Average			0.1317
			Standard Deviation			0.0042

Table 15. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.12 um Particles

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.12		g/sq.m.	%	%	
85%	15%	1	12.3	78.1	57.4	0.1101
		2	14.8	78.2	58.5	0.0965
		3	12.3	78.6	58.2	0.1131
		4	12.8	78.3	57.7	0.1069
		5	14.3	78.1	57.8	0.0967
		6	13.8	78.4	58.0	0.1006
		7	12.3	78.4	57.8	0.1116
		8	12.8	78.1	58.1	0.1139
		9	11.8	78.1	57.9	0.1175
		10	12.8	78.8	57.5	0.1049
			Average			0.1072
			Standard Deviation			0.0073

Table 16. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.12 um Particles

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.12		g/sq.m.	%	%	
80%	20%	1	15.3	78.3	55.1	0.0794
		2	13.8	78.1	54.4	0.0855
		3	14.3	78.3	54.5	0.0825
		4	13.8	78.0	53.8	0.0833
		5	13.3	78.0	52.7	0.0821
		6	14.8	78.2	56.9	0.0894
		7	13.8	78.6	54.5	0.0851
		8	14.8	78.5	54.8	0.0806
		9	13.3	78.5	55.1	0.0908
		10	13.8	78.1	54.8	0.0870
			Average			0.0846
			Standard Deviation			0.0037

Table 17. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.12 um Particles

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.12		g/sq.m.	%	%	
75%	25%	1	14.3	78.8	51.9	0.0728
		2	11.8	78.6	50.6	0.0833
		3	13.3	78.3	50.3	0.0734
		4	13.8	78.7	52.4	0.0772
		5	14.3	78.5	51.3	0.0712
		6	13.8	78.6	51.4	0.0740
		7	14.3	78.5	51.0	0.0702
		8	14.3	78.1	51.6	0.0726
		9	15.3	78.7	51.4	0.0666
		10	14.3	78.3	51.6	0.0724
			Average			0.7340
			Standard Deviation			0.0044

Table 18. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 0.66% Starch

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
100%	0%	1	12.8	77.0	66.4	0.1764
		2	11.8	77.2	65.9	0.1840
		3	12.8	77.7	66.0	0.1681
		4	12.8	77.0	66.1	0.1731
		5	13.8	77.2	66.5	0.1637
		6	12.8	77.6	67.8	0.1888
		7	11.8	78.1	66.7	0.1875
		8	12.3	77.1	66.1	0.1725
		9	12.8	77.9	66.8	0.1753
		10	12.3	78.0	67.8	0.1963
			Average			0.1783
			Standard Deviation			0.0097

Table 19. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 1.32% Starch

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
100%	0%	1	13.8	78.6	67.9	0.1703
		2	13.8	78.2	66.7	0.1602
		3	13.8	78.2	66.4	0.1574
		4	12.8	77.8	66.3	0.1706
		5	13.8	78.1	66.9	0.1628
		6	13.8	77.9	66.9	0.1639
		7	13.8	78.4	66.7	0.1592
		8	14.3	77.6	68.1	0.1728
		9	15.3	78.3	66.2	0.1399
		10	14.3	78.5	67.0	0.1561
			Average			0.1613
			Standard Deviation			0.0095

Table 20. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 1.99% Starch

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
100%	0%	1	12.3	78.1	64.9	0.1620
		2	14.8	78.0	66.2	0.1460
		3	14.3	78.4	67.3	0.1595
		4	14.3	77.6	68.0	0.1717
		5	14.3	78.5	66.9	0.1551
		6	13.3	78.2	65.4	0.1538
		7	13.8	78.5	66.1	0.1531
		8	16.8	78.9	69.9	0.1581
		9	14.8	78.6	67.6	0.1559
		10	13.8	78.4	66.9	0.1611
			Average			0.1576
			Standard Deviation			0.0590

Table 21. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 3.97% Starch

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
100%	0%	1	12.3	78.2	64.0	0.1536
		2	14.3	78.6	66.9	0.1546
		3	11.8	78.9	67.5	0.1918
		4	13.3	78.7	68.0	0.1770
		5	11.8	77.9	65.0	0.1707
		6	12.3	78.1	63.9	0.1532
		7	11.8	78.3	64.6	0.1649
		8	12.3	78.2	64.4	0.1570
		9	12.3	77.4	64.0	0.1571
		10	12.3	78.4	64.8	0.1597
			Average			0.1639
			Standard Deviation			0.0125

Table 22. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 5.96% Starch

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
100%	0%	1	14.3	79.0	64.0	0.1296
		2	15.8	78.8	65.0	0.1247
		3	13.8	79.1	64.6	0.1383
		4	12.8	78.7	64.0	0.1456
		5	14.3	79.2	64.2	0.1303
		6	12.3	78.9	64.8	0.1574
		7	13.8	79.4	67.9	0.1657
		8	12.8	79.0	65.0	0.1526
		9	11.8	78.6	64.1	0.1591
		10	13.3	77.9	64.1	0.1442
			Average			0.1448
			Standard Deviation			0.0139

Table 23. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 9.93% Starch

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
100%	0%	1	10.8	79.1	59.4	0.1350
		2	10.4	78.6	59.9	0.1464
		3	11.4	78.9	60.5	0.1367
		4	11.8	78.5	59.6	0.1265
		5	12.3	77.6	58.3	0.1163
		6	11.8	78.2	59.7	0.1279
		7	12.3	79.3	60.6	0.1254
		8	12.3	78.7	59.6	0.1209
		9	12.3	74.2	56.0	0.1118
		10	11.4	77.1	58.0	0.1258
			Average			0.1273
			Standard Deviation			0.0101

Table 24. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 1.00% Latex

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
100%	0%	1	12.3	77.9	67.6	0.1918
		2	15.8	78.6	70.7	0.1802
		3	15.8	77.9	69.6	0.1716
		4	14.8	77.8	69.3	0.1799
		5	13.3	77.3	66.1	0.1650
		6	13.3	77.6	67.0	0.1727
		7	12.8	77.0	65.8	0.1699
		8	14.8	77.6	67.8	0.1637
		9	14.3	77.6	66.7	0.1579
		10	13.3	77.3	66.8	0.1724
			Average			0.1725
			Standard Deviation			0.0096

Table 25. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 2.00% Latex

Particle size (um) 0.67	0.2	#	Coat Wt. g/sq.m.	Rw %	Rb %	Scattering Coeff.
100%	0%	1	13.8	78.1	66.8	0.1618
		2	13.8	77.3	66.8	0.1663
		3	13.8	77.2	64.7	0.1469
		4	13.3	77.9	66.2	0.1628
		5	13.3	78.1	67.6	0.1763
		6	13.8	77.5	66.4	0.1610
		7	13.3	77.4	65.0	0.1540
		8	14.3	77.5	66.9	0.1605
		9	13.3	77.4	66.7	0.1707
		10	13.8	77.9	65.4	0.1497
			Average			0.1610
			Standard Deviation			0.0090

Table 26. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 3.00% Latex

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
100%	0%	1	12.8	78.7	66.5	0.1677
		2	13.8	78.6	67.9	0.1703
		3	14.8	77.9	66.4	0.1483
		4	14.3	77.6	65.6	0.1477
		5	13.8	78.3	66.1	0.1541
		6	13.8	77.5	65.9	0.1562
		7	12.8	78.3	65.4	0.1592
		8	13.8	77.6	66.0	0.1566
		9	12.8	77.7	66.1	0.1696
		10	13.3	78.1	67.8	0.1786
			Average			0.1608
			Standard Deviation			0.0102

Table 27. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 6.00% Latex

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
100%	0%	1	16.7	79.8	68.9	0.1432
		2	20.3	79.7	70.0	0.1279
		3	20.7	80.0	70.3	0.1260
		4	20.3	79.4	69.6	0.1260
		5	21.2	79.4	69.8	0.1218
		6	20.3	80.3	71.4	0.1375
		7	20.7	79.7	70.8	0.1319
		8	25.6	80.6	73.9	0.1293
		9	20.3	80.1	70.9	0.1339
		10	20.7	79.4	70.1	0.1272
			Average			0.1305
			Standard Deviation			0.0060

Table 28. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 9.00% Latex

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
100%	0%	1	19.3	80.5	69.3	0.1249
		2	22.2	80.1	69.9	0.1141
		3	21.2	79.4	68.0	0.1085
		4	22.2	80.2	69.6	0.1115
		5	22.2	79.9	69.7	0.1134
		6	16.3	79.4	64.5	0.1157
		7	20.2	80.0	68.3	0.1136
		8	18.7	80.0	67.9	0.1197
		9	17.3	79.8	66.4	0.1194
		10	19.2	80.1	68.9	0.1235
			Average			0.1164
			Standard Deviation			0.0052

Table 29. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 15.00% Latex

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
100%	0%	1	16.8	80.5	66.1	0.1190
		2	22.7	80.9	67.6	0.0945
		3	19.7	80.0	64.5	0.0940
		4	19.7	79.6	61.3	0.0805
		5	17.3	80.8	62.2	0.0937
		6	18.3	79.6	61.6	0.0884
		7	18.3	80.7	66.0	0.1081
		8	19.7	80.7	65.7	0.0984
		9	20.7	81.1	66.9	0.0990
		10	21.7	81.0	67.5	0.0980
			Average			0.0974
			Standard Deviation			0.0105

Table 30. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 21.00% Latex

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
100%	0%	1	19.7	79.0	59.2	0.0736
		2	22.2	79.0	59.6	0.0667
		3	23.2	78.8	57.7	0.0585
		4	18.3	78.9	56.0	0.0686
		5	18.3	79.3	57.5	0.0730
		6	17.7	79.3	58.5	0.0786
		7	19.3	79.3	61.4	0.0836
		8	23.2	79.9	63.6	0.0765
		9	19.7	79.6	59.7	0.0745
		10	20.7	79.7	60.1	0.0722
			Average			0.0726
			Standard Deviation			0.0068

Table 31. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 0.66% Starch

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
90%	10%	1	14.3	78.1	64.6	0.1373
		2	13.8	78.5	64.7	0.1414
		3	14.3	77.8	65.5	0.1459
		4	13.3	78.2	65.0	0.1504
		5	13.3	77.6	64.7	0.1504
		6	13.3	78.0	65.3	0.1539
		7	12.8	78.1	62.3	0.1351
		8	13.3	78.8	65.2	0.1494
		9	13.3	78.1	65.4	0.1543
		10	12.3	78.5	65.5	0.1657
			Average			0.1484
			Standard Deviation			0.0089

Table 32. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 1.32% Starch

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
90%	10%	1	13.8	78.4	64.9	0.1434
		2	13.3	78.0	65.0	0.1512
		3	13.8	78.0	64.4	0.1410
		4	14.3	78.0	64.7	0.1385
		5	13.3	77.9	64.1	0.1442
		6	13.8	78.3	64.6	0.1414
		7	12.3	78.1	63.8	0.1523
		8	13.8	78.0	64.6	0.1426
		9	13.3	78.1	65.2	0.1525
		10	13.3	78.6	65.1	0.1495
			Average			0.1456
			Standard Deviation			0.0052

Table 33. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 1.99% Starch

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
90%	10%	1	12.8	78.2	64.3	0.1501
		2	13.3	78.6	64.8	0.1470
		3	13.3	78.6	64.1	0.1414
		4	12.3	77.7	63.9	0.1549
		5	12.8	79.1	64.9	0.1404
		6	12.3	77.9	63.6	0.1515
		7	12.8	79.0	65.5	0.1569
		8	11.8	78.4	64.6	0.1644
		9	13.3	78.9	64.0	0.1395
		10	12.3	78.3	65.2	0.1638
			Average			0.1510
			Standard Deviation			0.0091

Table 34. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 3.97% Starch

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
90%	10%	1	14.8	78.8	63.5	0.1226
		2	14.3	78.3	62.9	0.1245
		3	14.3	78.1	65.1	0.1413
		4	13.8	77.7	63.0	0.1316
		5	12.3	77.6	61.9	0.1394
		6	15.3	77.4	64.0	0.1266
		7	13.8	78.2	62.5	0.1265
		8	13.3	77.3	62.8	0.1365
		9	13.8	77.6	63.4	0.1349
		10	12.8	77.9	62.0	0.1336
			Average			0.1317
			Standard Deviation			0.0064

Table 35. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 5.96% Starch

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
90%	10%	1	12.3	78.5	61.4	0.1329
		2	11.3	78.6	60.9	0.1404
		3	11.8	79.0	61.0	0.1341
		4	12.8	78.8	60.8	0.1230
		5	11.3	78.5	60.6	0.1386
		6	10.4	78.1	61.2	0.1580
		7	10.8	78.3	60.7	0.1464
		8	12.8	78.4	61.3	0.1273
		9	11.8	78.7	61.2	0.1363
		10	11.8	78.7	61.8	0.1406
			Average			0.1377
			Standard Deviation			0.0098

Table 36. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 9.93% Starch

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
90%	10%	1	11.8	76.8	53.9	0.0998
		2	13.8	78.2	59.3	0.1076
		3	14.3	77.1	58.2	0.1008
		4	12.3	78.8	59.1	0.1178
		5	12.3	78.2	57.6	0.1110
		6	11.8	75.0	53.0	0.0988
		7	13.3	78.2	59.5	0.1126
		8	12.8	78.2	59.5	0.1169
		9	12.3	78.7	61.4	0.1323
		10	14.3	78.6	60.0	0.1066
			Average			0.1104
			Standard Deviation			0.0102

Table 37. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 1.00% Latex

Particle size (um) 0.67	0.2	#	Coat Wt. g/sq.m.	Rw %	Rb %	Scattering Coeff.
90%	10%	1	13.8	77.1	64.7	0.1473
		2	13.3	77.3	64.7	0.1518
		3	13.3	77.8	66.4	0.1653
		4	13.3	77.2	64.9	0.1541
		5	14.8	77.7	64.9	0.1366
		6	13.8	77.7	66.1	0.1571
		7	13.8	77.6	65.3	0.1503
		8	13.8	77.3	64.7	0.1464
		9	14.3	77.7	64.8	0.1405
		10	14.8	78.3	66.6	0.1481
			Average			0.1497
			Standard Deviation			0.0081

Table 38. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 2.00% Latex

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
90%	10%	1	13.3	77.9	65.6	0.1571
		2	13.3	77.9	63.7	0.1410
		3	13.3	77.6	64.1	0.1454
		4	12.8	78.3	64.2	0.1488
		5	14.3	78.4	64.1	0.1324
		6	13.3	77.2	63.9	0.1454
		7	13.3	77.7	64.5	0.1483
		8	13.8	77.2	63.3	0.1357
		9	12.8	76.9	63.2	0.1411
		10	13.3	76.9	63.2	0.1411
			Average			0.1436
			Standard Deviation			0.0073

Table 39. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 3.00% Latex

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
90%	10%	1	13.3	77.5	64.3	0.1475
		2	13.3	77.2	63.7	0.1438
		3	13.3	77.2	64.1	0.1471
		4	13.3	77.9	66.6	0.1668
		5	14.3	77.7	64.3	0.1366
		6	12.8	78.0	63.5	0.1444
		7	13.3	76.9	63.3	0.1418
		8	13.8	77.8	64.7	0.1442
		9	12.8	77.3	64.0	0.1458
		10	13.8	78.2	65.5	0.1492
			Average			0.1467
			Standard Deviation			0.0079

Table 40. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 6.00% Latex

Particle size (um) 0.67	0.2	#	Coat Wt. g/sq.m.	Rw %	Rb %	Scattering Coeff.
90%	10%	1	21.7	80.8	71.3	0.1247
		2	20.2	79.8	67.9	0.1116
		3	22.2	79.9	69.2	0.1098
		4	18.7	79.7	68.2	0.1231
		5	21.7	79.8	70.4	0.1220
		6	19.2	79.8	68.3	0.1203
		7	20.2	80.0	68.8	0.1172
		8	21.7	80.6	70.8	0.1215
		9	21.2	80.4	70.6	0.1236
		10	21.7	80.0	69.8	0.1163
			Average			0.1190
			Standard Deviation			0.0051

Table 41. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 9.00% Latex

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
90%	10%	1	21.7	80.1	67.8	0.1024
		2	21.7	80.0	67.7	0.1021
		3	22.2	80.5	70.1	0.1139
		4	25.2	80.8	71.1	0.1061
		5	23.7	81.2	72.7	0.1240
		6	22.2	80.2	68.8	0.1060
		7	20.2	79.4	64.1	0.0911
		8	20.2	79.6	64.0	0.0902
		9	20.2	79.7	67.9	0.1120
		10	21.7	80.3	68.3	0.1048
			Average			0.1053
			Standard Deviation			0.0101

Table 42. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 15.00% Latex

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
90%	10%	1	20.2	80.0	62.7	0.0844
		2	18.7	80.1	64.2	0.0972
		3	19.7	79.5	61.6	0.0819
		4	19.2	79.6	63.2	0.0909
		5	19.2	79.8	61.3	0.0822
		6	18.3	79.9	62.7	0.0928
		7	18.3	79.5	62.8	0.0941
		8	19.7	79.5	62.3	0.0849
		9	21.7	80.4	65.4	0.0887
		10	18.3	79.5	62.7	0.0937
			Average			0.0891
			Standard Deviation			0.0055

Table 43. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 21.00% Latex

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
90%	10%	1	20.7	80.2	57.5	0.0000
		2	21.7	79.7	57.7	0.0614
		3	21.7	79.3	58.1	0.0631
		4	21.7	79.3	57.0	0.0599
		5	21.2	80.7	61.7	0.0746
		6	18.7	80.1	56.2	0.0000
		7	19.2	79.4	53.8	0.0000
		8	22.2	79.5	61.2	0.0714
		9	20.2	80.8	59.5	0.0000
		10	20.2	79.9	55.7	0.0000
			Average			0.0661
			Standard Deviation			0.0065

Table 44. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 0.66% Starch

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
80%	20%	1	14.3	76.4	61.3	0.1201
		2	13.8	76.9	60.7	0.1189
		3	13.8	76.4	60.0	0.1161
		4	13.3	76.7	59.5	0.1165
		5	13.3	76.3	60.0	0.1207
		6	12.3	77.1	60.2	0.1291
		7	11.8	76.1	58.9	0.1289
		8	11.8	76.2	57.9	0.1223
		9	11.8	77.2	58.9	0.1257
		10	10.9	76.2	58.2	0.1355
			Average			0.1234
			Standard Deviation			0.0062

Table 45. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 1.32% Starch

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
80%	20%	1	13.3	77.7	61.2	0.1241
		2	12.3	77.6	60.6	0.1303
		3	12.8	77.2	59.4	0.1190
		4	12.8	77.3	60.3	0.1242
		5	11.8	77.6	59.8	0.1303
		6	12.3	77.3	61.0	0.1340
		7	12.8	78.0	60.3	0.1222
		8	12.3	77.5	60.2	0.1280
		9	12.8	78.1	61.6	0.1303
		10	11.8	77.6	60.3	0.1337
			Average			0.1276
			Standard Deviation			0.0050

Table 46. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 1.99% Starch

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
80%	20%	1	13.3	78.3	62.9	0.1336
		2	13.3	77.7	62.8	0.1350
		3	14.8	78.0	61.8	0.1144
		4	14.3	77.3	60.5	0.1126
		5	12.3	78.4	63.3	0.1471
		6	14.8	78.0	61.7	0.1138
		7	13.8	78.2	60.9	0.1165
		8	14.8	78.1	61.4	0.1118
		9	12.8	77.8	60.3	0.1228
		10	12.8	77.9	62.0	0.1336
			Average			0.1241
			Standard Deviation			0.0123

Table 47. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 3.97% Starch

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
80%	20%	1	10.8	77.5	59.6	0.1412
		2	10.8	77.6	59.1	0.1374
		3	11.4	77.9	58.2	0.1284
		4	11.4	77.8	60.3	0.1388
		5	13.8	77.8	60.2	0.1135
		6	12.3	77.6	59.9	0.1258
		7	11.4	78.2	59.7	0.1335
		8	11.8	77.4	59.2	0.1271
		9	10.8	78.0	60.6	0.1468
		10	12.3	78.1	60.4	0.1275
			Average			0.1320
			Standard Deviation			0.0095

Table 48. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 5.96% Starch

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
80%	20%	1	11.3	78.6	57.4	0.1184
		2	11.8	77.7	56.1	0.1087
		3	12.3	77.6	58.4	0.1168
		4	12.3	77.9	58.7	0.1177
		5	11.3	77.7	56.6	0.1161
		6	11.3	77.5	57.4	0.1211
		7	11.3	77.6	56.6	0.1163
		8	10.8	78.2	58.6	0.1324
		9	10.8	78.4	58.5	0.1312
		10	11.3	77.7	57.3	0.1201
			Average			0.1191
			Standard Deviation			0.0071

Table 49. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 9.93% Starch

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
80%	20%	1	11.3	78.0	51.9	0.0930
		2	11.3	76.9	51.5	0.0930
		3	11.8	78.0	54.9	0.1021
		4	12.3	78.1	54.8	0.0975
		5	12.3	77.1	52.8	0.0906
		6	12.3	77.1	53.0	0.0914
		7	11.3	78.5	54.3	0.1028
		8	10.8	77.9	54.6	0.1102
		9	10.3	77.8	54.2	0.1135
		10	10.8	78.4	54.5	0.1087
			Average			0.1003
			Standard Deviation			0.0084

Table 50. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 1.00% Latex

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
80%	20%	1	14.8	76.8	61.3	0.1148
		2	13.8	76.8	61.0	0.1130
		3	13.3	76.4	60.3	0.1223
		4	13.8	77.1	61.4	0.1228
		5	12.8	77.0	61.0	0.1297
		6	12.8	76.6	61.3	0.1331
		7	13.3	77.0	61.5	0.1283
		8	14.3	77.0	61.9	0.1220
		9	16.7	76.7	64.8	0.1235
		10	17.3	78.2	67.0	0.1305
			Average			0.1240
			Standard Deviation			0.0065

Table 51. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 2.00% Latex

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
80%	20%	1	12.3	77.0	60.6	0.1322
		2	12.3	78.0	60.4	0.1278
		3	12.3	77.5	60.5	0.1300
		4	11.3	77.3	60.7	0.1433
		5	12.3	77.9	62.0	0.1391
		6	11.8	76.8	60.2	0.1355
		7	12.3	76.9	60.4	0.1312
		8	11.8	76.7	59.7	0.1324
		9	11.8	77.3	60.9	0.1388
		10	12.3	77.8	62.6	0.1439
			Average			0.1354
			Standard Deviation			0.0056

Table 52. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 3.00% Latex

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
80%	20%	1	13.8	78.2	64.9	0.1420
		2	12.8	77.2	61.1	0.1298
		3	13.3	77.3	60.3	0.1196
		4	13.3	76.9	60.6	0.1227
		5	13.3	76.9	59.5	0.1160
		6	13.8	77.3	62.7	0.1309
		7	12.3	77.0	61.4	0.1378
		8	13.3	77.5	60.7	0.1214
		9	12.3	76.8	60.5	0.1322
		10	12.8	77.4	63.2	0.1444
			Average			0.1299
			Standard Deviation			0.0100

Table 53. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 6.00% Latex

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
80%	20%	1	14.3	79.0	60.2	0.1066
		2	16.3	79.2	64.4	0.1157
		3	16.8	79.0	63.8	0.1093
		4	14.8	78.6	61.7	0.1121
		5	19.2	79.4	67.0	0.1127
		6	16.8	79.5	64.7	0.1133
		7	16.3	79.7	64.2	0.1124
		8	18.7	79.1	64.5	0.1013
		9	19.7	79.4	66.2	0.1049
		10	15.3	79.0	60.8	0.1003
			Average			0.1091
			Standard Deviation			0.0049

Table 54. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 9.00% Latex

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
80%	20%	1	19.2	79.4	63.8	0.0943
		2	21.7	80.6	69.4	0.1110
		3	19.2	80.0	64.1	0.0944
		4	20.7	80.5	68.7	0.1118
		5	20.7	80.0	67.4	0.1051
		6	21.2	80.5	69.0	0.1112
		7	21.2	79.7	67.6	0.1049
		8	21.2	79.4	64.8	0.0903
		9	17.7	79.5	63.2	0.0988
		10	19.2	79.5	65.5	0.1031
			Average			0.1025
			Standard Deviation			0.0077

Table 55. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 15.00% Latex

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
80%	20%	1	17.8	79.3	60.9	0.0883
		2	19.2	79.1	59.0	0.0746
		3	19.2	78.9	59.5	0.0768
		4	18.7	79.4	59.9	0.0795
		5	19.2	79.4	62.6	0.0886
		6	19.2	79.3	60.7	0.0807
		7	18.7	79.3	60.6	0.0825
		8	18.7	79.2	62.0	0.0886
		9	18.3	79.5	60.4	0.0835
		10	17.3	79.0	59.2	0.0842
			Average			0.0827
			Standard Deviation			0.0049

Table 56. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 21.00% Latex

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
80%	20%	1	17.8	78.5	52.6	0.0608
		2	17.8	78.6	53.3	0.0626
		3	16.8	79.3	53.6	0.0000
		4	15.3	78.8	50.3	0.0000
		5	15.8	79.0	51.0	0.0000
		6	16.3	79.0	52.4	0.0000
		7	16.8	78.6	50.9	0.0000
		8	16.8	79.8	53.8	0.0000
		9	18.7	78.4	57.7	0.0730
		10	14.3	79.2	50.1	0.0000
			Average			0.0654
			Standard Deviation			0.0065

Table 57. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 0.66% Starch

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
60%	40%	1	15.8	77.2	61.0	0.1049
		2	13.8	75.7	58.1	0.1071
		3	14.3	75.4	58.3	0.1052
		4	13.3	75.3	56.9	0.1055
		5	13.8	76.2	58.3	0.1070
		6	13.8	75.6	58.5	0.1096
		7	13.3	75.9	57.4	0.0680
		8	13.3	75.5	57.7	0.1094
		9	12.8	76.4	57.6	0.1107
		10	16.3	77.5	62.2	0.1075
			Average			0.1074
			Standard Deviation			0.0019

Table 58. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 1.32% Starch

Particle size (um) 0.67	0.2	#	Coat Wt. g/sq.m.	Rw %	Rb %	Scattering Coeff.
60%	40%	1	13.3	76.9	57.7	0.1060
		2	12.3	77.1	57.5	0.1130
		3	12.3	77.0	58.4	0.1183
		4	11.3	77.1	57.9	0.1251
		5	12.8	77.4	57.5	0.1079
		6	13.8	77.3	58.8	0.1070
		7	13.3	77.4	58.4	0.1086
		8	11.8	76.9	58.1	0.1217
		9	12.8	76.6	58.0	0.1124
		10	12.3	77.4	58.4	0.1173
			Average			0.1137
			Standard Deviation			0.0066

Table 59. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 1.99% Starch

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
60%	40%	1	11.8	77.3	57.0	0.1144
		2	12.3	77.7	57.1	0.1094
		3	12.3	77.6	56.6	0.1071
		4	11.3	76.8	56.0	0.1149
		5	13.3	77.1	57.4	0.1041
		6	13.3	77.8	60.1	0.1171
		7	10.8	77.7	56.4	0.1203
		8	12.3	76.9	57.9	0.1157
		9	11.8	77.3	56.2	0.1101
		10	10.8	76.9	55.8	0.1188
			Average			0.1132
			Standard Deviation			0.0052

Table 60. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 3.97% Starch

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
60%	40%	1	13.3	77.1	58.1	0.1077
		2	11.3	77.5	57.5	0.1217
		3	16.3	77.4	60.4	0.0982
		4	10.8	77.3	57.1	0.1254
		5	13.3	77.5	59.0	0.1116
		6	13.3	77.4	59.0	0.1119
		7	14.3	77.8	61.2	0.1154
		8	13.3	77.4	58.3	0.1081
		9	13.8	78.1	60.2	0.1127
		10	12.8	77.8	58.4	0.1118
			Average			0.1125
			Standard Deviation			0.0075

Table 61. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 5.96% Starch

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
60%	40%	1	9.9	77.5	54.7	0.1227
		2	10.4	77.5	55.3	0.1202
		3	10.4	77.7	56.6	0.1272
		4	10.4	77.2	54.8	0.1180
		5	11.8	77.2	55.1	0.1047
		6	12.3	78.0	55.2	0.0995
		7	11.8	77.7	54.8	0.1023
		8	11.3	77.5	55.1	0.1086
		9	12.8	77.8	56.5	0.1021
		10	10.8	77.9	54.6	0.1102
			Average			0.1115
			Standard Deviation			0.0097

Table 62. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 9.93% Starch

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
60%	40%	1	11.3	77.7	51.9	0.0935
		2	10.8	78.6	52.0	0.0968
		3	12.8	78.4	55.4	0.0958
		4	12.8	78.3	52.3	0.0834
		5	14.3	77.5	52.8	0.0776
		6	11.3	78.3	53.2	0.0981
		7	11.3	77.3	51.4	0.0920
		8	13.8	77.0	54.6	0.0881
		9	12.8	78.1	56.4	0.1010
		10	11.8	77.9	51.2	0.0865
			Average			0.0913
			Standard Deviation			0.0072

Table 63. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 1.00% Latex

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
60%	40%	1	14.3	77.0	58.4	0.1020
		2	13.8	76.7	58.7	0.1079
		3	14.3	76.4	58.8	0.1055
		4	13.8	76.5	59.5	0.1129
		5	13.3	77.0	60.2	0.1199
		6	13.3	77.1	58.8	0.1114
		7	13.8	76.5	59.0	0.1101
		8	13.8	77.0	58.3	0.1051
		9	13.8	77.1	58.6	0.1064
		10	13.8	77.3	61.5	0.1228
			Average			0.1104
			Standard Deviation			0.0060

Table 64. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 2.00% Latex

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
60%	40%	1	12.8	76.7	58.5	0.1150
		2	12.8	76.9	57.6	0.1095
		3	13.3	76.7	58.6	0.1113
		4	13.3	77.4	58.4	0.1086
		5	12.8	77.4	59.6	0.1196
		6	12.8	77.0	59.1	0.1177
		7	12.3	76.9	58.2	0.1174
		8	12.8	77.0	58.2	0.1126
		9	12.8	76.9	59.0	0.1174
		10	13.3	77.5	59.4	0.1138
			Average			0.1143
			Standard Deviation			0.0037

Table 65. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 3.00% Latex

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
60%	40%	1	13.8	78.2	62.1	0.1239
		2	12.3	77.7	58.8	0.1188
		3	13.3	76.5	57.8	0.1075
		4	12.8	77.2	61.8	0.1346
		5	14.3	77.6	59.7	0.1074
		6	13.3	76.2	58.5	0.1120
		7	12.8	76.8	59.8	0.1225
		8	13.3	77.4	58.0	0.1065
		9	13.3	77.6	58.5	0.1086
		10	13.3	77.9	61.0	0.1222
			Average			0.1164
			Standard Deviation			0.0094

Table 66. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 6.00% Latex

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
60%	40%	1	16.8	79.2	66.0	0.1228
		2	16.8	77.1	60.7	0.0975
		3	14.8	78.1	62.3	0.1171
		4	21.2	78.4	66.2	0.1006
		5	17.8	78.6	64.8	0.1102
		6	16.8	77.4	60.2	0.0943
		7	18.3	78.1	62.5	0.0960
		8	16.8	78.3	62.4	0.1034
		9	19.2	78.3	65.0	0.1038
		10	15.8	77.5	60.0	0.0990
			Average			0.1044
			Standard Deviation			0.0094

Table 67. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 9.00% Latex

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
60%	40%	1	17.3	78.7	62.1	0.0979
		2	17.3	78.8	62.4	0.0992
		3	16.8	79.3	63.4	0.1062
		4	14.8	78.1	60.7	0.1078
		5	17.8	79.0	63.2	0.1000
		6	15.8	78.5	62.0	0.1071
		7	17.3	79.0	63.8	0.1062
		8	21.2	78.6	63.4	0.0855
		9	15.3	78.2	61.3	0.1074
		10	18.8	79.5	62.7	0.0912
			Average			0.1008
			Standard Deviation			0.0076

Table 68. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 15.00% Latex

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
60%	40%	1	14.8	78.0	56.6	0.0885
		2	16.3	77.9	56.0	0.0784
		3	15.8	78.3	58.0	0.0882
		4	13.8	77.7	53.9	0.0841
		5	15.3	77.5	53.9	0.0762
		6	23.7	78.3	62.7	0.0743
		7	17.3	77.9	56.3	0.0750
		8	15.3	77.8	53.6	0.0748
		9	15.8	78.5	59.5	0.0944
		10	12.3	78.1	55.5	0.1007
			Average			0.0834
			Standard Deviation			0.0093

Table 69. Calculation of Scattering Coefficient for the Mixture of 0.67 and 0.2 um Particles and 21.00% Latex

Particle size (um)		#	Coat Wt.	Rw	Rb	Scattering Coeff.
0.67	0.2		g/sq.m.	%	%	
60%	40%	1	17.8	79.1	57.1	0.0739
		2	18.3	79.1	52.3	0.0000
		3	17.8	78.7	49.1	0.0000
		4	16.3	79.0	48.4	0.0000
		5	19.2	78.7	53.3	0.0533
		6	16.3	78.9	52.6	0.0659
		7	16.8	79.1	48.7	0.0000
		8	18.3	78.8	53.9	0.0624
		9	16.3	77.9	49.4	0.0580
		10	18.3	79.0	54.3	0.0633
			Average			0.0628
			Standard Deviation			0.0070

Appendix D

Calculation of Pore Volume

Calculation of Pore Volume

$$PV = \frac{(O/SGo) * 100}{[(O/SGo) + (P/SGp) + (B/SGb)]}$$

where:

PV = Pore Volume (%)

P = Weight of pigment (grams)

B = Weight of binder (grams)

O = Weight of oil absorbed (grams)

SGp = Specific Gravity of the pigment (g/cc)

SGb = Specific Gravity of the binder (g/cc)

SGo = Specific Gravity of the oil (g/cc)

Table 70. Calculation of Percent Pore Volume for the Mixture of 100% 0.67 um Particles With Binder (Latex)

Binder %	Coated Wt g	Coat Wt g	Total Wt g	Oil Wt g	Coat Vol cc	Oil Vol cc	Total Vol cc	Pore Vol %	Av. P Vol %
1.00	0.171	0.026	0.182	0.011	0.025	0.013	0.038	34.147	34.2
	0.177	0.032	0.191	0.014	0.030	0.016	0.047	34.905	
	0.177	0.032	0.191	0.014	0.030	0.016	0.047	34.905	
	0.175	0.030	0.188	0.013	0.029	0.015	0.044	34.688	
	0.173	0.028	0.184	0.011	0.027	0.013	0.040	32.501	
2.00	0.174	0.029	0.192	0.018	0.028	0.021	0.049	43.206	42.6
	0.174	0.029	0.192	0.018	0.028	0.021	0.049	43.206	
	0.173	0.028	0.189	0.016	0.027	0.019	0.045	41.189	
	0.172	0.027	0.188	0.016	0.026	0.019	0.044	42.073	
	0.172	0.027	0.189	0.017	0.026	0.020	0.046	43.557	
3.00	0.172	0.027	0.186	0.014	0.026	0.016	0.042	38.857	34.0
	0.172	0.027	0.183	0.011	0.026	0.013	0.039	33.304	
	0.175	0.030	0.183	0.008	0.029	0.009	0.038	24.633	
	0.172	0.027	0.186	0.014	0.026	0.016	0.042	38.857	
	0.173	0.028	0.185	0.012	0.027	0.014	0.041	34.438	
6.00	0.180	0.035	0.197	0.017	0.033	0.020	0.053	37.316	34.3
	0.186	0.041	0.203	0.017	0.039	0.020	0.059	33.695	
	0.186	0.041	0.203	0.017	0.039	0.020	0.059	33.695	
	0.187	0.042	0.202	0.015	0.040	0.018	0.058	30.446	
	0.185	0.040	0.204	0.019	0.038	0.022	0.060	36.796	
9.00	0.185	0.040	0.201	0.016	0.038	0.019	0.057	32.897	29.9
	0.190	0.045	0.208	0.018	0.043	0.021	0.064	32.897	
	0.191	0.046	0.204	0.013	0.044	0.015	0.059	25.726	
	0.191	0.046	0.206	0.015	0.044	0.018	0.061	28.554	
	0.189	0.044	0.204	0.015	0.042	0.018	0.059	29.470	

Table 71. Calculation of Percent Pore Volume for the Mixture of 100% 0.67 um Particles With Binder (Starch)

Binder %	Coated Wt g	Coat Wt g	Total Wt g	Oil Wt g	Coat Vol cc	Oil Vol cc	Total Vol cc	Pore Vol %	Av. P Vol
0.66	0.169	0.024	0.183	0.014	0.023	0.016	0.039	41.689	36.4
	0.172	0.027	0.182	0.010	0.026	0.012	0.037	31.221	
	0.171	0.026	0.185	0.014	0.025	0.016	0.041	39.757	
	0.172	0.027	0.183	0.011	0.026	0.013	0.039	33.304	
	0.173	0.028	0.186	0.013	0.027	0.015	0.042	36.267	
1.32	0.172	0.027	0.185	0.013	0.026	0.015	0.041	37.112	38.8
	0.172	0.027	0.185	0.013	0.026	0.015	0.041	37.112	
	0.173	0.028	0.186	0.013	0.027	0.015	0.042	36.267	
	0.170	0.025	0.186	0.016	0.024	0.019	0.042	43.959	
	0.173	0.028	0.188	0.015	0.027	0.018	0.044	39.635	
1.99	0.172	0.027	0.184	0.012	0.026	0.014	0.040	35.264	34.5
	0.176	0.031	0.187	0.011	0.030	0.013	0.042	30.309	
	0.175	0.030	0.189	0.014	0.029	0.016	0.045	36.385	
	0.175	0.030	0.188	0.013	0.029	0.015	0.044	34.688	
	0.173	0.028	0.186	0.013	0.027	0.015	0.042	36.267	
3.97	0.168	0.023	0.180	0.012	0.022	0.014	0.036	39.004	34.1
	0.169	0.024	0.183	0.014	0.023	0.016	0.039	41.689	
	0.175	0.030	0.185	0.010	0.029	0.012	0.040	29.005	
	0.176	0.031	0.186	0.010	0.030	0.012	0.041	28.334	
	0.170	0.025	0.180	0.010	0.024	0.012	0.035	32.897	
5.96	0.173	0.028	0.185	0.012	0.027	0.014	0.041	34.438	34.3
	0.172	0.027	0.183	0.011	0.026	0.013	0.039	33.304	
	0.174	0.029	0.188	0.014	0.028	0.016	0.044	37.173	
	0.172	0.027	0.184	0.012	0.026	0.014	0.040	35.264	
	0.174	0.029	0.185	0.011	0.028	0.013	0.040	31.736	
9.93	0.166	0.021	0.178	0.012	0.020	0.014	0.034	41.189	28.8
	0.169	0.024	0.176	0.007	0.023	0.008	0.031	26.334	
	0.171	0.026	0.177	0.006	0.025	0.007	0.032	22.048	
	0.169	0.024	0.176	0.007	0.023	0.008	0.031	26.334	
	0.170	0.025	0.178	0.008	0.024	0.009	0.033	28.171	

Table 72. Calculation of Percent Pore Volume for the Mixture of 90% 0.67 um and 10% 0.2 um Particles With Binder (Latex)

Binder %	Coated Wt g	Coat Wt g	Total Wt g	Oil Wt g	Coat vol cc	Oil vol cc	Total Vol cc	Pore Vol %	Av. P Vol %
1.00	0.173	0.028	0.182	0.009	0.027	0.011	0.037	28.262	29.8
	0.171	0.026	0.181	0.010	0.025	0.012	0.036	32.037	
	0.174	0.029	0.184	0.010	0.028	0.012	0.039	29.708	
	0.172	0.027	0.182	0.010	0.026	0.012	0.037	31.221	
	0.173	0.028	0.182	0.009	0.027	0.011	0.037	28.262	
2.00	0.170	0.025	0.184	0.014	0.024	0.016	0.040	40.700	36.1
	0.172	0.027	0.184	0.012	0.026	0.014	0.040	35.264	
	0.171	0.026	0.184	0.013	0.025	0.015	0.040	37.997	
	0.172	0.027	0.183	0.011	0.026	0.013	0.039	33.304	
	0.172	0.027	0.183	0.011	0.026	0.013	0.039	33.304	
3.00	0.172	0.027	0.186	0.014	0.026	0.016	0.042	38.857	34.0
	0.172	0.027	0.183	0.011	0.026	0.013	0.039	33.304	
	0.175	0.030	0.183	0.008	0.029	0.009	0.038	24.633	
	0.172	0.027	0.186	0.014	0.026	0.016	0.042	38.857	
	0.173	0.028	0.185	0.012	0.027	0.014	0.041	34.438	
6.00	0.189	0.044	0.203	0.014	0.042	0.016	0.058	28.056	26.7
	0.184	0.039	0.194	0.010	0.037	0.012	0.049	23.912	
	0.189	0.044	0.203	0.014	0.042	0.016	0.058	28.056	
	0.184	0.039	0.196	0.012	0.037	0.014	0.051	27.385	
	0.190	0.045	0.203	0.013	0.043	0.015	0.058	26.149	
9.00	0.185	0.040	0.199	0.014	0.038	0.016	0.054	30.020	27.8
	0.189	0.044	0.204	0.015	0.042	0.018	0.059	29.470	
	0.189	0.044	0.203	0.014	0.042	0.016	0.058	28.056	
	0.195	0.050	0.206	0.011	0.048	0.013	0.060	21.237	
	0.193	0.048	0.210	0.017	0.046	0.020	0.066	30.269	

Table 73. Calculation of Percent Pore Volume for the Mixture of 90% 0.67 um and 10% 0.2 um Particles With Binder (Latex)

Binder %	Coated Wt g	Coat Wt g	Total Wt g	Oil Wt g	Coat Vol cc	Oil Vol cc	Total Vol cc	Pore Vol %	Av. P Vol %
0.66	0.175	0.030	0.186	0.011	0.029	0.013	0.041	31.006	32.9
	0.173	0.028	0.185	0.012	0.027	0.014	0.041	34.438	
	0.174	0.029	0.183	0.009	0.028	0.011	0.038	27.556	
	0.172	0.027	0.185	0.013	0.026	0.015	0.041	37.112	
	0.173	0.028	0.185	0.012	0.027	0.014	0.041	34.438	
1.32	0.173	0.028	0.186	0.013	0.027	0.015	0.042	36.267	35.3
	0.174	0.029	0.185	0.011	0.028	0.013	0.040	31.736	
	0.174	0.029	0.186	0.012	0.028	0.014	0.042	33.650	
	0.174	0.029	0.188	0.014	0.028	0.016	0.044	37.173	
	0.171	0.026	0.184	0.013	0.025	0.015	0.040	37.997	
1.99	0.170	0.025	0.183	0.013	0.024	0.015	0.039	38.925	34.0
	0.172	0.027	0.182	0.010	0.026	0.012	0.037	31.221	
	0.171	0.026	0.184	0.013	0.025	0.015	0.040	37.997	
	0.170	0.025	0.180	0.010	0.024	0.012	0.035	32.897	
	0.172	0.027	0.181	0.009	0.026	0.011	0.036	29.005	
3.97	0.178	0.033	0.187	0.009	0.031	0.011	0.042	25.052	28.6
	0.173	0.028	0.182	0.009	0.027	0.011	0.037	28.262	
	0.176	0.031	0.185	0.009	0.030	0.011	0.040	26.244	
	0.175	0.030	0.185	0.010	0.029	0.012	0.040	29.005	
	0.173	0.028	0.185	0.012	0.027	0.014	0.041	34.438	
5.96	0.172	0.027	0.181	0.009	0.026	0.011	0.036	29.005	33.7
	0.170	0.025	0.180	0.010	0.024	0.012	0.035	32.897	
	0.169	0.024	0.180	0.011	0.023	0.013	0.036	35.969	
	0.170	0.025	0.182	0.012	0.024	0.014	0.038	37.040	
	0.169	0.024	0.179	0.010	0.023	0.012	0.035	33.805	
9.93	0.171	0.026	0.178	0.007	0.025	0.008	0.033	24.811	24.2
	0.173	0.028	0.179	0.006	0.027	0.007	0.034	20.801	
	0.175	0.030	0.182	0.007	0.029	0.008	0.037	22.238	
	0.170	0.025	0.179	0.009	0.024	0.011	0.034	30.615	
	0.170	0.025	0.176	0.006	0.024	0.007	0.031	22.729	

Table 74. Calculation of Percent Pore Volume for the Mixture of 80% 0.67 um and 20% 0.2 um Particles With Binder (Latex)

Binder %	Coated Wt g	Coat Wt g	Total Wt g	Oil Wt g	Coat vol cc	Oil vol cc	Total Vol cc	Pore Vol %	Av. P Vol %
1.00	0.175	0.030	0.187	0.012	0.029	0.014	0.043	32.897	33.3
	0.175	0.030	0.187	0.012	0.029	0.014	0.043	32.897	
	0.172	0.027	0.184	0.012	0.026	0.014	0.040	35.264	
	0.176	0.031	0.186	0.010	0.030	0.012	0.041	28.334	
	0.172	0.027	0.185	0.013	0.026	0.015	0.041	37.112	
2.00	0.170	0.025	0.180	0.010	0.024	0.012	0.035	32.897	33.0
	0.170	0.025	0.180	0.010	0.024	0.012	0.035	32.897	
	0.171	0.026	0.180	0.009	0.025	0.011	0.035	29.788	
	0.168	0.023	0.179	0.011	0.022	0.013	0.035	36.955	
	0.170	0.025	0.180	0.010	0.024	0.012	0.035	32.897	
3.00	0.174	0.029	0.186	0.012	0.028	0.014	0.042	33.650	36.8
	0.170	0.025	0.183	0.013	0.024	0.015	0.039	38.925	
	0.173	0.028	0.183	0.010	0.027	0.012	0.038	30.446	
	0.170	0.025	0.186	0.016	0.024	0.019	0.042	43.959	
	0.172	0.027	0.185	0.013	0.026	0.015	0.041	37.112	
6.00	0.173	0.028	0.181	0.008	0.027	0.009	0.036	25.936	30.9
	0.179	0.034	0.192	0.013	0.032	0.015	0.048	31.909	
	0.179	0.034	0.190	0.011	0.032	0.013	0.045	28.394	
	0.172	0.027	0.184	0.012	0.026	0.014	0.040	35.264	
	0.182	0.037	0.197	0.015	0.035	0.018	0.053	33.194	
9.00	0.185	0.040	0.195	0.010	0.038	0.012	0.050	23.454	23.4
	0.192	0.047	0.202	0.010	0.045	0.012	0.056	20.684	
	0.183	0.038	0.195	0.012	0.036	0.014	0.050	27.904	
	0.188	0.043	0.201	0.013	0.041	0.015	0.056	27.036	
	0.189	0.044	0.197	0.008	0.042	0.009	0.051	18.223	

Table 75. Calculation of Percent Pore Volume for the Mixture of 80% 0.67 um and 20% 0.2 um Particles With Binder (Starch)

Binder %	Coated Wt g	Coat Wt g	Total Wt g	Oil Wt g	Coat vol cc	Oil vol cc	Total Vol cc	Pore Vol %	Av. P Vol %
0.66	0.172	0.027	0.185	0.013	0.026	0.015	0.041	37.112	34.1
	0.173	0.028	0.184	0.011	0.027	0.013	0.040	32.501	
	0.172	0.027	0.182	0.010	0.026	0.012	0.037	31.221	
	0.171	0.026	0.181	0.010	0.025	0.012	0.036	32.037	
	0.171	0.026	0.184	0.013	0.025	0.015	0.040	37.997	
1.32	0.170	0.025	0.179	0.009	0.024	0.011	0.034	30.615	31.9
	0.170	0.025	0.178	0.008	0.024	0.009	0.033	28.171	
	0.172	0.027	0.181	0.009	0.026	0.011	0.036	29.005	
	0.168	0.023	0.179	0.011	0.022	0.013	0.035	36.955	
	0.168	0.023	0.178	0.010	0.022	0.012	0.034	34.763	
1.99	0.173	0.028	0.182	0.009	0.027	0.011	0.037	28.262	28.8
	0.173	0.028	0.183	0.010	0.027	0.012	0.038	30.446	
	0.176	0.031	0.185	0.009	0.030	0.011	0.040	26.244	
	0.173	0.028	0.183	0.010	0.027	0.012	0.038	30.446	
	0.172	0.027	0.181	0.009	0.026	0.011	0.036	29.005	
3.97	0.167	0.022	0.179	0.012	0.021	0.014	0.035	40.067	34.6
	0.170	0.025	0.183	0.013	0.024	0.015	0.039	38.925	
	0.169	0.024	0.175	0.006	0.023	0.007	0.030	23.454	
	0.166	0.021	0.178	0.012	0.020	0.014	0.034	41.189	
	0.171	0.026	0.180	0.009	0.025	0.011	0.035	29.788	
5.96	0.168	0.023	0.175	0.007	0.022	0.008	0.030	27.168	27.2
	0.168	0.023	0.176	0.008	0.022	0.009	0.031	29.889	
	0.170	0.025	0.177	0.007	0.024	0.008	0.032	25.550	
	0.171	0.026	0.178	0.007	0.025	0.008	0.033	24.811	
	0.169	0.024	0.177	0.008	0.023	0.009	0.032	29.005	
9.93	0.167	0.022	0.176	0.009	0.021	0.011	0.031	33.395	37.3
	0.165	0.020	0.175	0.010	0.019	0.012	0.031	37.997	
	0.165	0.020	0.179	0.014	0.019	0.016	0.035	46.177	
	0.168	0.023	0.179	0.011	0.022	0.013	0.035	36.955	
	0.168	0.023	0.177	0.009	0.022	0.011	0.032	32.414	

Table 76. Calculation of Percent Pore Volume for the Mixture of 60% 0.67 um and 40% 0.2 um Particles With Binder (Latex)

Binder %	Coated Wt g	Coat Wt g	Total Wt g	Oil Wt g	Coat vol cc	Oil vol cc	Total Vol cc	Pore Vol %	Av. P Vol %
1.00	0.172	0.027	0.184	0.012	0.026	0.014	0.040	35.264	34.2
	0.175	0.030	0.186	0.011	0.029	0.013	0.041	31.006	
	0.173	0.028	0.184	0.011	0.027	0.013	0.040	32.501	
	0.174	0.029	0.186	0.012	0.028	0.014	0.042	33.650	
	0.172	0.027	0.186	0.014	0.026	0.016	0.042	38.857	
2.00	0.171	0.026	0.179	0.008	0.025	0.009	0.034	27.385	27.4
	0.171	0.026	0.180	0.009	0.025	0.011	0.035	29.788	
	0.173	0.028	0.182	0.009	0.027	0.011	0.037	28.262	
	0.173	0.028	0.181	0.008	0.027	0.009	0.036	25.936	
	0.173	0.028	0.181	0.008	0.027	0.009	0.036	25.936	
3.00	0.173	0.028	0.187	0.014	0.027	0.016	0.043	37.997	36.1
	0.172	0.027	0.183	0.011	0.026	0.013	0.039	33.304	
	0.173	0.028	0.184	0.011	0.027	0.013	0.040	32.501	
	0.172	0.027	0.186	0.014	0.026	0.016	0.042	38.857	
	0.173	0.028	0.187	0.014	0.027	0.016	0.043	37.997	
6.00	0.179	0.034	0.189	0.010	0.032	0.012	0.044	26.497	27.5
	0.179	0.034	0.189	0.010	0.032	0.012	0.044	26.497	
	0.175	0.030	0.186	0.011	0.029	0.013	0.041	31.006	
	0.189	0.044	0.202	0.013	0.042	0.015	0.057	26.585	
	0.181	0.036	0.192	0.011	0.034	0.013	0.047	27.246	
9.00	0.179	0.034	0.191	0.012	0.032	0.014	0.046	30.196	27.6
	0.181	0.036	0.191	0.010	0.034	0.012	0.046	25.398	
	0.179	0.034	0.188	0.009	0.032	0.011	0.043	24.496	
	0.176	0.031	0.186	0.010	0.030	0.012	0.041	28.334	
	0.180	0.035	0.192	0.012	0.033	0.014	0.047	29.588	

Table 77. Calculation of Percent Pore Volume for the Mixture of 60% 0.67 um and 40% 0.2 um Particles With Binder (Starch)

Binder %	Coated Wt g	Coat Wt g	Total Wt g	Oil Wt g	Coat vol cc	Oil vol cc	Total Vol cc	Pore Vol %	Av. P Vol %
0.66	0.177	0.032	0.189	0.012	0.030	0.014	0.044	31.489	27.4
	0.173	0.028	0.183	0.010	0.027	0.012	0.038	30.446	
	0.174	0.029	0.181	0.007	0.028	0.008	0.036	22.830	
	0.171	0.026	0.179	0.008	0.025	0.009	0.034	27.385	
	0.174	0.029	0.182	0.008	0.028	0.009	0.037	25.267	
1.32	0.171	0.026	0.184	0.013	0.025	0.015	0.040	37.997	36.4
	0.170	0.025	0.182	0.012	0.024	0.014	0.038	37.040	
	0.170	0.025	0.180	0.010	0.024	0.012	0.035	32.897	
	0.171	0.026	0.183	0.012	0.025	0.014	0.039	36.130	
	0.171	0.026	0.184	0.013	0.025	0.015	0.040	37.997	
1.99	0.168	0.023	0.178	0.010	0.022	0.012	0.034	34.763	32.8
	0.168	0.023	0.178	0.010	0.022	0.012	0.034	34.763	
	0.169	0.024	0.180	0.011	0.023	0.013	0.036	35.969	
	0.168	0.023	0.176	0.008	0.022	0.009	0.031	29.889	
	0.172	0.027	0.181	0.009	0.026	0.011	0.036	29.005	
3.97	0.170	0.025	0.181	0.011	0.024	0.013	0.037	35.035	35.6
	0.170	0.025	0.179	0.009	0.024	0.011	0.034	30.615	
	0.175	0.030	0.187	0.012	0.029	0.014	0.043	32.897	
	0.167	0.022	0.179	0.012	0.021	0.014	0.035	40.067	
	0.171	0.026	0.185	0.014	0.025	0.016	0.041	39.757	
5.96	0.165	0.020	0.171	0.006	0.019	0.007	0.026	26.884	25.8
	0.168	0.023	0.175	0.007	0.022	0.008	0.030	27.168	
	0.167	0.022	0.174	0.007	0.021	0.008	0.029	28.056	
	0.166	0.021	0.172	0.006	0.020	0.007	0.027	25.936	
	0.168	0.023	0.173	0.005	0.022	0.006	0.028	21.039	
9.93	0.167	0.022	0.172	0.005	0.021	0.006	0.027	21.787	21.4
	0.166	0.021	0.173	0.007	0.020	0.008	0.028	29.005	
	0.169	0.024	0.174	0.005	0.023	0.006	0.029	20.340	
	0.170	0.025	0.174	0.004	0.024	0.005	0.028	16.395	
	0.170	0.025	0.175	0.005	0.024	0.006	0.030	19.687	

Appendix E

Calculation of Gloss

Table 78. Gloss of Coating With Blend A and Starch.

S. No.	% Binder				
	1.0	2.0	3.0	6.0	9.0
1	60.7	57.2	57.8	56.6	56.4
2	59.7	57.8	57.9	56.5	58.2
3	62.3	57.0	57.6	56.1	55.0
4	61.8	58.4	58.5	58.0	56.3
5	60.6	57.8	58.7	57.3	52.6
AVG	61.0	57.6	58.1	56.9	55.7
STD	0.9	0.5	0.4	0.7	1.9

Table 79. Gloss of Coating With Blend B and Starch

S. No.	% Binder				
	1.0	2.0	3.0	6.0	9.0
1	64.5	62.1	60.3	58.0	56.9
2	60.3	61.0	56.4	60.0	56.0
3	61.4	61.5	60.2	57.3	55.8
4	61.0	61.9	59.7	57.6	57.2
5	61.4	62.0	60.4	56.8	56.5
AVG	61.7	61.7	59.4	57.9	56.5
STD	1.4	0.4	1.5	1.1	0.5

Table 80. Gloss of Coating With Blend C and Starch.

S. No.	% Binder				
	1.0	2.0	3.0	6.0	9.0
1	70.2	66.3	64.2	61.2	56.6
2	69.4	66.9	66.6	61.2	58.5
3	68.3	66.8	64.3	60.5	60.3
4	67.8	66.4	65.2	62.4	56.8
5	65.6	66.5	64.3	61.1	57.5
AVG	68.3	66.6	64.9	61.3	57.9
STD	1.6	0.2	0.9	0.6	1.4

Table 81. Gloss of Coating With Blend D and Starch.

S. No.	% Binder				
	1.0	2.0	3.0	6.0	9.0
1	73.2	68.4	65.6	65.0	62.0
2	75.4	71.1	65.9	64.6	60.1
3	74.5	68.9	67.4	63.6	61.5
4	73.2	70.8	66.4	66.2	61.2
5	75.6	70.5	66.3	66.4	61.6
AVG	74.4	69.9	66.3	65.2	61.3
STD	1.0	1.1	0.6	1.0	0.6

Table 82. Gloss of Coating With Blend A and Latex.

S. No.	% Binder				
	1.0	2.0	3.0	6.0	9.0
1	64.6	62.1	63.8	58.0	53.4
2	62.6	61.9	64.3	58.2	52.1
3	64.7	63.3	64.5	57.0	52.4
4	63.1	62.8	64.4	59.1	53.4
5	64.1	63.2	63.0	58.7	52.8
AVG	63.8	62.7	64.0	58.2	52.8
STD	0.8	0.6	0.6	0.7	0.5

Table 83. Gloss of Coating With Blend B and Latex.

S. No.	% Binder				
	1.0	2.0	3.0	6.0	9.0
1	70.8	70.0	68.8	61.1	53.3
2	70.0	68.8	68.0	60.7	54.8
3	70.0	70.5	68.9	61.8	55.1
4	68.9	69.9	69.2	61.2	53.5
5	70.6	70.1	68.9	61.4	56.5
AVG	70.1	69.9	68.8	61.2	54.6
STD	0.7	0.6	0.4	0.4	1.2

Table 84. Gloss of Coating With Blend C and latex.

S. No.	% Binder				
	1.0	2.0	3.0	6.0	9.0
1	83.8	83.8	81.2	66.0	56.3
2	84.3	84.4	81.3	64.6	61.1
3	80.8	84.6	81.2	65.1	57.9
4	83.2	83.7	78.7	65.5	58.8
5	82.7	83.3	81.2	65.3	57.0
AVG	83.0	84.0	80.7	65.3	58.2
STD	1.2	0.5	1.0	0.5	1.7

Table 85. Gloss of Coating With Blend D and latex.

S. No.	% Binder				
	1.0	2.0	3.0	6.0	9.0
1	78.3	76.8	77.3	57.7	51.9
2	79.1	79.0	77.6	58.0	51.4
3	79.0	78.8	76.2	57.4	52.7
4	79.2	79.3	75.3	59.0	54.3
5	77.1	77.1	76.7	58.4	54.3
AVG	78.5	78.2	76.6	58.1	52.9
STD	0.8	1.0	0.8	0.6	1.2

Appendix F

Summary of Statistical Analysis

Summary of Statistical Analysis

This experiment was designed to study the effect of binder on the coating structure and to explain how addition of binder affects the packing characteristics of pigment particles and, thereby, pore size and scattering coefficient. The data were analyzed using Analysis of Variance at Alpha = 0.05 and the results are as below.

Scattering Coefficient

Analysis of Variance

Source	Sum of Squares	DF	F	Prob
Model	0.02485667	17	22.92	0.0001
Blend	0.01141917	3	59.66	0.0001
Type of Binder	0.00108300	1	16.97	0.0003
Amount of Binder	0.01209369	10	18.96	0.0001
Blend * Binder Type	0.00026083	3	1.36	0.2730
Error	0.00191400	30		

With the help of ANOVA Table it can be concluded that

1) there is a significant difference between the scattering coefficient of the coatings with four different pigment blends,

2) there is also a significant difference between the scattering coefficient of the coatings with starch and

latex, and

3) there is a significant difference in scattering coefficient of the coatings with different amount of binder added.

Gloss

Analysis of Variance

Source	Sum of Squares	DF	F	Prob
Model	4648.04667	17	34.49	0.0001
Blend	872.591666	3	36.69	0.0001
Type of Binder	66.270000	1	8.36	0.0071
Amount of Binder	3680.76000	10	46.43	0.0001
Blend * Binder Type	28.425000	3	1.20	0.3283
Error	237.82333	30		

With the help of ANOVA table it can be concluded that

4) there is a significant difference between the gloss of the coatings with four different pigment blends,

5) there is a significant difference between the gloss of the coatings with starch and latex,

6) there is a significant difference in gloss of the coatings with different amounts of binder added.

Pore Volume

Analysis of Variance

Source	Sum of Squares	DF	F	Prob
Model	681.310208	17	2.78	0.0069
Blend	105.330625	3	2.44	0.0838
Type of Binder	23.941875	1	1.66	0.2071
Amount of Binder	541.660416	10	3.76	0.0023
Blend * Binder Type	10.377291	3	0.24	0.8676
Error	431.914583	30		

With the help of ANOVA table it can be concluded that

7) there is a significant difference in pore volume resulting from the coating with starch and latex.

8) there is not significant difference between the pore volume of the coatings with four different pigment blends, and

9) there is no significant difference between the pore volume of the coatings with different amounts of binder added.

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