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THE EFFECT OF TEMPERATURE, MOISTURE CONTENT AND LATEX PARTICLE SIZE ON LATEX COATING GLOSS

by
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The Course Requirements For
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ABSTRACT

This thesis involved the study of the effects on gloss of moisture, temperature, and particle size of styrene butadiene bound pigmented coatings. Variables investigated were substrate absorbancy, latex particle size, moisture content and calander stack temperature. Substrate absorbancy was varied by comparing an unsized 70 g/m^2 paper base sheet to a polymer drafting film (mylar). Latex particle size was varied by method of emulsion manufacture so that each was uniform and monodispersed. Moisture content was varied by allowing the sheets to come to equilibrium in a room where the humidity was changed. The temperature of the calander stack was changed with an electric heating coil. An Ircon infrared temperature recorder was used to monitor the stack temperature.

It was found that an increase in calender stack temperature increased coating gloss for all cases studied. The statistical analysis of data obtained in this study showed moisture content significantly interacted with temperature such that coating gloss could be adversely affected at the lower temperatures studied. For the higher temperatures studied, increases in moisture content always led to increases in coating gloss. Coating opacity was found to decrease with increasing temperature and/or increasing moisture content. It is recommended that since this study showed temperature and moisture content

significantly interacted to effect the development of styrene-butadiene bound pigmented coating gloss, that further studies similar in scope to this one be conducted on other binders used in the coating industry.

INTRODUCTION

This paper is a contribution toward an improved understanding of the role of latex binders in achieving higher levels of gloss of pigmented coatings. Gloss is a measure of the ability of paper to reflect light specularly, and this is of functional importance in achieving color printing excellence. Achieving higher levels of gloss may be considered as one of the most important properties of coatings as it is characteristic of high quality coated papers and coated paper boards.

The literature review section of this paper studies the factors considered most important in gloss development. Five major factors were found as being of critical importance, they are: coat weight, pigment type, binder level, binder behavior, and finishing conditions. Other factors were also discussed and are included in the section in which they are most closely related.

All facets of coating gloss were investigated in the literature search to give a strong foundation for an experimental investigation on the subject involving the relationship between temperature, moisture content, and latex particle size on styrene-butadiene latex bound pigmented coatings.

THEORETICAL DISCUSSION

THEORIES OF GLOSS

It has been stated that gloss is a measure of the ability of a coating surface to reflect light specularly.

According to the Fresnel theory, the specular reflection of light on an optically smooth surface is a function of refractive index and angle of incidence. Chinmayanandam has shown that the specular reflection of rough surfaces is a function of angle and wavelength of incident light as well as surface roughness.

Recently, Gate (11) demonstrated that the equation:

$$I/I_o = F(N, i)\ \exp\left[-(4\pi\sigma \cos i/\lambda)^2\right]$$

is applicable to paper coating, where:

> I and I_o are specularly reflected and incident light intensities, F(N,) is the Fresnel coefficient of specular reflection is a function of refractive index and of incident light, is the standard deviation of the surface roughness, and is the wavelength of incident light.

According to the definition of T.A.P.P.I., gloss and the effective wavelength for the spectral conditions of the T.A.P.P.I. gloss meter = 0.55. The T.A.P.P.I. 75° gloss of coatings can be given by:

$$\text{T.A.P.P.I. } 75^\circ \text{ gloss} = 384.6\ F(N, 75^\circ)\ \exp -(4\pi\sigma \cos 75^\circ/0.55)^2$$

This shows that T.A.P.P.I. gloss is only dependent upon their refractive indexes and surface roughness. Since all paper coating additives besides TiO_2 have similar refractive indexes, it can be assumed that T.A.P.P.I. 75° gloss of paper coatings is dependent mainly upon their surface roughness regardless of material used. Thus a clay could give a gloss that was higher than TiO_2 if its microroughness is less than that of the TiO_2. Concerning macroroughness and microroughness, a high coating gloss can be achieved if the surface is microscopically smooth even if it is macroscopically rough. Conversely, a macroscopically smooth surface could exhibit poor gloss if it was microscopically rough.

As applied to latexes, gloss is believed to be achieved via three different methods. The first method goes along with a theory of film shrinkage and states that binders undergo film shrinkage when dried between the point of immobilization and the point where the film of coating is completely dry. This film shrinkage causes the surface to become rougher because unbalanced stresses and thus increases gloss. This theory then explains differences in binder gloss effectiveness by stating that they have varying degrees of film shrinkage.

The second method explains the glossability of various binders by postulating that those with a greater degree of viscous flow and least amount of elastic response under supercalendering conditions would be able to obtain the higher gloss.

The third method states that gloss is a function of binder strength. The higher the strength the lower the gloss obtainable because the stronger binder holds the clay platelets tighter during calendering, not allowing them to form a smooth surface.

FACTORS AFFECTING GLOSS

This section looks at five factors that are considered most important in influencing the development of gloss. These factors are: coat weight, binder level, binder movement, pigment type, and the finishing conditions. Other factors of lesser importance are included in the discussion in one of the six categories listed above according to where they best fit.

Coat Weight

It was first shown that coating gloss increased with increasing coat weight in latex systems by Hagerman (1). Walsh (2) also found this to be the case but neither attempts to explain their finding.

Kraske (3) used an X-ray defraction method to measure orientation of pigment platelets in coatings using two different coat weights (10.8 lbs/ream and 21.1 lbs/ream). He found that the lighter coat weight had a lower degree of orientation than the heavier coatings, and explained that the vehicle drains from the light weight coating into the raw stock and immobilizes the clay platelets before they have an opportunity to orientate as well as they do in the heavier coatings.

LePoutre (4), in studying the effect of coat weight, actually measured the time it takes for a coating to lose its watery sheen (the setting time). He found that at slow evaporation rates, the pigment particles had time to undergo further orientation; but when the water is drained rapidly, the structure of the pigment cake formed tended to reflect the degree of parallel orientation of the kaolin plates that existed in solution (an inverse function of solids content). As the coat weight was raised, the resistance to flow by the deposited pigment cake increased causing more time for the top layers of pigment particles to pack more efficiently. Thus he found that anything that would slow down the drainage rate--such as water retention aids--would help improve the pigment packing efficiency. He tested C.M.C. and found this to be true.

Kaliski (5) found that the coat weight interval where the greatest change in the rate of gloss development occurred was approximately between 4 and 5 g-m^{-2}. This is believed to be associated with a critical pigment demand that is dependent upon several factors which include coating formulations used and to a greater extent upon the characteristics of the base sheet used. Other factors include the mode of application and of drying.

Suitable modification of these factors should lead to a reduction in the critical pigment demand and thus to a higher gloss development at a given coat weight. Examples of modification would be: pre-finish the base sheet by calendering, by size press applications to modify capillary-network structures to reduce the rate of sorption of the liquid phase into the substrate, and as mentioned earlier by adding a water-retention agent to the coating formulation.

Do Ik Lee (6) studied coat weight with respect to the theoretical ultimate gloss level obtainable with a given coating formulation. He found that the gloss of calendered coated papers increased as coat weight increased, but leveled off as it approached the ultimate gloss for any given system. For low coat, the gloss of coated papers is dependent upon the coat weight and the particular system. At high coat weights, the gloss was independent of the system. This suggests that the gloss of coated paper is dependent upon the coating holdout of a particular system at low coat weights.

Pigment Type

Kraske (3) studied the effect of clay particle size on the coating structure with respect to: unbound surface area, pore size distribution, internal void volume and particle orientation. The unbound surface area of these coating increased substantially as the particle size of the clay was decreased. This follows from consideration of the size and number of clay particles per unit weight of coating. He used X-ray defraction techniques to observe the orientation of the clay platelets and showed that as the clay particle size decreased, the orientation increased. He postulated that with the large clay particle sizes, poor orientation could result from the comparatively large interparticle spaces which exist in this coating during vehicle migration stages of drying. If this is so, the particles would not have time to allign themselves before they were immobilized. The larger the mass of the particles, the more resistance to allignment by the fluid friction forces operating during drying. For pore size and void volume, Kraske found that both went up as the particle size was increased.

Kaliski (13) studied No. 1, No. 2, and mechanically delaminated clays (M.D.) with respect to unfinished, super-calendered and brush finishing conditions.

With unfinished conditions, the highest coating gloss at each binder-volume fraction was obtained with No. 1 clay followed by M.D. and No. 2 respectively. There was one exception to this pattern at the binder-volume fraction of 0.245 where the gloss of the M.D. clay exceeded the No. 1 clay gloss. With calendered coatings, the order of gloss decreased as follows: M.D. clay, No. 1, and then No.2. This same pattern was obtained with the brush finishing.

Kaliski (5) speculated that the platey clay particles are orientated nearly parallel to the mean plane of the substrate and that the frequency distribution of all particles is uniform throughout the liquid film initially applied to the base sheet. The parallel orientation of the clay plateleys should be greatest at the coating substrate interface and grow less. So as you move to the coating film surface, this says that the relative disarrangement of the pigment lattice of clay particles in liquid coating films are strongly dependent on their morphology. With No. 1 clays, the average dimensions in the x, y-plane are considerably smaller than with the M.D. clays where these dimensions exceed the thickness of most liquid films. This leaves the M.S. clays hampered and their contour-following tendency limited even on relatively rough paper substrates. The No. 1 clay will thus have a more orderly initial spatial arrangement but should also be subject to subsequent disarrangement.

This explains why higher coating gloss was obtained with No. 1 clay than with M.D. clay when a smooth substrate such as glass was used. But, the opposite was true when the coating substrate was rough (13)--as with paper.

Trader (9) showed that gloss increased linearly with particle size decrease of clay. This explains why No. 1 clay has a higher coating gloss than No. 2 clay because No. 1 has a higher proportion of fines. Since M.D. clay has a lower proportion of fines, a different explanation must be used.

Kaliski (5) believed the allignment of the platey clay particles in M.D. clay accounted for the higher coating gloss.

When 100% M.D. clay and 100% No. 2 clay were looked at for gloss, the No. 2 was superior. This shows that under binderless conditions, M.D. clay was highly disordered with relatively high pore volume.

Gate (11) put forth a theory that the gloss is directly related to the surface roughness of the coating. By obtaining a profile of the microtexture of a coating surface, he showed that the variations were on the order of .1 um. This is a significant fraction of the wavelength of light (0.45 um for blue light) and so we can expect to find that a surface microtexture of this order has a strong influence on the reflection of spectral light from the surface. Since clay fines are relatively large compared to this scale, we would not expect them to play a significant role between gloss and clay type.

Kaliski (5) further speculated that clay particle fines affect coating gloss in an indirect way. The considerable reduction of coating gloss under severe conditions of drying where heavy strains and stresses are expected supports the hypothesis that lowering stress conditions promotes spectral reflection of light (higher gloss). Clay fines in coatings thus can be seen as inhibitors of convection currents before the coating film solidifies and as dissapation of stress afterwards.

Lee (6) related the effect of particle size distribution to surface roughness. He states that anything that will decrease the surface roughness will improve the coating gloss. Thus as you go to smaller particle sizes, you increase the packing efficiency by filling in void spaces--subsequently increasing gloss by lowering the surface roughness.

Hemstock and Bergman (25) have shown that destabilization or floculation of suspended particles leads to a porous sediment or coating. They showed that the gloss of clay coatings reaches a maximum at the point of optimum defloculation and then decreases with increasing additions of defloculant. Thus the gloss decreases with increasing destabilization of pigment particles.

La Poutre (15) found that the introduction of plastic pigments (spherical in shape) into either a delaminated clay or sphere-like-precipitated Calcium Carbonate produces coatings of different structure depending on the size and amount added.

Gloss development indicates that when the plastic pigment is added in sufficient amounts, it can decrease surface roughness and contribute to an improved gloss. He determined that gloss is a function of the manner in which the packing of the particles effect the smoothness of the surface.

Binder Level

It has long been known that increasing binder level had an adverse effect on gloss. McLaughlin (7) was the first to show these same adverse effects for latex binder (acrylic). He found that at low Pigment Volume Concentration (PVC), binder properties such as grease proofness, resistance to transmission of water vapor, color and gloss are important. At high PVC, or above the CPVC, the pigment properties dominate and the binder has a secondary role.

Webber (8) showed that gloss of coated papers decreased as binder concentration increased and went through a minimum at the CPVC. Below the CPVC, at higher binder concentrations, the gloss began to increase once again. To explain this, he postulates that as the binder content is increased, there is a general increase in the amount of pigment-adhesive interaction which makes reorientation of pigment particles during supercalendering more difficult.

Trader (9) studied a series of 100% clay systems and the effects of adding various levels of binder to these systems. The clays were of varying equivalent spherical diameters ranging between 1.50 m (premium clay) and 0.15 m filler clay.

The decrease in gloss as latex levels were increased was greater with the filler clay than with premium clay. A mechanism he suggested was that as the clay becomes coarser, the addition of binder caused floculation (or aggregate formation) which increased or decreased the scattering power. Addition of latex thus caused an effective shift in the clay particle size distribution in the coarser direction decreasing gloss.

He found that by comparing the two systems, the pore volume was similar with or without binder, indicating that the latex was not simply filling in pores among the clay platelets.

Trader also found that the gloss went through a minimum with increasing binder level (30-40% latex) but after this point, it continues to increase up to 100% binder content.

La Poutre (10) found that the addition of a secondary colloidal system (latex) to a colloidal pigment system (clay) affected the stability by depressing the electrical double layer and the lubrication effect by stearically interfering with the orientation of the clay platelets. Below a critical latex content, between 5 and 10 percent (depending on the latex), the consolidation of the structure was determined by the packing of the clay. In this range, he proposed that the latex affects the packing through changes in colloidal properties that create a less ordered structure.

The rigidity of the clay network resists the coalescence and flow of the latex so that the thickness is essentially unchanged. Above this range, the coalescence and flow of the latex control the consolidation. Above this critical range, the consolidation becomes controlled by the ease of coalescence and flow of the latex at the drying temperature, and the clay platelet orientation now increases with increasing proportion of latex.

The surface orientation continued to decrease with increased latex content; however, due to irregular collapsing in the structure as the latex coalesces forming gloss inhibiting surface depressions.

Lee (6) found that the gloss decreased with increasing binder level for coatings systems above the CPVC. He proposes a theory of film shrinkage of binders that cuases an increase in the surface roughness. It has been shown by Gate (11) that as the surface roughness of a coating is increased, the gloss decreases linearly. Thus for any given binder, as you increase the amount you would decrease gloss.

Binder Behavior

Heiser and Cullen (14) studied the effects of drying rates on adhesive redistribution using gravemetric methods of analysis. The variables they looked at were drying rate, coating color solids, latex particle size and raw stock. They found that the prime factor influencing binder migration seemed to be the solid's content of the coating formulation. The higher the solids, the lower the migration. At slow drying rates binder migration was toward the substrate. Conversely, rapid drying rates caused the adhesive to migrate mainly to the surface. The high solid's coating (thus less binder migration) gave better gloss than low solids coating and slow drying rates gave better gloss than fast drying rates.

In this study, Heiser found that latex particle size had no effect upon binder migration; but in a lter study (16), Heiser found that the degree of binder migration decreased as you increased latex particle size. In another paper (17), he found that in comparing two latices one of particle size 500A (determined by light-scattering techniques) and one of 3000A, that the smaller particles migrated more at a fast rate than when dried at a slow rate. Also, the smaller particles migrated more than the larger particles at the same drying rate as evidenced by brighter K & N ink for the smaller particle surfaces.

They also examined the effect of binder migration on calendered gloss and found that calendered gloss increased with increasing surface pigment concentration and decreased with increased surface binder concentration.

This was believed to be due to the coalescence (film shrinkage) of latex particles under drying conditions which results in an increase of the surface roughness which is detrimental to gloss as shown by Gate (11) and Lee (6). He also found that higher solids and slower drying rate gave the expected superior calendered gloss when compared to fast drying rates and low solids.

Another factor that helps explain the lower gloss and higher K & N ink adsorption for the smaller latex particles is the fact that with the larger size latex, there are fewer latex to pigment and latex to latex bonds. As a result, the sheet is more porous and less tightly held enabling the pigment particle to orientate more freely during calendering.

Krishnagopalen (18) reported that moisture migration in drying was an internal process of liquid flow which proceeded by one or more of several mechanisms such as applied mechanical force, capillary force, and adsorption. He relates these mechanisms to migration experiments which involve the variables of drying rate, base sheet sizing, and coating solids.

Migration was studied by tagging the latex adhesive with osmium and the aqueous medium with dissolved Potassium Chloride and using an electron microscope to measure the distribution of the tracers as a function of depth. Mechanical forces were constant while capillary forces were varied by comparing sized and unsized paper. The date showed a large difference between unsized and sized paper.

In unsized papers, capillary forces favored penetration of the water. Both water and binder were found to have migrated deeply into the sheet with the binder assumed to have followed the water.

With the well-sized paper, capillary forces opposed water retention and latex was adsorbed to the fibers. This adsorption caused latex to build up on the sheet leading to pore blocking and a reduction in fluid migration.

Sizing the sheet as in the above case is one way in which to limit binder migration. Heiser, Morgan, and Reder (26) attempted to control binder migration by using alkali setting cationic latices. In the first study, cationic latex was compared to an anionic latex. Both latices were applied to paper by air knife in formulation that varied the levels of latex binder. The cationic latex was gelled after application with ammonia gas. The gloss for the cationic was found to be lower. In the more recent study, the cationic latex was applied in a formulation of 100 parts clay and 20 parts of latex. Binder migration was controlled in one half of the coating by exposure to ammonia gas immediately after the air knife application. The other half of the coating was untreated allowing binder migration to proceed unrestricted. The ammonia gas causes the coating to gell. The analysis shows that the ungelled portion had a higher binder concentration at the surface, but the gelled portion gave a higher calendered gloss, the opposite of what would be expected from previous experiments. Heiser and Baker tentatively explained this phenomena by postulating that enough binder had migrated to the ungelled surface to give it high gloss characteristics the same as gloss developed below the CPVC level.

Lee (6) studied the effect of binder film shrinkage, defined as the percentage of volume change between the immobilization point and the dried film.

In this study, the pore volumes were measured using a mercury porosimeter and the binder level was 15 parts per 100 parts No. 1 clay. Four binder systems were used, S/B latex (low Butadiene), S/B latex (high Butadiene), starch and protein. It was found that the extent of film shrinkage increases in the order of S/B latices, starch and protein.

A wet coating applied to an ideal substrate may be fluid enough to maintain a smooth surface until it becomes immobilized. Even when immobilized, the binder can still move in interstitial space. Upon further drying, the binder will become further immobilized or gelled and start film-forming. Due to unbalanced stresses, the coating surface in particular will go through a greater change and become very rough. From this visualization of coating formation, Lee predicts that surface roughening will go through a greater change and become very rough decreasing the coating gloss. This theory better explains the inherent glossing ability of binders and coating formulation used in the paper industry.

Lee also predicted that surface roughening would increase for more porous coatings and gloss thus decreases.

This explains why gloss increases with increasing styrene content. The more styrene the less shrinkage of the film.

This increase in gloss with increasing styrene content can also be explained by a theory first introduced by Taber (19). He states that the increase in gloss with increase in styrene content results from the fact that the polymer becomes more thermoplastic and thus easier to calender.

Tompkins (24) studied the effect of varying the gloss transition temperature of Polyvinyl Acetate polymers by cross-linking them with acrilates. He found that as the Tg temperature decreased, the gloss increased on non-absorbant substrates. This is the opposite of S/B latices behavior and he speculated that for this system the viscous flow may be caused by functionality groups present in the vinyl acetate-acrilate which cause them to plasticize when water is introduced.

Finishing Conditions

Finishing conditions as related to gloss with respect to binder is a function of many variables. McLaughlin (7) compared the supercalendered gloss of an acrylic latex when the gloss transition temperature was varied from -4°C to +17°C. He found that the softer latex gave the highest gloss.

Yasuda and Stannet (20) studied the effect of supercalendering conditions, temperature and pressure on gloss development with different latexes in 50/50 blends with starch. The conclusions were made that the softer the binder, the easier it is supercalendered. Differences due to binder were not great at high temperatures and pressures where the maximum gloss obtainable with the pigment used is almost achieved. The differences become increasingly greater at lower temperatures and pressures. For latices, the higher the temperature the greater the gloss and the easier it was to calender and the less the differences between the different latex binders.

The effects of supercalendering conditions, pressure, and number of nips on gloss of poly vinyl alcohol and starch bound coatings was investigated by Colgan (21). Both pressure and nips increases were shown to increase gloss.

Kraske (3) showed that surface particles became rearranged during supercalendering with the use of X-ray defraction methods of studying orientation. He found that an increase in free surface area of the coatings resulted from reallignment of the clay particles indicating rupture of pigment/adhesive, and/or adhesive/adhesive bonds. His data showed a compression of some pores while at the same time an opening up of others. This occurs without a change in the void volume. This indicates elastic solid behavior since the compression was reversible.

Avary (22) studied the effect of varying the glass transition temperature of styrene butadiene latex by varying the amount of styrene. He obtained a higher degree of smoothness for the higher sytrene content and stated that this was due to the greater degree of viscous flow and lower degree of elasticity. He believes that while being more difficult to deform in supercalendering the viscous flow ability makes it easier to calender overall.

Lee's (6) findings offer a different explanation for this increased glossing effect by theorizing that the increased styrene content decreases the amount of film shrinkage and thus the surface becomes less rough and the gloss increases.

Heiser (16) and Bundy (23) have said that calendered gloss is also a function of coating porosity with large size particle surfaces more loosely constructed and more easily rearranged resulting in higher gloss and smoothness when calendered. Lee (6) confers these findings on porosity in his work.

LaPoutre (4) looked at supercalendering with respect to coating properties and found that reduction in coating thickness of 7%, paper backing thickness to 21%, and a reduction in void volume of up to 25%. He showed by electron micrograph that low pressure calendering did little while at high pressure macroroughness had been removed by flattening of the hills. Examination at high magnification shows that the kaolin platelets had been pressed into the coating, squeezing out the latex polymer, which flowed sideways and filled out adjacent depressions. As a result, the microroughness is also reduced. Here we can see why the more thermoplastic flowability of the latex, the better gloss achievable.

Lee (6) showed however that the supercalendering action can never remove all microscopic surface irregularities so there is a limit to supercalendering's gloss effect.

Walsh (2) studied nine different synthetic binders and the effect of a gloss calender on several formulation variables. His results indicated no significant difference in gloss development in 36 separate experiments. Gloss calendering conditions were 300°F and 450 PLI. He postulated this was because at these conditions the thermoplastic flow properties were equivalent.

Brush finishing has been used as a way of obtaining higher gloss while densification of the coating structure is less than other methods. Walsh (2) found that the higher percentage of synthetic binder the higher the gloss and the stiffer the synthetic binder the better the gloss. He studied three latices: Polyvinyl Acetate, S/B, and Acrylic. He found Polyvinyl Acetate to give the best gloss and S/B giving the worst when brush coated. He found brush coating gave a more uniform gloss and stated that the Polyvinyl Acetate was best because of its stiffness.

Kaliski (5) (13) found that gloss increased with binder content and number of brush strokes. He proposed a theory that says gloss generated by brushing does not come about by orientation of pigment fines in the top layer but by redistribution of polymer material at the surface. The polymer is believed to migrate to the surface during drying and should increase in amount when the overall proportion of the binder in the formulation increases. He also states that depending on the amount of binder at the surface, the gloss should have a limited value regardless of the additional brush strokes once this value is achieved. His findings verify both of these assumptions.

Summary

The literature review shows that in considering the effect of binder on gloss, type and concentration of binder in the coating formulation are the primary factors. High binder concentrations adversely effect gloss except in one case where Kaliski (11) showed an increase in binder livel in a brushed finished coating increased the gloss.

Degree of binder shrinkage during drying was found to be characteristic of a given binder. Furthermore, the greater the degree of binder shrinkage, the lower the coating gloss. This is due to unbalanced stresses in the coating leading to a rougher coating surface.

Latex gloss was found to be lower with the smaller latex particles. This is because there are fewer latex to latex and latex to pigment particle bonds. As a result, the sheet is more porous and less tightly held enabling the pigment particles to orientate themselves more freely during calendering.

In conventional coating and supercalendering, there is disagreement about the effect of latex polymer hardness on gloss development. Where styrene-butadiene latices are concerned, gloss increases with increaseing styrene content in the copolymer indicating that hard polymers give a higher gloss than softer ones. Soft acrylics develop higher gloss than hard acrylic latices. In another study, an evaluation of five different latex systems indicated that the softer latexes finished easier than harder latexes.

Other factors that affect the gloss level that can be achieved with different latex binders are drying rate, binder migration, binder shrinkage, finishing conditions, clay type, and coat weight. Rapid drying of all latex binder systems resulted in an adhesive righ surface which adversely affected gloss development.

Finishing conditions have a major effect on gloss. Increasing the number of nips, the pressure, or the temperature during supercalendering all tend to improve gloss. Little difference in gloss was found between latexes at high temperature and pressure on a gloss calender. Brush finishing created gloss on a coated paper. Gloss increased with number of brush strokes and is optimized by the use of a stiff hard latex in the coating.

Clay type was found to affect coating gloss. On a paper substrate mechanically delaminated clay was found to be superior to No. 2 clay, but inferior to a No. 1 clay under unfinished conditions. Under calendered conditions, No. 1 clay was found to be superior to No. 2 clay, but in this case was inferior to the mechanically delaminated clay. Regardless of clay type, gloss increased as coat weight increased.

STATEMENT OF THE PROBLEM

It is common practice in the paper and paperboard industry to add moisture to or increase the temperature of the calender stack to aid in coating gloss development. Nowhere in the literature, however, has there been a study conducted to measure quantitatively the effects of temperature, moisture content, and their interaction on coating gloss. It has been theorized that temperature and moisture aid in plasticizing the coating particles so that there is more viscous flow during calendering allowing the surface of the coating to be smoothed out. Since coating gloss is a function of surface roughness, this would lead to higher gloss. Furthermore, it is believed different latices undergo different amounts of plasticization depending on their makeup. Therefore, the experimental section of this study will involve three different styrene-butadienes with varying particle size, and their gloss development characteristics at four different calender stack temperatures and four different coating moisture contents.

EXPERIMENTAL

Experimental Design

The experimental design was structured as that its scope only involved particle size of the latex, coating substrate absorbancy, calander stack temperature and coating moisture content. How these properties and conditions affected styrene-butadiene latex bound coating gloss development was evaluated. This was accomplished by preparing three different coatings containing three different particle size latices and applying them to a non-absorbant polyester drafting film and to an unsized 70 g/m^2 publication grate paper substrate. The coated substrates were allowed to condition in a room where the humidity was varied allowing them to absorb varying amounts of moisture. Conditioned sheets were then super calendered on a stack where temperatures were varied from $70^{\cdot F}$ to $170^{\cdot F}$.

Coating Preparation

Huber Hydrosperse #1 clay was dispersed at 70% solids in a Cowles disperser. Three coatings were prepared with 20 parts latex/100 parts clay. Each coating preparation varied in latex particle size. Table I shows the coating formulations.

Table I: Coating Formulations

	Latex Used (Particle Size)	% Solids
Coating A	1510 A	60
Coating B	1660 A	60
Coating C	1890 A	60

Coating formulations were hand mixed in 500g sample sizes with the order of addition being water, clay, latex.

Coatings were applied to a polyester drafting film and to an unsized 70 g/m^2 paper substrate with Mayer metering rods to give a coat weight of approximately 10.0 lbs/ream*. Immediately after application coated substrates were placed in 105$^{\cdot C}$ ovens for drying.

Supercalendering

The humidity of the room where the calender stack is located was adjusted to the desired level. Four absorbant and four non-abosrbant coated sheets for each latex particle size (total of 24) were allowed to condition over night. The calender stack was heated using radiant electric heating coils. Six sheets, three on absorbant and three on non-absorbant substrates with a representative latex particle size coating on each, were then supercalendered at a given calender stack temperature. This was repeated for all four temperatures using six different sheets each time. This totaled twenty-four sheets for each humidity. This was repeated for four separate humidities with a total of 96 sheets being calendered. to aid in statistical analysis, the entire sequence above was repeated.

Evaluation Procedure

Coat weight was determined by measuring the basis weight difference before and after application. Coating moisture

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* Ream size: 25 x 3 x 500

content was determined by measuring coated mylar sheets conditioned at various humidity levels and substrating the oven dry weight of the coated sheet.

Gloss and opacity were measured according to T.A.P.P.I. standard methods T-480 and T-425.

Experimental data was statistically evaluated as to analysis of variance between the different variables and standard deviation between the two runs.

RESULTS AND DISCUSSION

Coating gloss values based on an average between two runs for the three latices on paper and on mylar are compiled in Table II and Table III. Figures 1 through 16 aid in discussion and visualization of this data.

Particle Size vs. 75° Gloss

Figures 1 and 2 show plots of gloss vs. particle size on paper and on mylar substrates. For paper as particle size increased, the coating gloss also increased. A possible explanation might be that due to fewer amounts of latex to latex and latex to pigment binds, with the larger size latex, a more porous and less tightly bound coating surface resulted. This would have enabled the pigment particles to orientate more freely during calendering giving the higher gloss. On mylar as particle size increased, the coating gloss decreased. Here a possible explanation might be in a theory proposed by Kaliski (11) that says gloss generated by brushing does not come about by orientation of pigment fines but by redistribution of polymer material at the surface of the coating. On mylar the latex probably migrated to the coating surface, during drying, to such concentrations where Kaliski's theory became applicable. The higher gloss development with the smaller latex particle coatings might then be explained by Lee (6) who related the effect of particle size distribution to surface roughness. He stated that as you decrease the surface

TABLE II
Paper Substrate

		70°C			105°C			140°C			170°C		
Humidity		1890	1660	1510	1890	1660	1510	1890	1660	1510	1890	1660	1510
30%	2	64.0	58.0	55.0	68.6	66.0	63.1	70.1	67.3	63.2	76.5	74.3	69.0
No. of Nips	4	72.5	66.6	63.4	76.2	70.4	66.4	78.9	76.4	69.4	83.4	81.9	76.4
	6	79.1	73.4	70.9	81.7	73.3	68.6	83.9	79.2	74.7	86.7	84.3	78.8
Humidity 50%	2	63.1	59.3	58.0	68.5	61.7	59.3	83.3	81.4	68.9	75.5	72.0	67.9
No. of Nips	4	69.4	66.7	62.5	75.9	69.9	67.0	85.4	82.9	77.8	82.4	78.6	75.7
	6	78.2	72.3	65.0	81.7	73.3	68.6	86.4	84.3	81.6	85.0	81.5	77.4
Humidity 70%	2	63.5	61.0	56.0	70.1	69.2	66.8	78.4	72.9	70.5	77.3	74.0	72.6
No. of Nips	4	70.7	66.6	62.3	76.4	75.3	73.9	85.9	83.2	79.0	85.1	82.8	79.3
	6	76.5	71.3	68.5	83.7	81.4	79.3	88.9	85.4	82.5	86.2	83.9	81.8
Humidity 90%	2	64.0	62.1	61.6	74.5	70.1	67.0	80.1	75.3	74.7	86.7	83.9	80.9
No. of Nips	4	73.3	68.1	66.2	77.3	76.6	74.9	87.1	84.1	82.2	92.1	90.0	88.0
	6	79.0	73.4	70.9	87.7	84.1	81.2	92.0	87.4	87.0	95.3	92.2	89.4

TABLE III

Mylar Substrate

		70°C			105°C			140°C			170°C		
Part. Size		1890	1660	1510	1890	1660	1510	1890	1660	1510	1890	1660	1510
Humidity 30%	2	42.0	43.1	53.4	49.2	54.3	63.7	60.0	64.4	68.5	71.0	76.6	79.5
	4	54.2	55.1	66.1	59.0	64.8	73.6	69.0	75.2	78.3	77.0	82.7	84.8
	6	62.8	66.3	68.6	66.6	70.0	79.9	74.7	80.2	83.9	82.2	86.9	89.8
Humidity 50%	2	51.2	52.1	53.6	58.0	64.2	67.3	67.1	71.4	73.9	77.5	80.3	81.1
	4	55.2	58.1	61.9	69.9	71.2	75.3	75.1	78.3	81.0	82.1	83.9	85.1
	6	60.5	62.7	67.3	73.9	79.6	82.7	80.5	83.7	86.5	87.0	87.8	90.9
Humidity 70%	2	48.1	50.3	52.2	68.1	69.4	70.8	75.1	76.0	79.3	80.1	81.4	82.0
	4	54.5	60.2	61.1	76.9	78.4	79.9	81.8	83.9	87.9	86.1	88.2	89.3
	6	66.6	74.5	79.3	83.1	84.5	86.5	86.1	87.5	90.1	88.8	90.8	92.5
Humidity 90%	2	50.2	53.7	61.8	69.2	70.1	76.1	78.4	81.3	82.4	82.8	84.8	85.6
	4	59.1	65.0	73.2	78.5	79.6	84.6	83.8	86.9	87.8	90.8	91.2	93.4
	6	75.1	78.0	80.7	86.5	84.3	90.1	88.2	91.3	93.1	92.8	94.8	96.7

FIGURE 1: PAPER SUBSTRATE
75° Gloss vs. Particle Size

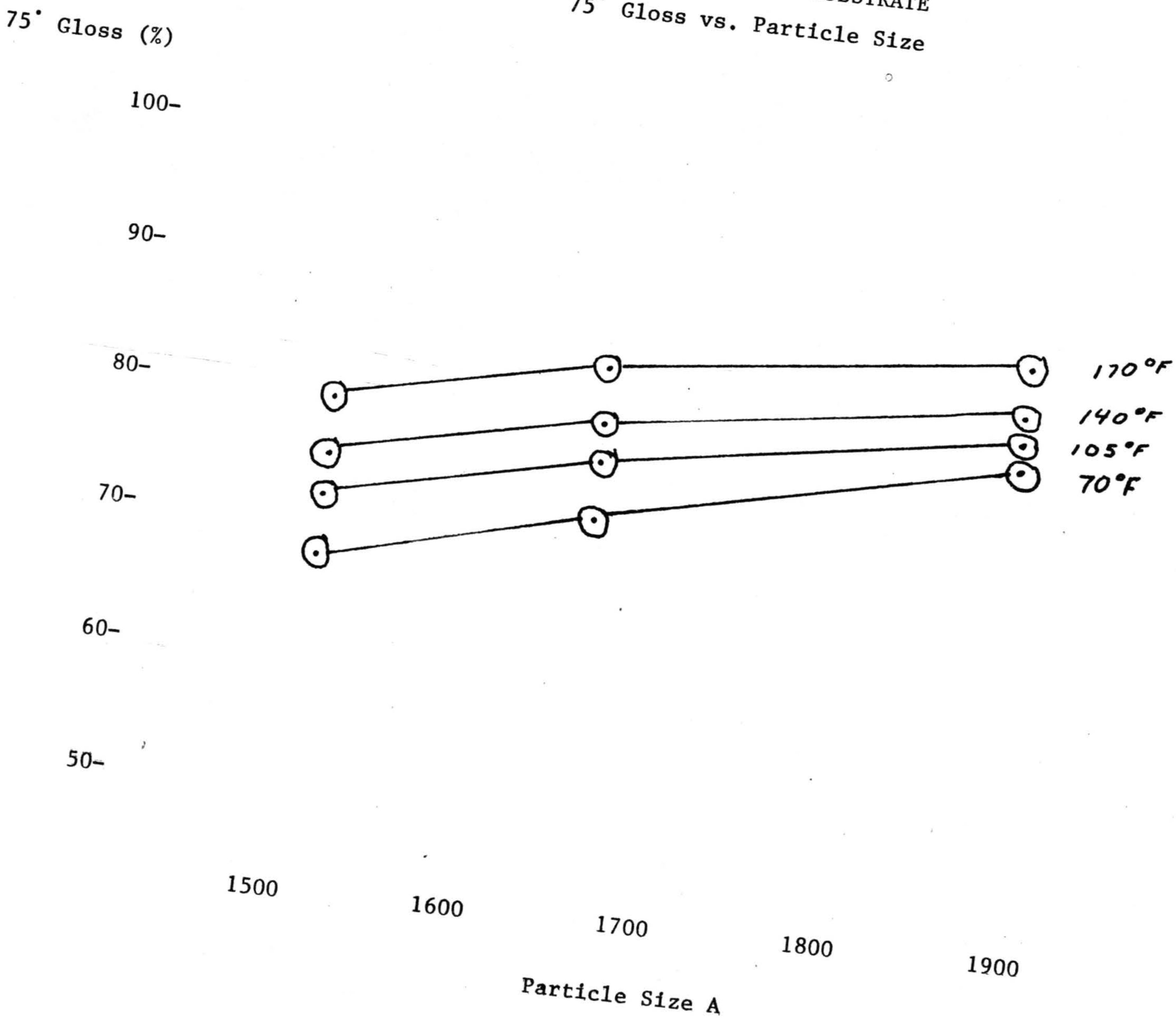
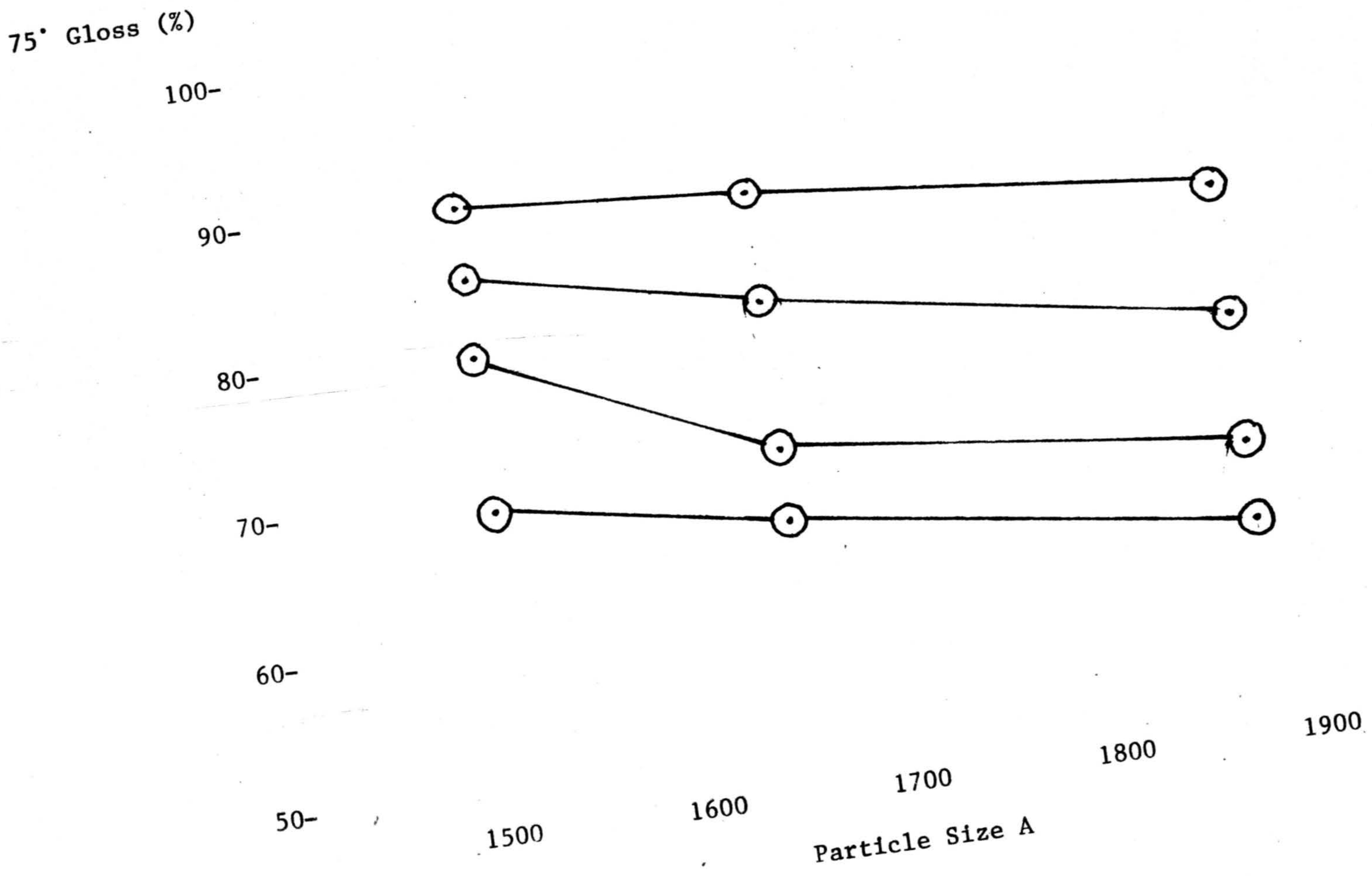


FIGURE 2: MYLAR

75° Gloss vs. Particle Size



roughness coating gloss improves. Thus as you go to smaller particle sizes, you increase the packing efficiency by filling in void spaces, subsequently increasing gloss by lowering the surface roughness.

Temperature vs. 75° Gloss

Figures 3 through 8 show gloss development vs. temperature for the three coatings on the paper and mylar substrates at varying coating moisture contents. For all six cases, we see gloss increased with increased temperature. This indicates that the coating is becoming more pliable at the higher temperature and undergoes a greater degree of viscous flow in the nip to yield a smoother sheet.

The slopes of the lines on the mylar substrate are much greater than those on the paper indicating a greater response of coating gloss to calendering with increased temperature. One possible explanation is that the paper is more pliable so that it spreads out in the calender nip more than the mylar. This would lead to a reduction in the P.L.I. load on the coating surface. At lower P.L.I., the coating surface roughness would not be smoothed as much for the paper substrate resulting in lower gloss development.

On Figures 3 through 8, it is seen that the various moisture content lines cross over each other. This indicates that there is a temperature--moisture content interaction occuring with respect to coating gloss development. The cross-overs occur on all six figures indicating the interaction is consistently reproducible.

FIGURE 3: PAPER

75° Gloss vs. Temperature

1510 A

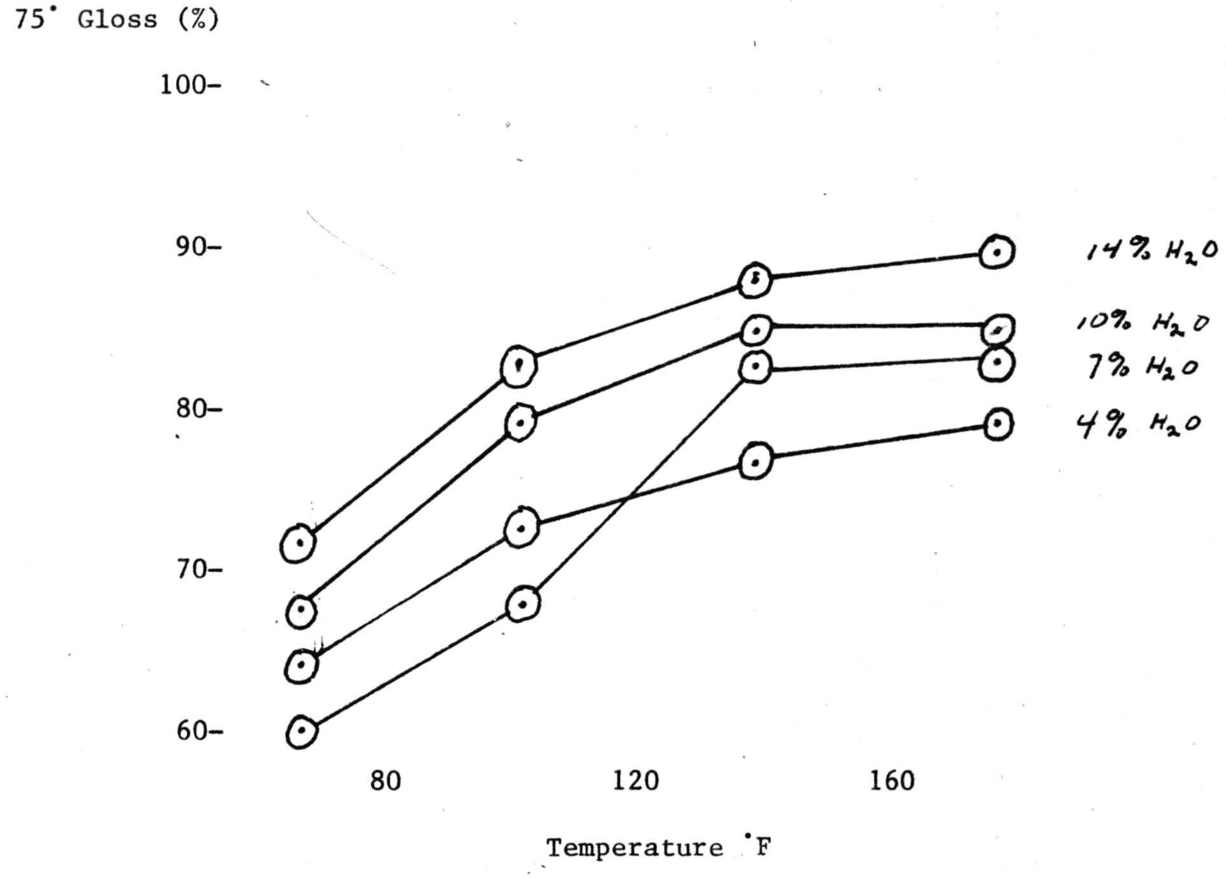


FIGURE 4: PAPER

75° Gloss vs. Temperature

1660 A

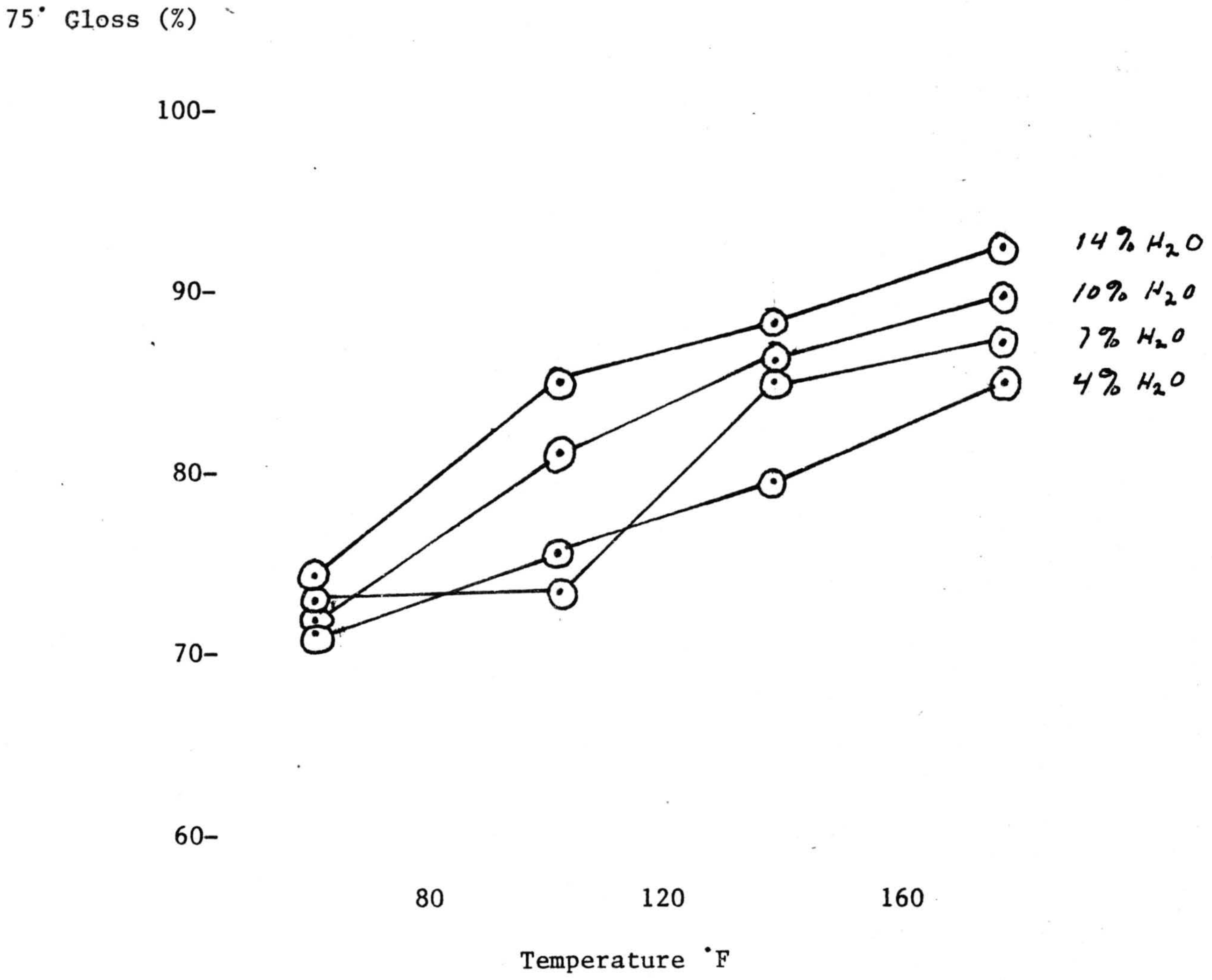


FIGURE 5: PAPER

75° Gloss vs. Temperature

1890 A

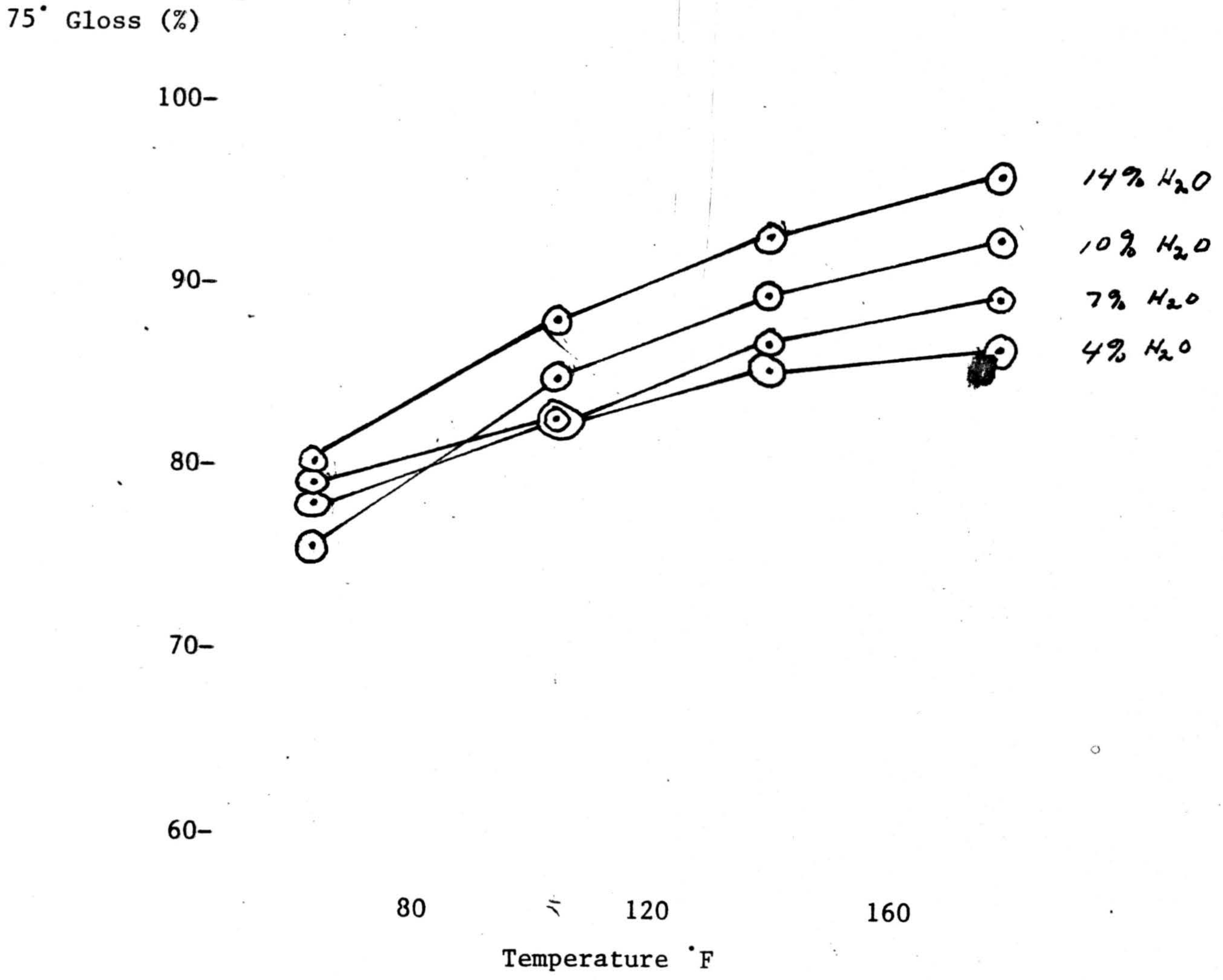


FIGURE 6: MYLAR

75° Gloss vs. Temperature

1510 A

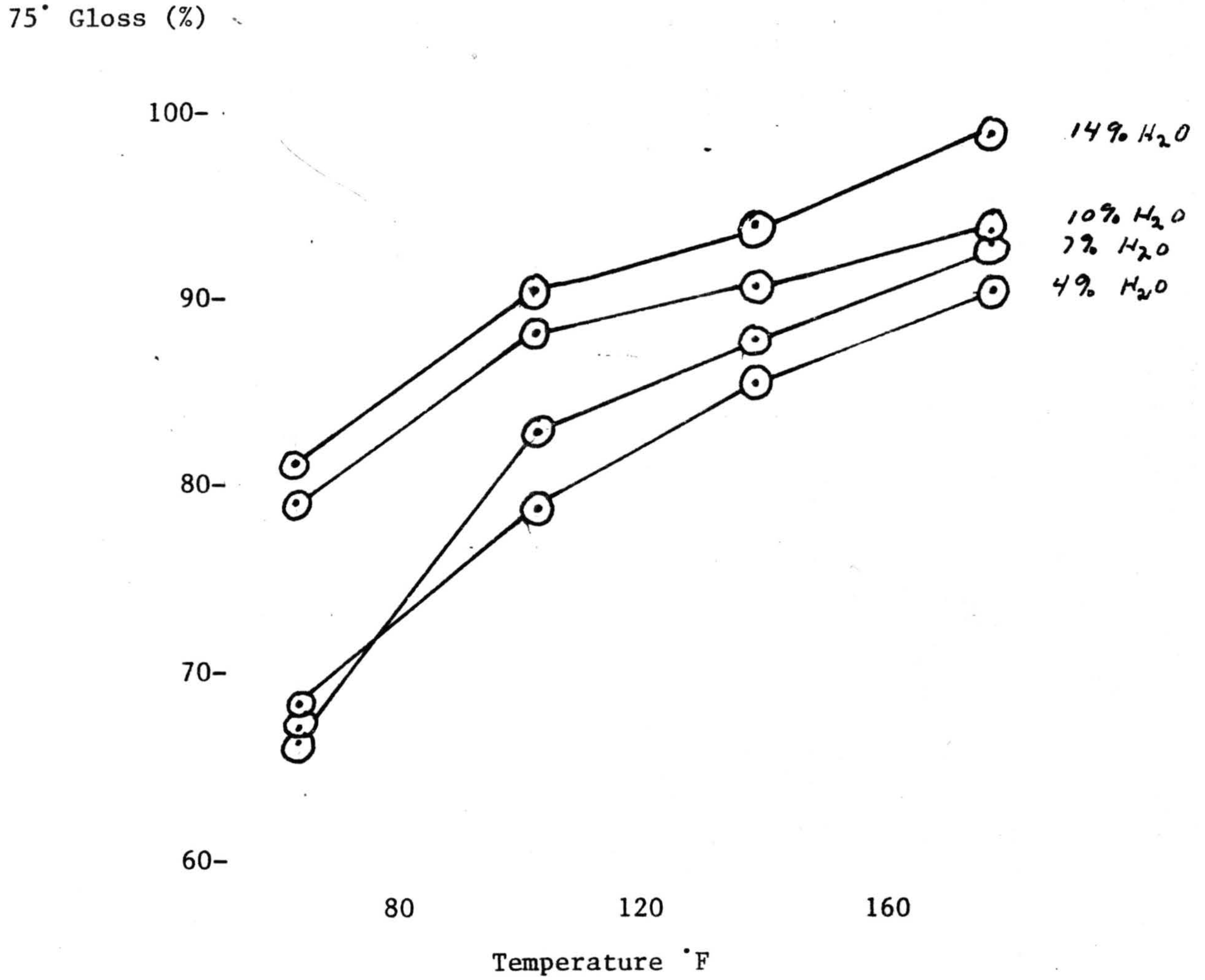


FIGURE 7: MYLAR

75° Gloss vs. Temperature

1660 A

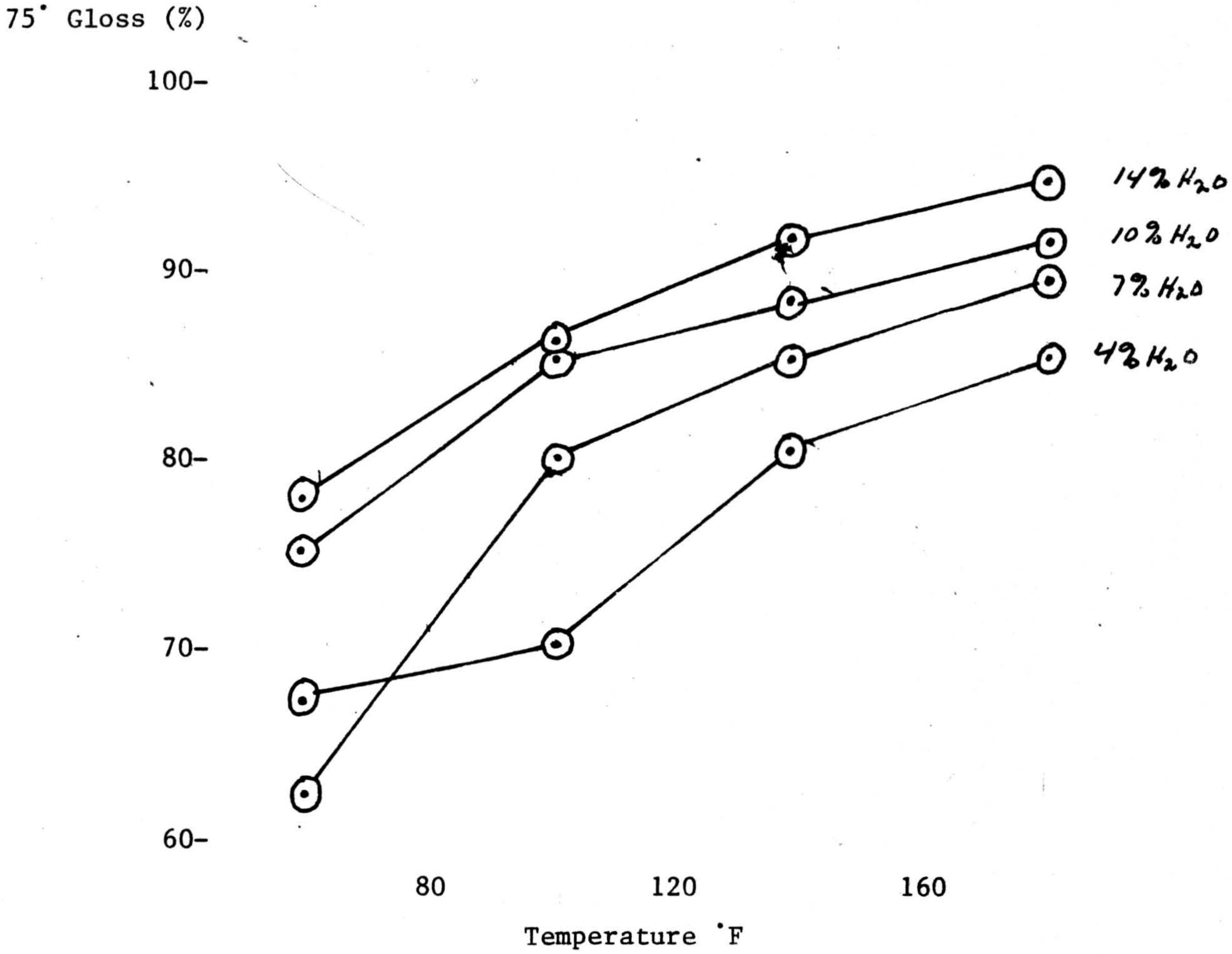
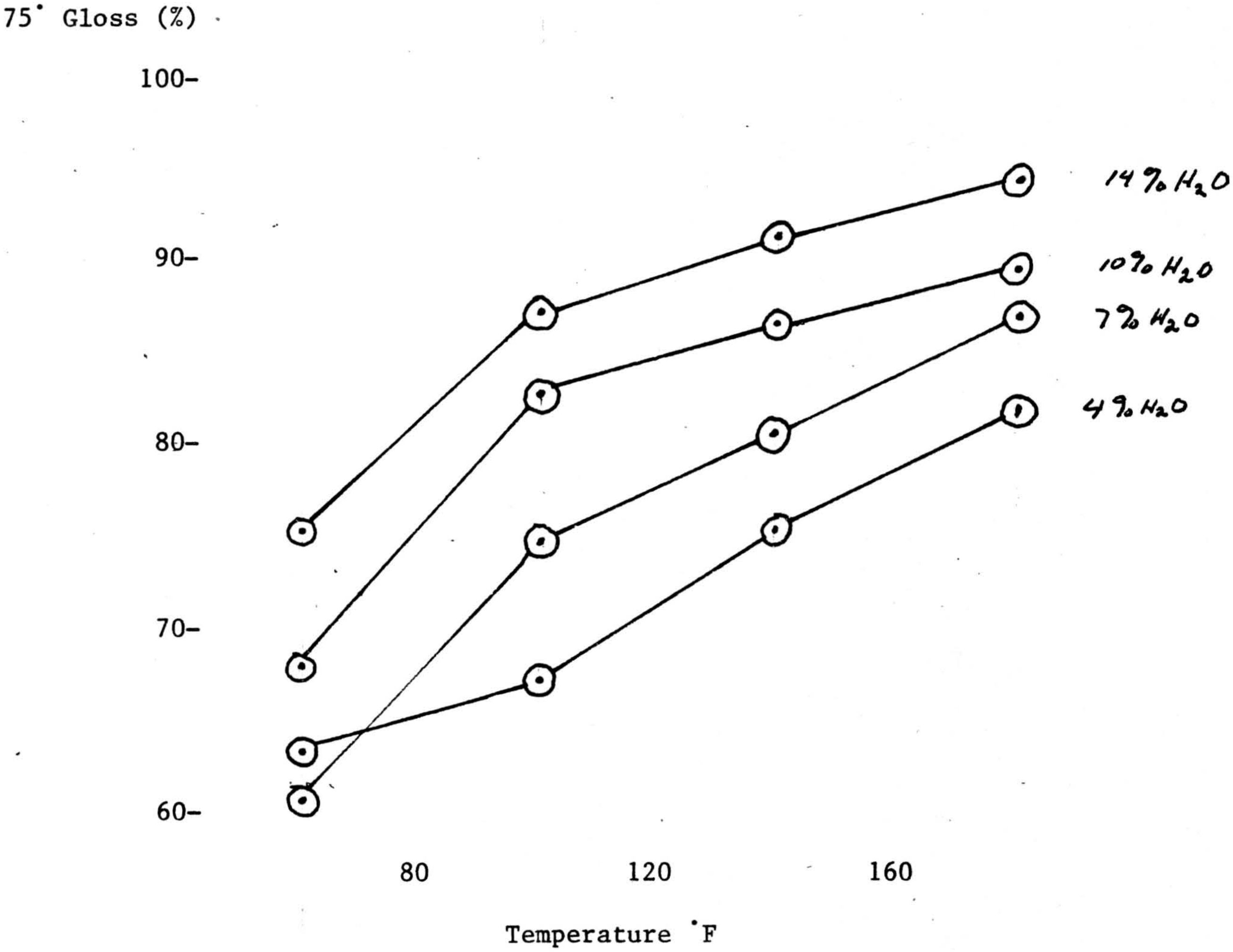


FIGURE 8: MYLAR

75° Gloss vs. Temperature

1890 A



Moisture Content vs. 75° Gloss

Figures 9 through 15 show gloss development vs. moisture content for the three coatings on the paper and mylar at the various temperatures. At low temperatures increased moisture content resulted in either adverse or negligible affects on coating gloss development. At high temperatures, all six figures showed increased gloss development as moisture content increased. The effect of moisture content therefore depends on the temperature of the calender stack.

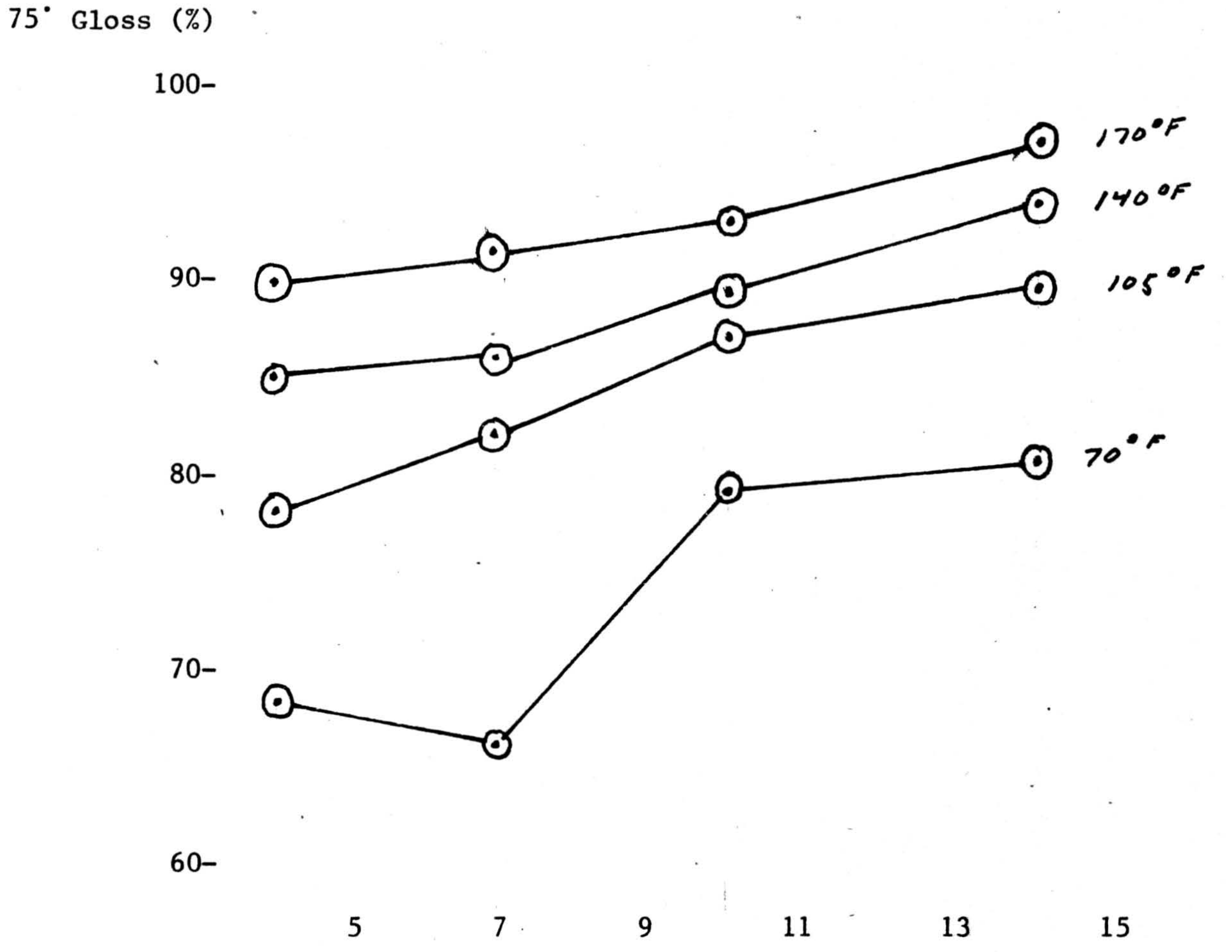
On Figures 9, 10, and 11, the gloss of the coating supercalendered at 170°F and the two middle moisture contents is lower than expected. This probably resulted from the fact that difficulty in removing the sheet from the stack at high temperature occured. It was found that as the speed of the sheet removal increased lower gloss development was obtained under these sticking conditions. Care in removing the sheet on the low and high moisture content sheets and higher gloss resulted. It is speculated that violent sheet removal under sticking conditions resulted in the sheet surface being disrupted.

The dependence on temperature of moisture content effects on coating gloss may be analogous to the behavior of lignin. Lignin in wood acts like acapillary gel in that it can be swelled. Lignins do not have melting points but they appear to soften and appear to develop adhesive powers over a temperature range.[27] It is speculated here that the latices

FIGURE 9: MYLAR

75° Gloss vs. Moisture Content

1510 A



Moisture Content of Coating (%)

FIGURE 10: MYLAR

75° Gloss vs. Moisture Content

1660 A

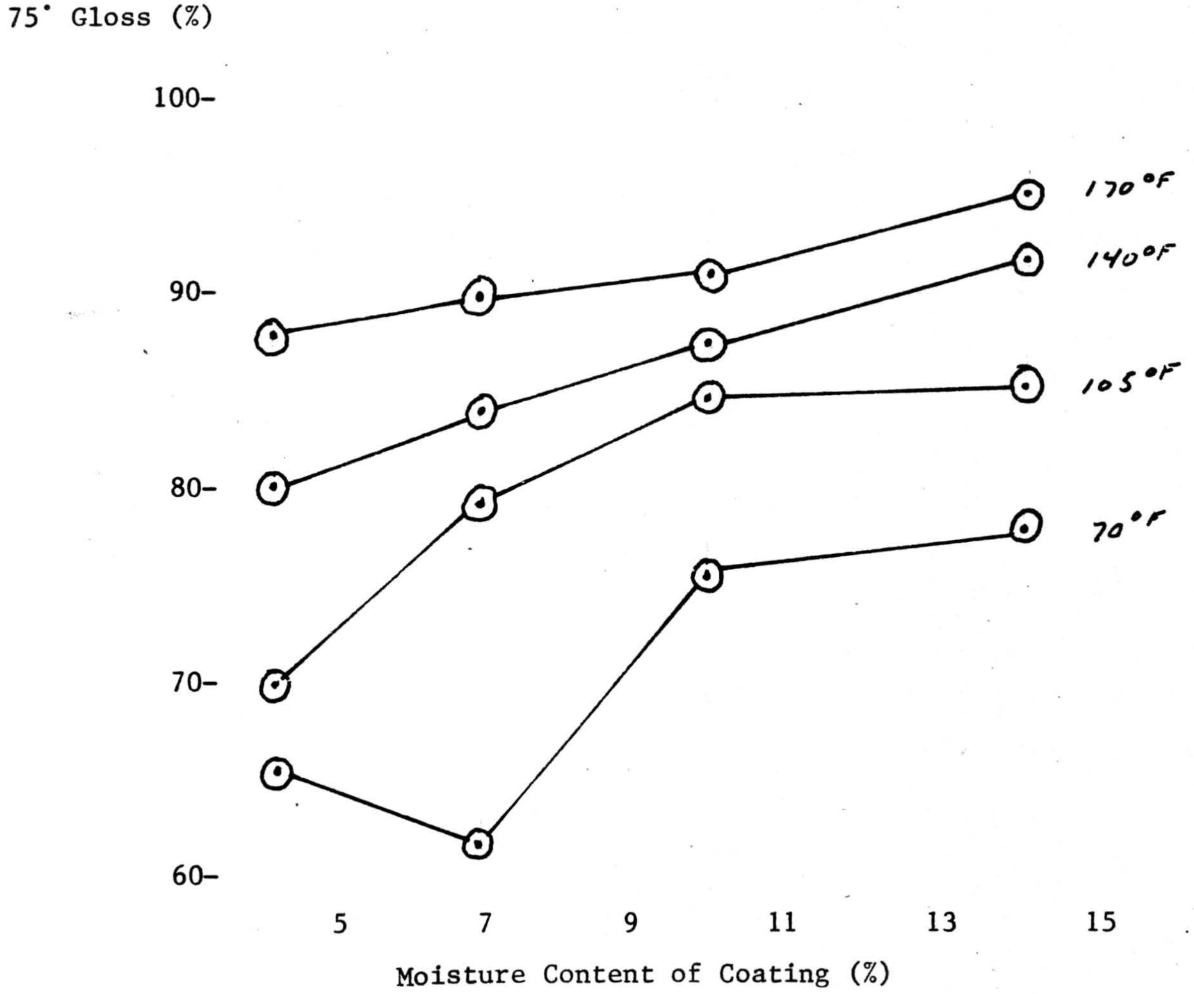


FIGURE 11: MYLAR

75° Gloss vs. Moisture Content

1890 A

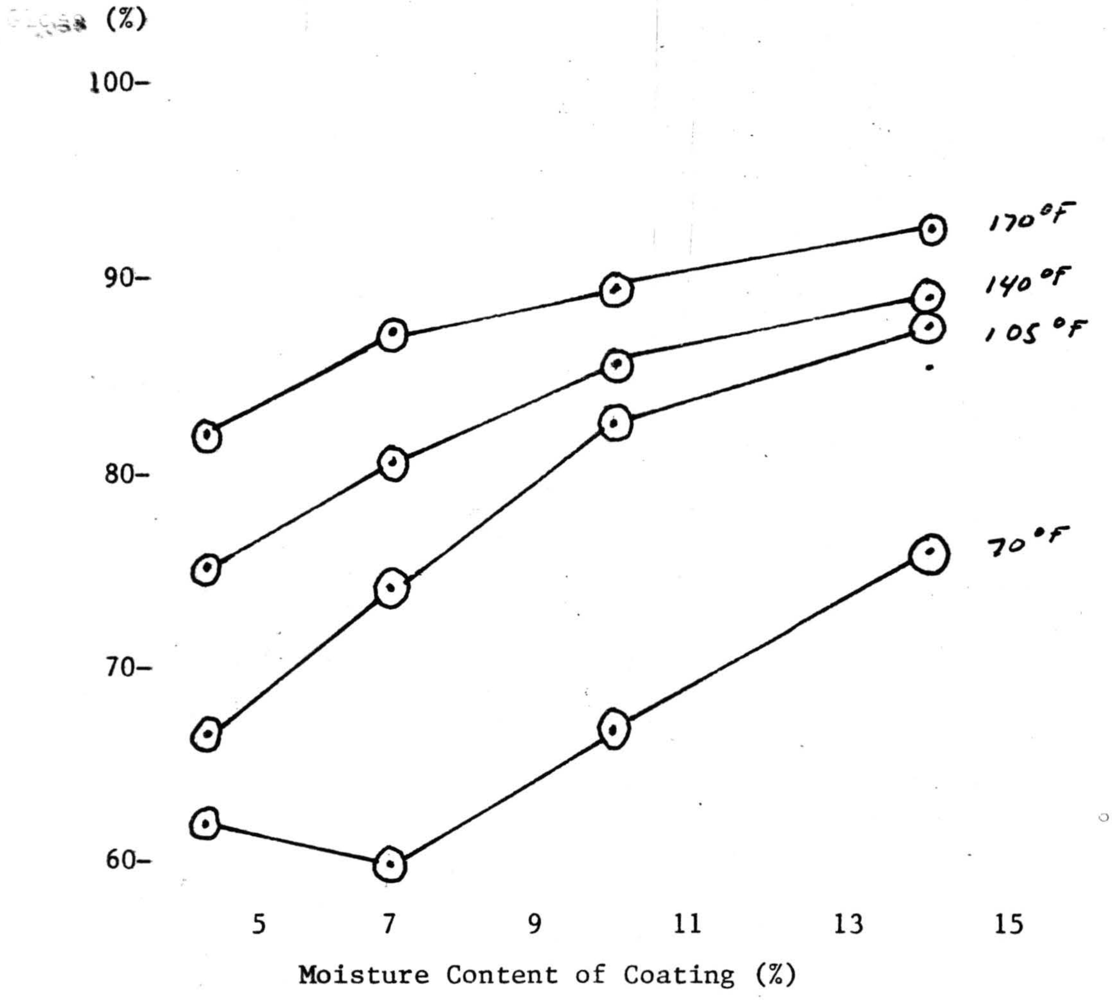


FIGURE 12: PAPER
75° Gloss vs. Moisture Content
1510 A

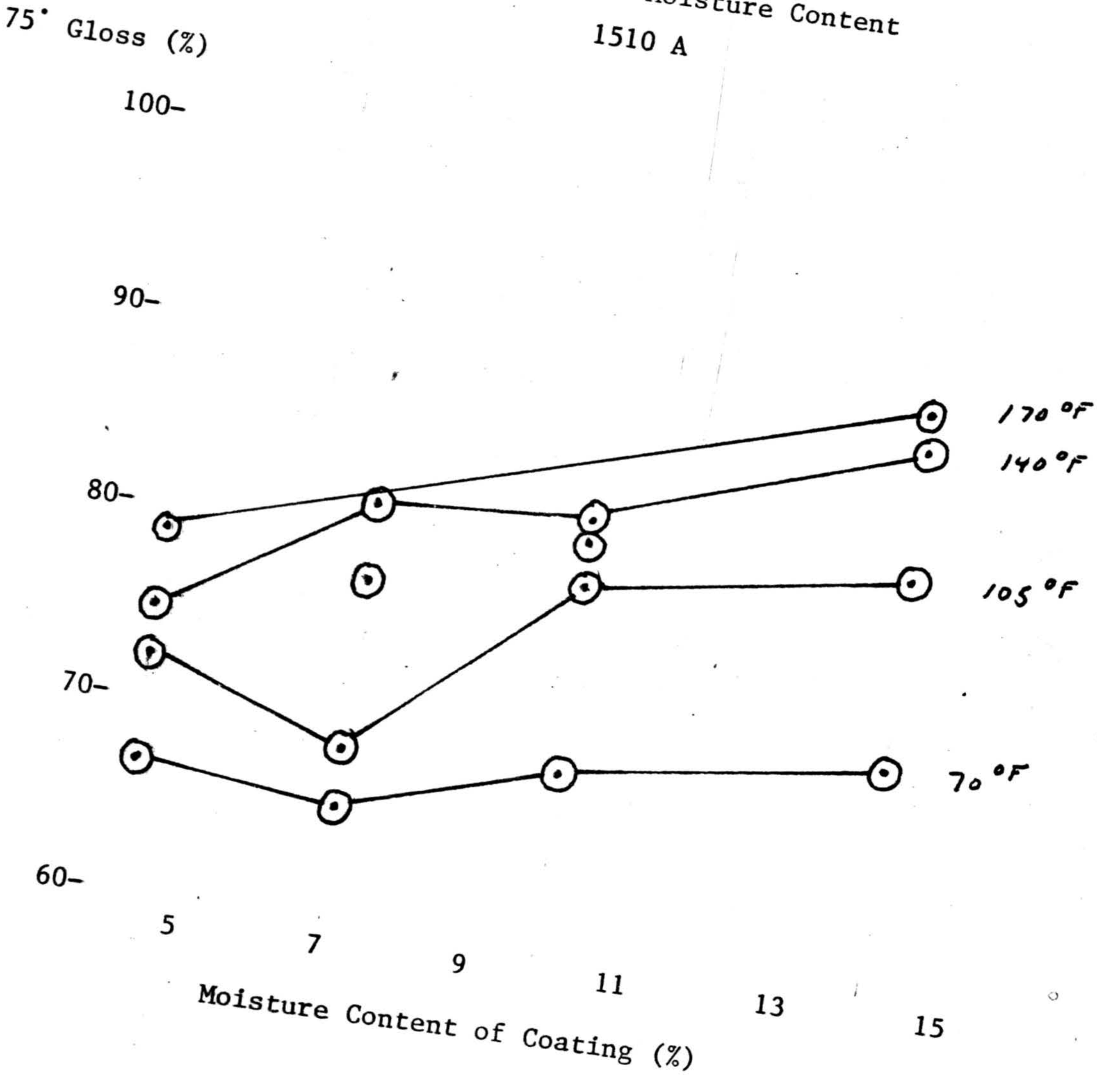


FIGURE 13: PAPER
75° Gloss vs Moisture Content
1660 A

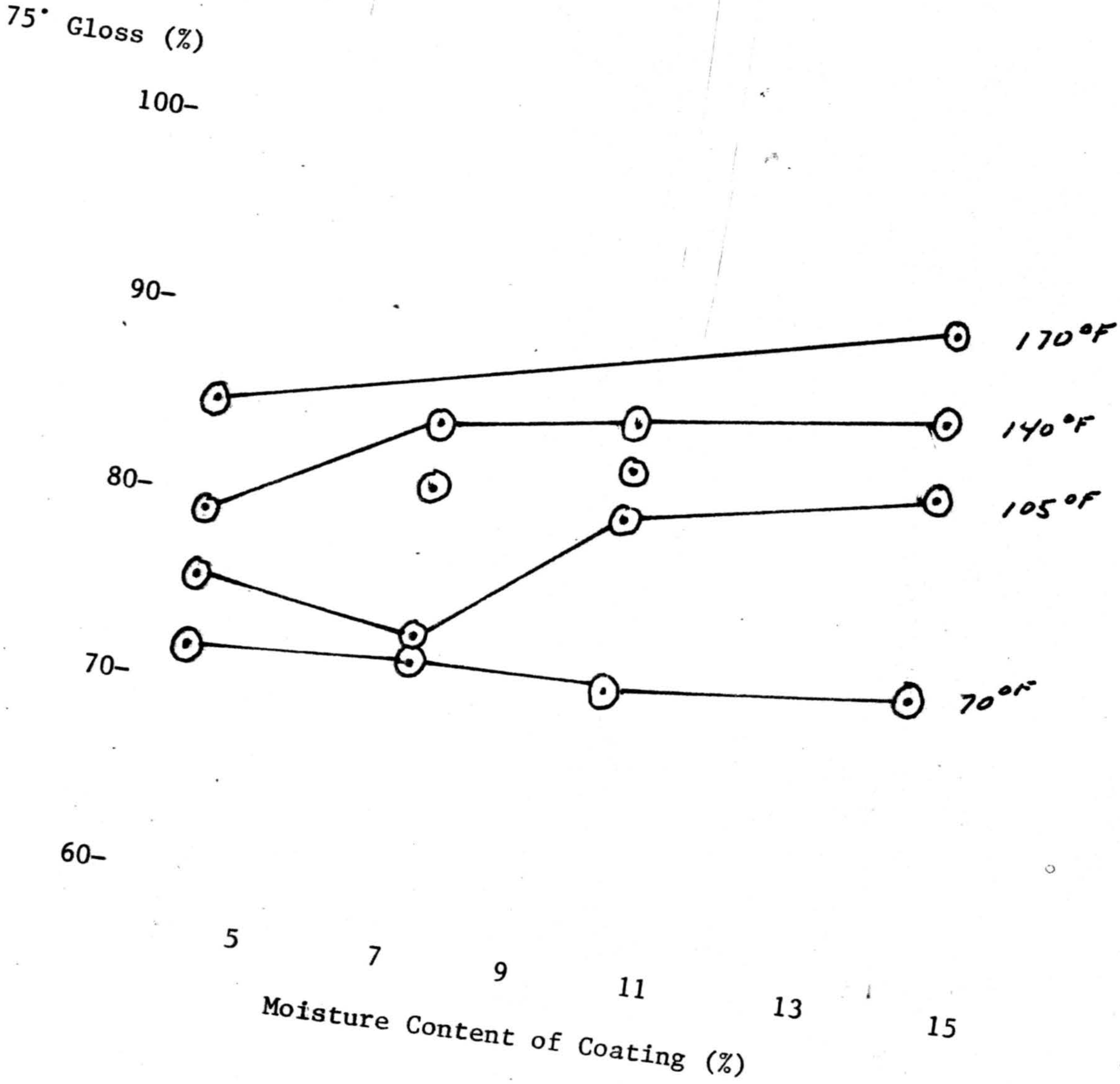
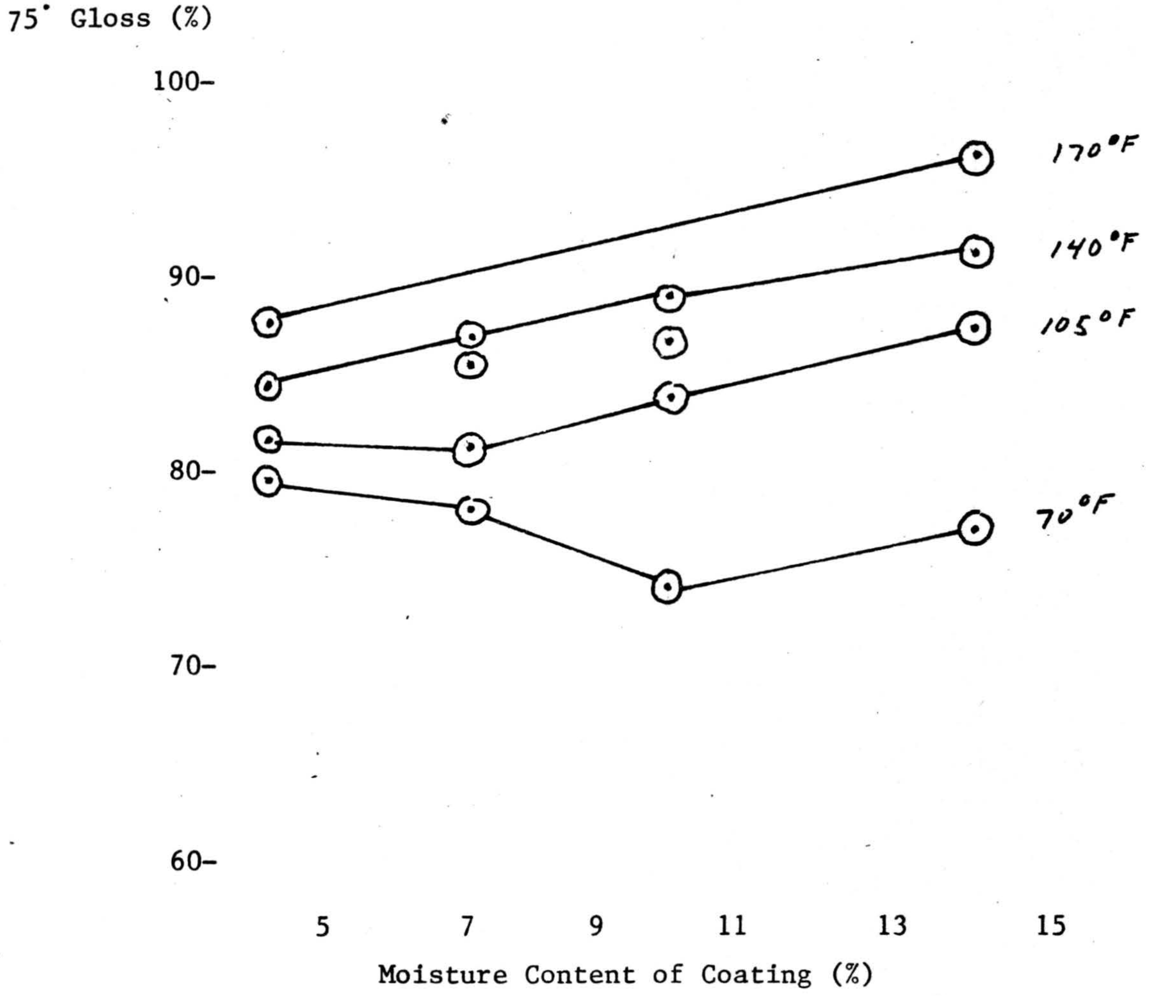


FIGURE 14: PAPER

75° Gloss vs. Moisture Content

1890 A



studied are swelled by increasing moisture content and softened with increasing temperature. At low temperatures, the latex particles are probably rigid and are not swelled to any great extent when moisture content increased.

Figures 9 through 14 show the slopes of the lines on mylar substrate are greater than those on the paper substrate, indicating a greater response of coating gloss to calendering with increased moisture content. A possible explanation would be the same as that discussed earlier in respect to coating gloss response to calendering with increased temperature.

Figures 15 and 16 show gloss vs. nip passes through the supercalender on paper and on mylar at various temperatures. As the temperatures increased, the slope of the lines decreased indicating the higher temperatures allow an ease of calendering greater than that at the lower temperatures. This would have valuable mill application as a greater sheet bulk may be retained for a given coated gloss.

Figures 17 and 18 show opacity vs. temperature and opacity vs. moisture content. Opacity decreased with increased temperature and with increased moisture content. This implies that an increased ease of compaction with increased temperature and with increased moisture content.

Statistical Analysis

Statistical analysis showed that the degree of interaction between temperature and moisture content had a significant effect on styrene-butadiene latex bound coating gloss development. Standard deviations between the two separate experimental runs were extremely low indicating a high degree of repeatability.

FIGURE 18

Opacity vs. Moisture Content

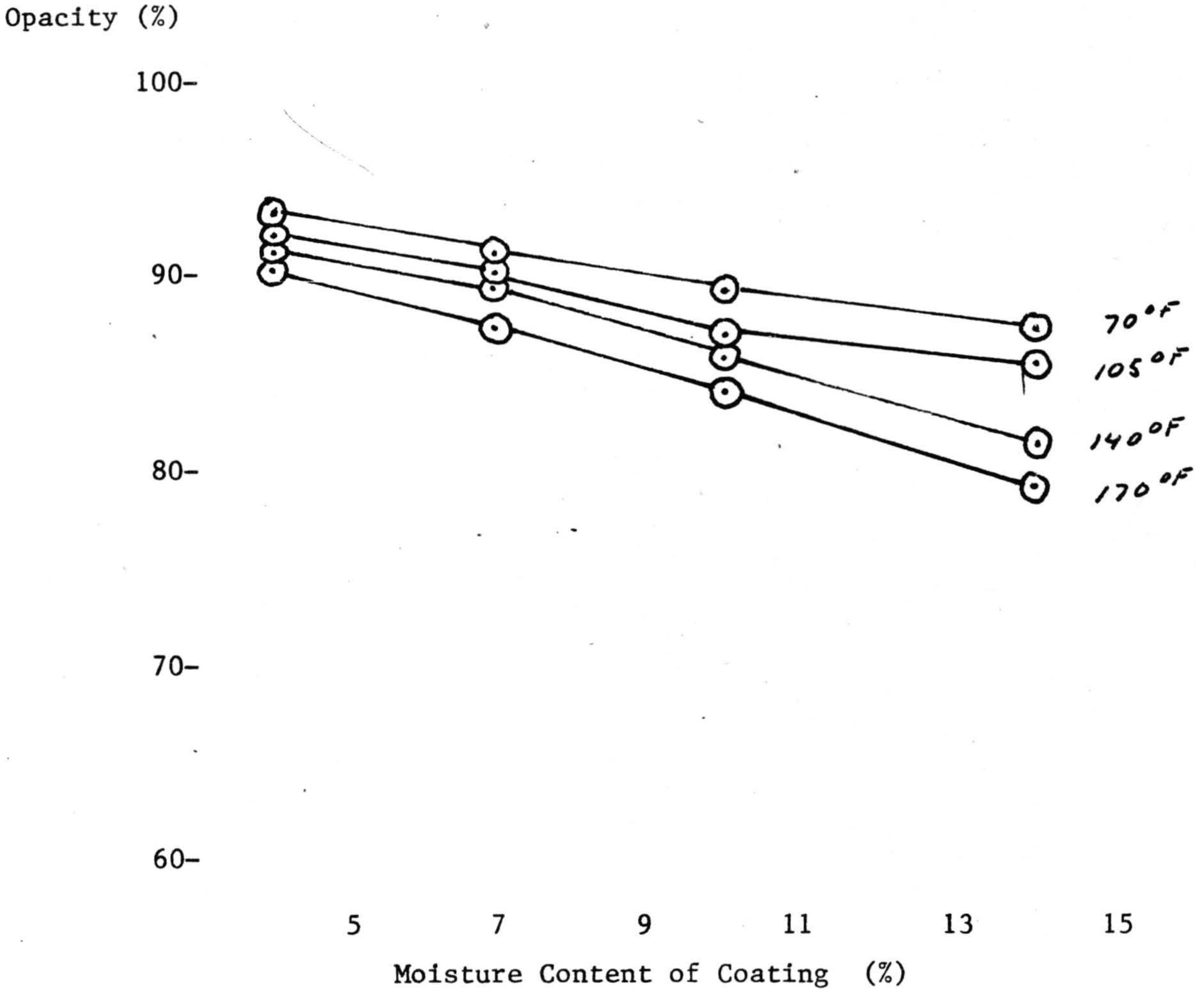


FIGURE 17

Opacity vs. Temperature

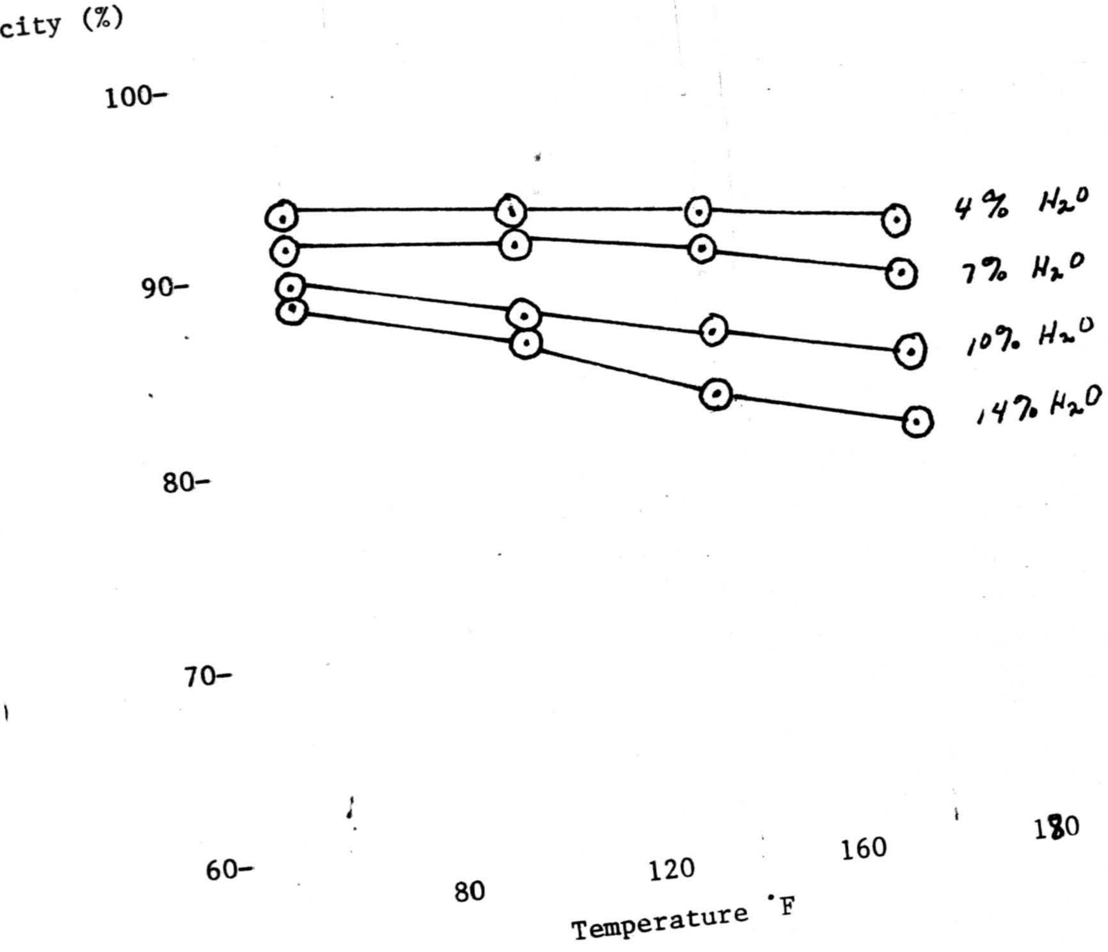


FIGURE 16: MYLAR

75° Gloss vs. Nip Passes

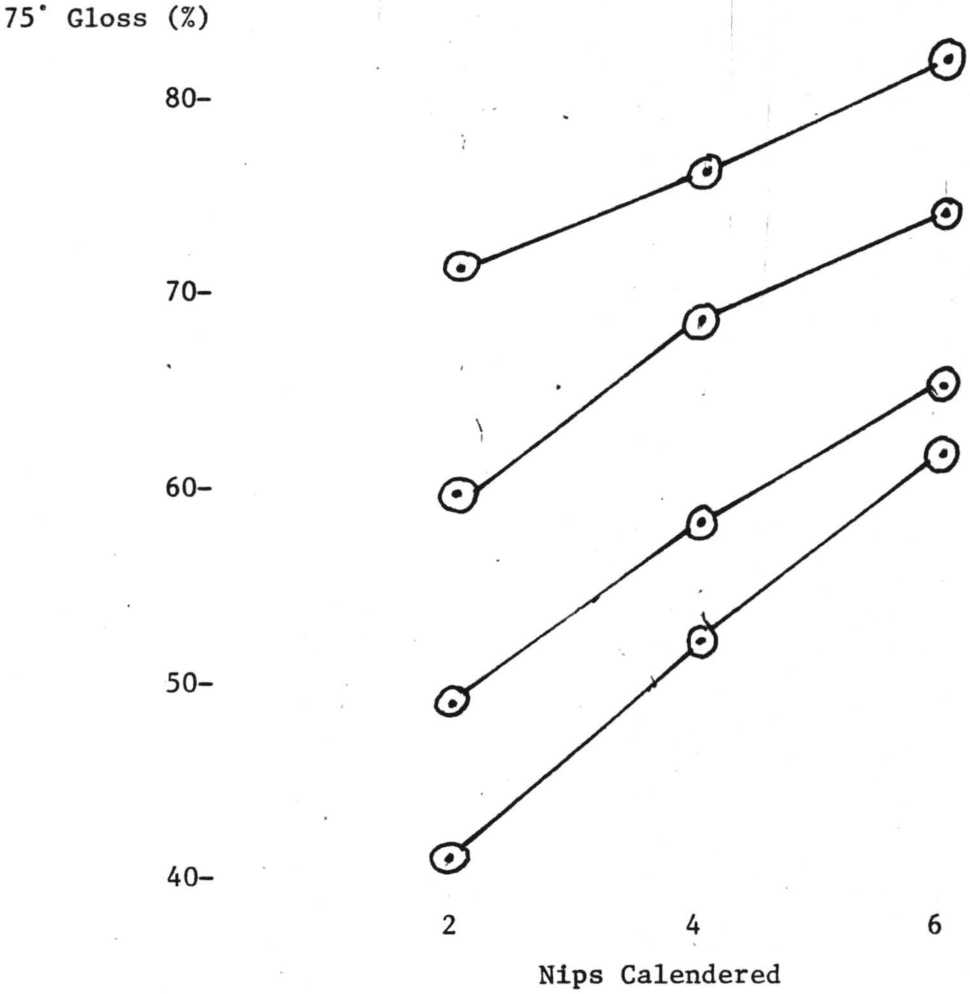
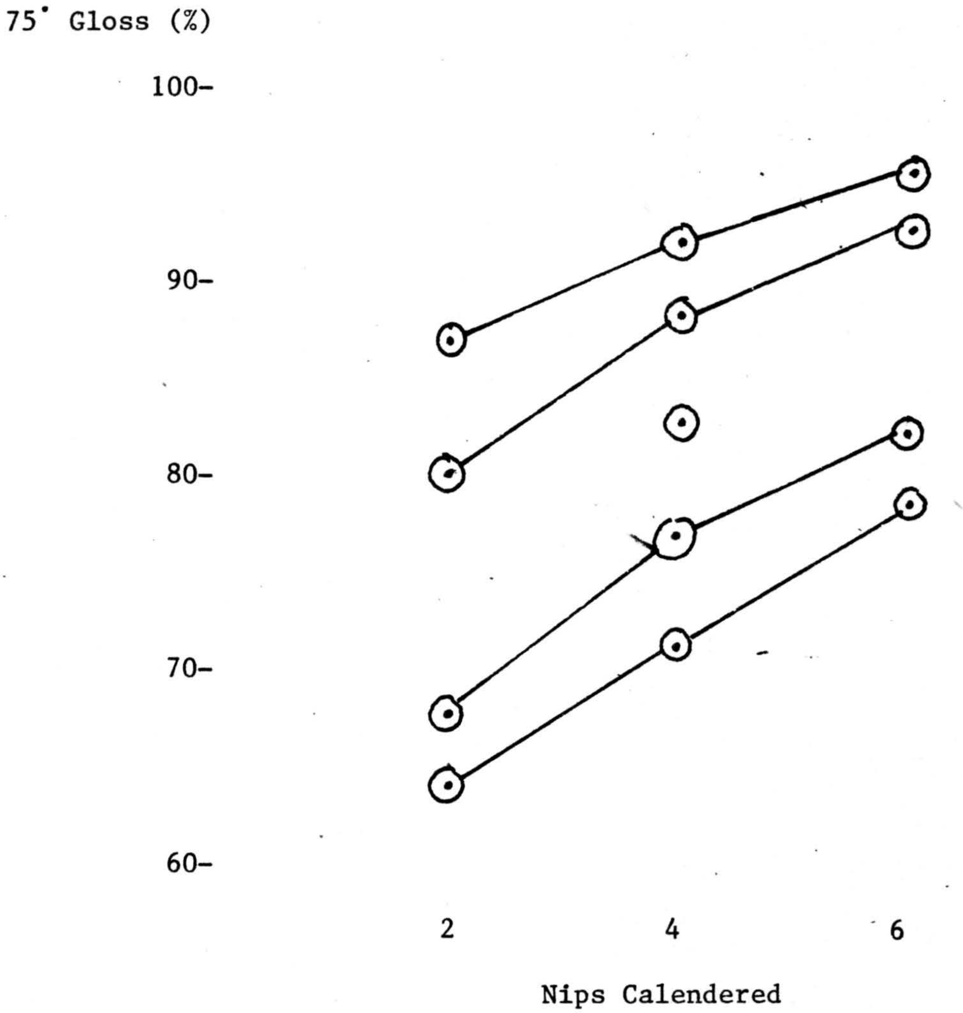


FIGURE 15: PAPER

75° Gloss vs. Nip Passes



CONCLUSIONS

In this study, it has been found that increased calender stack temperature increased coating gloss for all cases. Statistical analysis of the data obtained in the study showed moisture content significantly interacted with temperature. Increased moisture content at low temperatures had negligible or adverse affects on coating gloss development. At high temperatures, increased moisture content always led to increased coating gloss development. Opacity decreased with increased temperature and decreased with increased moisture content.

The interrelationship between the effects of temperature and humidity on styrene-butadient bound coating gloss development indicated that temperature is the most important variable, as it always led to increased coating gloss when it increased.

The increased ease of calendering at higher temperature and moisture content as shown by gloss vs. nip passes supported the theory that increased moisture content and temperature plasticized the binder and this increased the binder flow characteristics in the calender nip.

The opposite glossing response on non-absorbant and the absorptive substrates indicated that particle packing ability and binder strength both play a part in styrene-butadiene bound coating gloss response. It is suggested that the extent as to which factor will dominate depends on the degree of binder migration.

RECOMMENDATION

According to the data obtained in this study, temperature and moisture content significantly interacted to affect the development of styrene-butadiene bound pigmented coating gloss. Since it is common practice in the paper and paperboard industries to add moisture or increase temperature at the calender stack to increase coating gloss development. It is recommended that further studies similar in scope to this one be conducted on other binders used in the paper industry.

Some suggested modifications would be:

(1) to monitor bulk and opacity losses during calendering. This would enable definition of maximum conditions for obtaining the highest bulk, opacity, and gloss for a given system.

(2) casting straight latex films of varying particle size on a non-absorbant substrate and measuring the effect of temperature and moisture content on latex gloss development. Slopes of curves obtained might offer insight as to the mechanism of gloss development.

(3) study the effect of varying the drying rate in a study similar to this one. This would enable insight into the effects of binder migration.

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