A Study of Bentonite as an Additive for Starch Size Press Treatment

C. Ted Romer
Western Michigan University

Follow this and additional works at: https://scholarworks.wmich.edu/engineer-senior-theses

Part of the Wood Science and Pulp, Paper Technology Commons

Recommended Citation
https://scholarworks.wmich.edu/engineer-senior-theses/394

This Dissertation/Thesis is brought to you for free and open access by the Chemical and Paper Engineering at ScholarWorks at WMU. It has been accepted for inclusion in Paper Engineering Senior Theses by an authorized administrator of ScholarWorks at WMU. For more information, please contact maira.bundza@wmich.edu.
A STUDY OF BENTONITE AS AN ADDITIVE
FOR STARCH SIZE PRESS TREATMENT

by C. Ted Romer

In Partial Fulfillment
of
Senior Thesis
for
Western Michigan University
Department of Paper Science and Engineering

April 19, 1978
ABSTRACT

The size press has been examined in the past for its application for coating or pre-coating. Bentonite has been found to be a rheology modifier and also has been found to form a film on paper. Bentonite has been found to improve holdout and printing properties as well. In this study, bentonite was applied in small quantities on a pilot machine size press and the paper thus produced was examined for any improvements in coating, physical, and optical properties. Testing showed that bentonite had the greatest effect on porosity and pick strength, in that porosity decreased with increasing bentonite and pick increased with small amounts of bentonite but then fell off with higher levels of bentonite. Generally, it was found that addition of bentonite could be beneficial to some properties at one level of addition while being beneficial to other properties at other levels of addition.
# TABLE of CONTENTS

I. Literature Review
   A) Introduction ........................................ 1
   B) History of Size Press Coating ..................... 1
   C) Reasons for Size Press Coating ................... 2
   D) Blade Coating Considerations ...................... 3
   E) Base Stock Requirements ............................ 4
   F) Size Press Variables ................................ 6
   G) Effects of Coating Components .................... 7
   H) Results of Size Press Coating ..................... 9
   I) Equipment Considerations .......................... 11
   J) Effect of Dentonite ................................ 15

II. Statement of Problem .................................. 18

III. Experimental .......................................... 19

IV. Results ................................................. 23

V. Discussion of Results ................................ 26

VI. Conclusions ............................................ 32

VII. Literature Cited ...................................... 33
LITERATURE REVIEW

INTRODUCTION

The literature was searched from 1977 to 1959, with several articles dating to as early as 1940 being reviewed as well. The aim of the search was to find information regarding requirements of coating base stock, size press operation variables, coating with the size press, and rheological properties of bentonite.

HISTORY OF SIZE PRESS COATING

The size press application of pigmented coatings has been tried off and on for over thirty years with varying degrees of success. Renewed interest in size press coating has arisen due to competition exerted on uncoated grades by machine-coated printing grades. The use of the size press for coating purposes allows the improvement of machine-finished offset and opaque grades with little or no capital expenditure(1). Size press coating allows the noncoating mill the opportunity to produce coated papers in order to compete with off-machine grades, but without the huge expense of installing an off-machine coater(2). Furthermore, using the size press as a final coater is particularly useful for developing countries whose consumption of coated papers is not high enough to support high-speed off-machine coaters(3).
In the area of size press coating, companies in the United States tend to use the size press for precoating whereas European companies tend to use the size press for final coating. This difference is due to the fact that European companies have lower quality expectations for coated papers than do companies in the United States. Therefore, the Europeans have had much more experience with the use of the size press for final coating. In fact, a study of several different types of coated and uncoated papers of European origin for suitability for gravure printing found that size press coated papers were superior to air-knife coated papers.

REASONS FOR SIZE PRESS COATING

Size press coating has been found to be somewhat related to tub sizing. Its application for precoating has become well established in recent years, and is normally used for clay coated grades to improve smoothness and uniformity of the raw stock, to increase total coat weight, and to reduce penetration and adhesive migration of the topcoat. Furthermore, precoating provides a better surface for reproduction processes if a topcoat is not going to be applied, improved final product quality and performance, reduced overall cost, improved optical properties, improved sheet surface by leveling surface fibers, a foundation for subsequent coatings and enhanced wetting and adhesion of the topcoat to the raw stock, and can be used to impart functional properties and also to apply saturation coatings to increase internal sheet bonding.

The principal function of the pigment is to fill in the valleys
in the surface of the raw stock. The binder in the coating acts to bond the pigment layer and to seal the surface against excessive penetration of the aqueous phase of the topcoat. The topcoat may be applied after the precoat has been dried, or may be applied on-machine while the precoat is still wet. Although unpigmented sizings are used in some cases, pigmented coatings using a variety of natural and synthetic adhesives are normally used.

BLADE COATING CONSIDERATIONS

The control of scratches in blade coating is a big concern of paper converters. Scratches appear in blade coating because of poor base stock (too absorbent, etc.), bad coating color (too dilatent, etc.), or unfavorable machine conditions (very low speed, etc.). There are two types of scratches, mechanical and rheological, both of which are caused by solid particles or coagulated color lodging at the blade tip and disturbing the surface of the liquid coating layer.

Rheological scratches result when too much water penetrates the sheet and causes an increase in the percent solids of the coating which then coagulates under the high shear of the blade. Mechanical scratches result from solid particles, such as undispersed lumps of pigment, lodging at the blade tip.

Scratches can be controlled by reducing the transfer of water from the coating color to the base stock. This is achieved by using a nonabsorbent or precoated base stock, a color with good water-retention ability, and a coating head that will keep formation of
color lumps to a minimum and also eject them past the blade tip as soon as they form. Precoating plugs the base stock and thus reduces the transfer of water from the coating color to the fibers. The precoating should contain a water-retention, water-swellable agent which forms a continuous film to protect the base stock. Natural binders such as casein, protein, and starch, and synthetic water-retention agents are particularly useful. The precoating can be applied at either the size press or at a coating head, and the precoating can be effective at a coat weight as low as 1.5 g/m$^2$.

Besides increasing the total attainable coat weight and permitting the binder level in the topcoat to be reduced and providing a smoother surface to the base stock, precoating the sheet allows it to run better under the blade of the coating head which thereby reduces the incidence of breaks and color strike-through. Precoating with calcium carbonate or course clay (No. 2 clay) imparts, due to the coarseness of the pigment particles, a microscale roughness on the sheet which allows easier control of scratches by aiding the scratch-producing particles in getting past the blade tip. The amount of calcium carbonate in the precoating varies widely, but is usually around 30 parts; however, some manufacturers use as much as 75 parts calcium carbonate in their precoating formulations. The price differential between calcium carbonate and No. 2 clay (No. 2 clay costs approximately half as much as calcium carbonate) affects the relative amount of each used in the precoating(6).

BASE STOCK REQUIREMENTS

The ideal base stock is a substrate with both sides having the
smoothness of a Machine Glaze finish, free of all defects, and within the established physical specifications. In actuality, coating does not hide defects. Rather, it accentuates them. Thus, marginal paper which might be acceptable for an uncoated paper would be unacceptable as a coated paper. Moisture streaks in the base stock will carry through the coating and printing operations to produce variations in the paper and ink gloss. Moisture profile differences of 3-4% over narrow (1/2 inch) widths are unacceptable. Variations in cross-machine basis weight of more than ±1.5% in a 10-15 inch width may cause severe corrugations when the sheet is supercalendared. Good formation is needed because bunchy or wild formation will have an adverse effect on printing. Two-sidedness must be minimized; machine calendaring does not decrease two-sidedness. The use of high levels of hardwood will help produce a tighter sheet. Uniform caliper is needed; there can be no curl, cockles, or dimples. Also, the base stock must meet other specifications such as mullen, tear, fold, tensile, wax pick, Scott Bond density, smoothness, ash, brightness, opacity, and sizing(7).

It has been found that three basic sheet factors influence coating penetration. These are degree of compaction or porosity of the sheet, deformability or expansion of the sheet when rewetted by the coating, and wettability of the fibers. Higher porosity gives more adhesive penetration, better supercalendared smoothness, more cushioning, and better gloss. Wettability is crucial for penetration by capillary action, and capillary action is also reduced at higher levels of sheet compaction. Sheet expansion is influenced by interfiber bonding within the sheet by the relation-
ship that more bonding gives less expansion. Coating compaction is maximized when applied to a smaller pore substrate, and coating starch also forms a thinner, more concentrated layer. Larger pore size substrates allow deeper adhesive migration, a less concentrated starch layer, and a less dense coating. The rigidity of the base sheet surface, adhesion between it and the coating pigment, and its cushioning and deformability govern supercalendar response. A rigid base sheet surface leads to a relatively rough supercalendared sheet and also causes fiber blackening and undertone. Decreased adhesion aids the development of gloss. Uncompacted, bulky base sheets reduce the supercalendaring load and reduces its effect on the coating in that you will obtain less coating densification, higher proosity and ink absorbency, lower gloss, and less fiber blackening(8).

SIZE PRESS VARIABLES

Nip loading pressure is the major factor in controlling the coat weight. Higher nip pressure leads to lower pick up. Pneumatic loading of the nip is prevalent. The amount of coating deposited on the web also depends on the relative affinity of the coating for the web and for the applicator roll, the absorbtivity of the web, the wettability of the coating, sheet moisture, the relative speeds of the web and size press rolls, porosity and sizing of the raw stock, the uniformity of the raw stock, the solids content and temperature of the coating, and the sheet density. Increasing the sheet density reduces its ability to absorb, increasing the surface
smoothness results in reduction of the caliper and thus an increase in density and also leads to lower pick up because of the smoother surface, greater internal sizing leads to lower pick up, internal migration of size towards the sheet surface gives lower pick up, and increasing solids content of the coating yields increased pick up. The viscosity of the coating is also a major factor because, in the case of sizes, lower viscosity yields greater penetration and higher viscosity yields greater pick up. The viscosity can be changed to a certain extent by changing the temperature of the coating. Because higher coating viscosity leads to streaking and pattern formation, viscosity must be limited to a low value. At 600 feet per minute, for instance, viscosity should not exceed 175 centipoises\(^{(1,2,10,11)}\). The operating conditions for the paper machine and size press are best obtained by trial and error. Optimum sheet moisture entering the size press is 5-6\%. Lower moisture content causes repulsion of the coating and higher moisture content may cause cockling if the sheet is dried too fast\(^{(1)}\).

Film splitting of the coating leaves a pattern on the web. The severity of the pattern depends on the rheology of the coating, the speed of the rolls, and the volume being split. The pattern is worse at higher speeds and/or higher film thickness\(^{(1)}\).

**EFFECTS OF COATING COMPONENTS**

Until recently, unpigmented sizings only were applied at the size press due to operating problems with the pigmented formulations. Many of these problems have been worked out now and a number of
mills are now applying clay coatings at the size press. The pigment coatings usually have 15-50% solids and viscosities in the range of 10-200 centipoises. Usually, 15-40% solids is used for surface leveling for printing. Pigmented sizes usually have total solids in the range of 10-15%. The precoats are uncomplicated, usually containing starch, latex, pigment, sizing materials, and sometimes a cross-linking agent which is adjusted to give the desired base sheet filling, porosity reduction, surface character, and binder demand satisfaction. One pigment and one binder has been found to be the most efficient combination (1,2,4).

Internal sizing is used to prevent excessive adhesive migration and also to provide some wet strength. The range of internal size levels for adequate coating is quite broad, but inadequate sizing leads to high pick up levels, increased binder demand, curl, and web control problems due to excessive wetting. Too much sizing results in excessive film-split patterning, lower pick up, and drying problems due to inability of the coating to set which then causes coating to build up on the first dryer can after the size press (1,12).

Starch is the most common adhesive for both pigmented and unpigmented size press formulations. Selection of the proper starch is essential because starches that work well for normal surface sizing may not work well in pigmented applications. The starch should have excellent viscosity stability in the presence of pigments. However, the use of polyvinyl alcohol and synthetic latexes in conjunction with starch has shown the advantages of improved holdout and adhesion. The use of all-synthetic adhesives is becoming very
interesting in the desirability of tailoring coating formulations to achieve minimum cost and maximum compatibility between the base stock, precoat, topcoat, and end use in order to obtain maximum product quality. Addition of latex having good compatibility with both protein and starch to the size press coating is useful when the topcoat is a protein or casein formulation, because otherwise, adhesion difficulties may be encountered between the topcoat and precoat due to dissimilarity between the two binder systems. Also, substitution of latex for some of the starch helps reduce viscosity and make higher solids content possible. Coating screening is essential, and the temperature effect on viscosity must also be considered. A good starting point is around 150°F. (2, 4, 5, 12).

If a colored coating is to be used, the raw stock should be tinted to the same color. (1).

Finally, it was found that coating colors of 40% solids and a viscosity of less than 100 centipoises could be obtained by alkaline treatment of casein in the pigmented formulation, and by adding urea as a rheological modifier for the appropriate latexes. The resulting coating color had pseudoplastic flow and thixotropy (10).

RESULTS OF SIZE PRESS COATING

Size press coating (11 lb./3000 ft.², 40 parts binder per 100 parts pigment) raised K & N ink holdout by 60% as opposed to uncoated paper, had little effect on base sheet gloss, raised IPI Blue Gloss Ink Test at 20% Densichron Transmittance reading by 400%, markedly improved Sheffield smoothness, and also markedly improved Sheffield porosity by closing up the sheet. Other
results of size press coating are a slight increase in opacity, higher ink absorption, but unchanged sheet strength. Pick strengths are generally lower because the base sheet is of lower basis weight and the binder does not migrate as far into the sheet in order to strengthen it, and because the hot wax used for the wax pick test affects the thermoplastic coating (thermoplastic due to the inclusion of synthetic latex). Also, IGT readings are lower because the sheet surface is smoother and thus there is greater contact area. Furthermore, in terms of pick resistance, the weakest link in the chain is the connection between the first layer and the base sheet. The pressure used in applying this layer is useful in that part of the coating is forced into the web structure. But, if pick resistance or projecting fibers present a problem, it may be advantageous to use straightforward surface sizing because the lower solids content allows better penetration and anchors the surface layer well into the fiber structure\(^{(1,12,13)}\).

The use of 100% clay as the pigment tended to reduce the size test, but addition of as little as 5% calcium carbonate helps. Also, the use of 100% clay in the furnish for size press coating can lead to savings as compared to the cost of an uncoated sheet. The savings decrease as the amount of expensive coating ingredients (such as synthetic latexes, titanium dioxide, etc.) increases, and also as the amount of coating pick up increases\(^{(12)}\).

The nip pressures encountered in size press coating result in a strong connection between the base stock and coating layer. Also, fibers projecting above the surface are pressed back into
Studies of size press coated paper have shown that, comparing tracts across the width of the web, variations in basis weight did not affect the coat weight across the web, and that regions of greater basis weight had higher smoothness and lower porosity than did the regions of lower basis weight, after supercalendaring, because of increased compression in the regions of higher basis weight.

A main disadvantage of double coating (precoat and topcoat) is that the interface between the coatings is a possible zone for delamination if the two coating layers are not firmly bonded together. Kitts has stated that, although its use for applying a slight precoating before final off-machine coating is rapidly increasing, the possibility for use of the size press for final coating is somewhat limited.

EQUIPMENT CONSIDERATIONS

The most common difficulty in switching to the use of the size press for pigment coating is the major differences of preparation with the kitchen equipment in order to get good pigment dispersion. Because pigment dispersion is very critical, the pigment preparation system should be similar to a conventional pigmented-coating preparation system.

Many size presses are used for precoating, and size presses are used to apply anything from lightly-pigmented sizes all the way to high-solids coatings. Any vertical, horizontal, or inclined size press in good running condition can be used to apply coatings.
The horizontal size press is better for applying heavy coatings because larger ponds are possible (thus creating a hydraulic head), but whether the horizontal or vertical size press is better for low coat weights is debatable. Premetering of the coating has to be accomplished in the nip by means of gap opening or relative roll speeds, both of which increase patterning tendency. Coating slips of up to 50% solids can be handled by a size press, and the necessary drying capacity for the coating does not present any great problems. But, more careful consideration is needed with regard to the question of orange peel effects and also the problem of wet coating adhering to the bottom exit lead or turning roll (1, 13).

The hardness of the rolls is a factor in size press performance. It is usually advantageous to have one roll slightly more resilient than the other, which causes a momentary acceleration of the web as it goes through the nip which in turn leads to a smoother coating surface. Too much resiliency leads to a heavier coat weight, because of a wider nip line, and therefore more pattern. It is usually recommended that the bottom roll have a P & J hardness of 25-35 and that the top roll have an artificial stone cover and also be doctored. The use of a helper drive for the top roll aids in reducing two-sidedness because the surface fibers are then not disturbed by having to drive the top roll. The roll diameter is a factor since larger rolls require less crowning and allow a greater range of nip pressures. However, the large rolls require greater nip pressure to squeeze out the same amount of coating. It is usually advantageous to crown the bottom, rubber-covered roll since the rubber-covered roll is softer and wears faster and thus needs to
be ground more often\(^1,2\).

Usually, some modifications have to be made to the size press, including the use of a calendar water box to feed the bottom roll to insure a uniform pond for the web bottom and thus reduce pattern, and also end sealing of the size press which thus allows adjustment of the pond depth. Generally, both rolls are driven in a horizontal size press while one or both rolls are driven in the vertical size press. Also, if one side only is to be treated, it is useful to apply water to the other side to reduce curl, gain some increase in sheet finish, and prolong roll life. A much more radical modification is the conversion of the size press to a gate roll coater. This can be done by removing several dryer cans before and after the size press. The loss in drying capacity is compensated for by the ability to run at higher solids\(^1,3,9\).

Good wet pressing and formation are good for obtaining a smooth sheet surface for size press treatment since less coating is thus needed. The use of a single- or double-nip controlled crown calendar or breaker stack in front of the size press when running pigmented coatings is useful, and the use of higher loading on the wet end smoothing presses can also be used, since both will lead to better sheet smoothness\(^1,3\).

The machine speed is governed by the drying capacity of the post dryer section. For coating, the machine can run at nearly the speed that would be used for normal surface sizing of a similar sheet. Usually, 17-38\% of the drying capacity (26\% is average) should be in the post dryer section. Also, it is generally necessary to run the first two post dryer cans at slightly lower surface
temperatures in order to obtain a gradient so as to avoid picking the sheet, counteract transverse shrinking of the sheet, avoid cockling and blistering and grainy edges and flaking, and avoid case-hardening of the sheet which would further retard drying and cause curl. The first two dryer cans are normally unfelted and supplied with doctors. Pick off of the coating can be further reduced by using Teflon coated cans on the first two dryers. Extending the draw between the size press and the after dryer section or addition of a flat box air dryer is helpful for setting the coating before it reaches the dryer cans. The rate of drying is important because it, as well as the absorbency of the raw stock, affects adhesive migration. Normally, the adhesive migrates into the substrate; but, at high drying rates, the adhesive migrates toward the coating as well as into the substrate (1,4).

The conditions for normal surface sizing are a good starting place for coating. It should be remembered that, when coating, the surface strengths of the web will vary, with the top side usually being weaker. Furthermore, pigment coating demands at the size press are quite different compared to starch demands because of differences in rheology, pick up, etc. Also, filters and strainers in the coating preparation system, formerly the size press cooking kitchen, should be able to handle the higher solids content of the coating slip as opposed to the previous sizing formulations. Also, with regard to non-steam drying, hot air drying is often preferred over infrared drying because hot air dries from the surface rather than from the mass of the web (1,4).

Finally, for precoating with a horizontal size press, which
is considered more efficient than a vertical size press, the influence of operational parameters (machine speed, nip pressure, depth of coating puddle at the nip) on the coating weight were found to be unimportant compared to the parameters of the coating color (especially viscosity) and of the paper (especially air permeability)\(^\text{(11,14)}\).

**EFFECT OF BENTONITE**

Bentonite has been found to yield a rheology similar to that obtained from alginate and carboxymethyl cellulose - that is, thixotropic and pseudoplastic flow with no dilatency. The bentonite has greater thixotropy producing power than does alginate or CMC, yielding the highest thixotropy and Hercules high-shear viscosity. Also, replacement of starch with latex for binding requires an increase in the amount of bentonite, or alginate or CMC, to attain the same thixotropy and viscosity. Replacement of CMC or alginate with bentonite required 8-14 parts bentonite per part of CMC or alginate. Also, increasing the pH from 7 to 10 substantially increased Brookfield viscosity, Hercules high-shear viscosity, and degree of thixotropy, regardless of whether the coating contained CMC, alginate, bentonite, or none of these. Temperature effect on the coating is insignificant compared to the pH effect. Also, coatings containing one of these three additives are more stable to aging than are coatings containing none of them. Also, bentonite gives good water-holding ability.

Coatings containing high levels of bentonite and having
Brookfield viscosities greater than 1800 centipoises at 100 r.p.m. need good pan circulation to avoid formation of a gel in the dead areas of the pan. These gels are reversibly dispersed by mild agitation.

For web offset printing, slightly more blanket water is needed when using bentonite (probably because of its water-loving nature), and some accumulation of debris on the blanket cylinder may be encountered. This, however, should not hurt print quality nor create any press down-time. Bentonite works well for gravure printing. The worst performance of bentonite for gravure printing is brightness, and the worst for offset printing is gloss, Sheffield smoothness, and blanket debris. Bentonite gives superior performance in K & N ink holdout, Diamond-National print smoothness, opacity, and air barrier for both offset and gravure printing. Also, of the three additives, bentonite gives the highest printing quality and ink gloss, and the highest IGT wet pick strength for offset printing.

Nevada bentonite has a higher brightness value than does Wyoming bentonite, but a lower brightness than that of Kaolinite No. 2. Since bentonite is a pigment and thus substitutes for some of the kaolin, economic advantages can be had as opposed to using CMC or alginate.

High shear mixing is required to disperse the bentonite into a clay slip. For size press coating, size press pattern improves as the total solids of the coating increases from 30 to 55%. The pattern also improves as the binder level increases from 11 to 20 p.p.h., based on pigment. As the percentage of starch in the adhesive increases, size press pattern improves. Coatings of pseudoplastic-
thixotropic flow produce the finest size press patterns. Thixotropic coatings tend to have good water-retention because they contain either a high level of natural binder or a hydrocolloid additive(15, 16).
STATEMENT OF PROBLEM

As mentioned in the Literature Review, the size press has been used for pre-coating paper. Furthermore, it has been found that bentonite can affect the rheology of a coating and also the holdout and printing properties of paper. The purpose of this experiment, then, is to apply, at the size press, starch coatings of different levels of both bentonite and total solids and then to evaluate the paper thus produced for its suitability as a base stock for coating or printing. Evaluation will be by means of accepted tests for optical, physical strength, and coating properties.
EXPERIMENTAL

The first stage in the experiment involved selection of the solids levels and bentonite levels for the coatings. It was decided that coatings of 10, 12, and 14% solids should be used and that bentonite levels should be determined by means of a rheology study. Small quantities of coating containing different amounts of bentonite were mixed at each solids level and then the Brookfield viscosity at 100 revolutions per minute was measured. A plot of viscosity versus bentonite level (Figure I) was made for each solids level and then, from the plots, the amounts of bentonite to produce viscosities of 550, 400, and 200 centipoises were determined. In all, a total of eleven coating formulations were selected. A twelfth coating was the blank, consisting only of water. The eleven coatings chosen were 0, 5.5, 13.8, and 20% bentonite at 10% total solids, 0, 4.2, 10, and 14.1% bentonite at 12% solids, and 0, 4.6, and 8% bentonite at 14% solids.

The next stage of the experiment was the actual machine run. The amounts of water, bentonite, and starch needed to make approximately 40 pounds of each coating was calculated, and the bentonite was dispersed in the water the afternoon before the machine run. The coatings were mixed in five-gallon buckets. The starch was cooked, at 25% solids, in the morning, prior to the machine run. The starch that was to be used for the machine run
was Penford Gum 280, since this was used in the rheology study. Unfortunately, there was not enough Penford Gum 280 for the machine run, and so Penford Gum 290 had to be used instead. After cooking, the correct amount of starch for each coating was measured out and dispersed into the coating by means of mild agitation.

The pulp furnish consisted of a mixture of 132 pounds (bone dry weight) of Espanola softwood kraft and 88 pounds of Espanola hardwood kraft. The furnish was beaten and refined to 350 Canadian Standard freeness, and then 3/4% rosin size and 2% alum was added. The furnish was run on Western Michigan University's pilot Fourdrinier machine at pH 7 and a speed of 70 feet per minute for a target basis weight of 44 pounds per 3300 square feet. It should be noted that even though the pH was abnormally high for rosin size, the blank sheet had an average holdout of 290 seconds for the Hercules coating holdout test at 80% reflectance. Temperature at the size press was 115 degrees Fahrenheit. Samples of each of the coatings were saved and their Brookfield viscosities at 100 r.p.m. were measured. During the run, pickup at the size press was measured by timing the drop in liquid level in the size press feed tank in order to get an estimate of the amount of starch being applied to the sheet.

The final stage of the experiment was sampling and testing. A length of paper from each coating run was removed at the reel and samples of approximately 10 inches by 12 inches were cut along the center of each length of paper. Nine sheets from each sample set were chosen for testing. The sheets were tested for Sheffield smoothness, Sheffield porosity, TAPPI brightness, TAPPI opacity,
IGT pick strength, IGT gloss, K and N ink holdout, sheet basis weight, burst, and Hercules coating holdout. The IGT pick test was run with a polybutene oil of 822 poise viscosity and an ink roller pressure of 50 kilograms, IGT gloss was run with gloss orange ink at 1.0 meters per second, and the Hercules coating holdout was measured to 95% reflectance using a coating of #2 clay, 10% latex, 5% Penford Gum 280, and Naphthol Green B dye for coloration.
RESULTS

Pickup at the size press was in the range of 1-1.5 pounds per side per ream, depending on the solids level. Brookfield viscosity ranged between a low of approximately 50 centipoises for the coating of 10% solids and 0% bentonite, and a high of approximately 125 centipoises for the coating of 14% solids and 8% bentonite. Table I shows the viscosities, pickup, and actual solids (determined by oven-drying a portion of the coating) of the coatings. It was found that, as expected, viscosity increased with increasing solids and also that viscosity tended to increase with increasing levels of bentonite. Sheet weights were in the range of 65-70 grams per square meter. Table II presents the results of the tests. The sample code is as follows: in the column headed "Sample", the first number is the total solids and the second number is the amount of bentonite as a percentage of the total solids.
<table>
<thead>
<tr>
<th>Sample</th>
<th>Viscosity (cps.)</th>
<th>Pickup (#/side/ream)</th>
<th>Solids (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10-0</td>
<td>51</td>
<td>0.92</td>
<td>9.97</td>
</tr>
<tr>
<td>10-5.5</td>
<td>52</td>
<td>0.77</td>
<td>9.68</td>
</tr>
<tr>
<td>10-13.8</td>
<td>54</td>
<td>1.23</td>
<td>10.22</td>
</tr>
<tr>
<td>10-20</td>
<td>72</td>
<td>0.46</td>
<td>10.17</td>
</tr>
<tr>
<td>12-0</td>
<td>82</td>
<td>--</td>
<td>12.54</td>
</tr>
<tr>
<td>12-4.2</td>
<td>77</td>
<td>0.18</td>
<td>12.51</td>
</tr>
<tr>
<td>12-10</td>
<td>80</td>
<td>--</td>
<td>12.68</td>
</tr>
<tr>
<td>12-14.1</td>
<td>93</td>
<td>1.11</td>
<td>12.43</td>
</tr>
<tr>
<td>14-0</td>
<td>114</td>
<td>1.50</td>
<td>14.74</td>
</tr>
<tr>
<td>14-4.6</td>
<td>106</td>
<td>2.15</td>
<td>14.69</td>
</tr>
<tr>
<td>14-8</td>
<td>124</td>
<td>1.29</td>
<td>14.57</td>
</tr>
</tbody>
</table>
### TABLE II

**TEST DATA**

<table>
<thead>
<tr>
<th>Sample</th>
<th>Basis Weight (g/m²)</th>
<th>Sheffield Smoothness</th>
<th>Sheffield Porosity</th>
<th>TAPPI Brightness (%)</th>
<th>TAPPI Opacity</th>
<th>IGT Pick (cm/sec)</th>
<th>IGT Gloss (%)</th>
<th>K&amp;N Ink (%)</th>
<th>Burst Factor (x10⁵)</th>
<th>Hercules Coating Holdout (sec)</th>
</tr>
</thead>
<tbody>
<tr>
<td>blank</td>
<td>69.35</td>
<td>245.1</td>
<td>43.2</td>
<td>83.3</td>
<td>78.8</td>
<td>83.3</td>
<td>14.60</td>
<td>47.85</td>
<td>3.57</td>
<td>29.3</td>
</tr>
<tr>
<td>10-0</td>
<td>69.26</td>
<td>247.1</td>
<td>37.8</td>
<td>82.8</td>
<td>75.8</td>
<td>178.3</td>
<td>16.06</td>
<td>44.55</td>
<td>4.23</td>
<td>23.0</td>
</tr>
<tr>
<td>10-5.5</td>
<td>69.41</td>
<td>238.3</td>
<td>34.1</td>
<td>82.7</td>
<td>76.4</td>
<td>205.6</td>
<td>15.60</td>
<td>43.79</td>
<td>4.31</td>
<td>22.9</td>
</tr>
<tr>
<td>10-13.8</td>
<td>64.42</td>
<td>239.2</td>
<td>31.3</td>
<td>82.7</td>
<td>75.0</td>
<td>178.3</td>
<td>16.33</td>
<td>44.50</td>
<td>4.50</td>
<td>21.9</td>
</tr>
<tr>
<td>10-20</td>
<td>67.64</td>
<td>237.1</td>
<td>27.2</td>
<td>82.9</td>
<td>76.8</td>
<td>183.8</td>
<td>17.03</td>
<td>45.08</td>
<td>4.40</td>
<td>26.6</td>
</tr>
<tr>
<td>12-0</td>
<td>65.71</td>
<td>229.8</td>
<td>29.8</td>
<td>82.6</td>
<td>75.1</td>
<td>229.4</td>
<td>15.08</td>
<td>44.88</td>
<td>4.77</td>
<td>14.9</td>
</tr>
<tr>
<td>12-4.2</td>
<td>67.88</td>
<td>241.3</td>
<td>28.7</td>
<td>82.6</td>
<td>75.5</td>
<td>247.2</td>
<td>16.32</td>
<td>43.70</td>
<td>4.40</td>
<td>14.6</td>
</tr>
<tr>
<td>12-10</td>
<td>68.71</td>
<td>235.3</td>
<td>29.7</td>
<td>82.7</td>
<td>75.0</td>
<td>223.9</td>
<td>16.98</td>
<td>43.25</td>
<td>4.41</td>
<td>15.9</td>
</tr>
<tr>
<td>12-14.1</td>
<td>65.67</td>
<td>235.1</td>
<td>27.9</td>
<td>82.4</td>
<td>74.7</td>
<td>216.1</td>
<td>16.35</td>
<td>44.56</td>
<td>4.56</td>
<td>18.7</td>
</tr>
<tr>
<td>14-0</td>
<td>71.85</td>
<td>238.1</td>
<td>28.1</td>
<td>82.4</td>
<td>74.9</td>
<td>253.8</td>
<td>16.19</td>
<td>44.29</td>
<td>4.93</td>
<td>16.4</td>
</tr>
<tr>
<td>14-4.6</td>
<td>72.60</td>
<td>242.8</td>
<td>26.0</td>
<td>82.4</td>
<td>75.1</td>
<td>267.8</td>
<td>16.31</td>
<td>42.72</td>
<td>4.61</td>
<td>20.0</td>
</tr>
<tr>
<td>14-8</td>
<td>67.69</td>
<td>245.6</td>
<td>22.8</td>
<td>82.4</td>
<td>73.4</td>
<td>263.3</td>
<td>17.69</td>
<td>42.62</td>
<td>4.92</td>
<td>8.2</td>
</tr>
</tbody>
</table>

* K&N Ink = \( \frac{\text{Brightness(white)} - \text{Brightness(inked)}}{\text{Brightness(white)}} \) x 100
DISCUSSION OF RESULTS

Examination of the data reveals that the tests which showed the most significant results were porosity and IGT pick strength. Porosity was seen to decrease with increasing solids and increasing bentonite levels. As Figure II shows, this decrease is fairly linear. A possible explanation for this is that the increasing solids level provided more starch to seal the sheet surface which would thus make it more resistant to the passage of air. Also, the increasing bentonite levels would allow formation of a more continuous film of bentonite (since bentonite has been found to form a film on paper) which would then plug the sheet more fully.

IGT pick strength showed a definite improvement with increasing solids levels, and even more of an improvement with small amounts of bentonite. However, as bentonite levels got higher, the pick strength fell off, as shown in Figure III. The increase with increasing solids was probably due to the starch acting as a binder to strengthen the sheet surface. The more starch on the sheet the more strongly the surface would be bound. The improvement with small amounts of bentonite could be the result of the bentonite acting as an extender for the starch to thus improve the surface bonding. The decrease in pick at higher levels of bentonite could be the result of either the bentonite overpowering and thus interfering with the starch to leave flaws where picking could
FIGURE II
POROSITY vs. %BENTONITE

10% SOLIDS
12% SOLIDS
14% SOLIDS

% Bentonite

CITADEL© NO. 641 - SCIENCE - 10 SQUARES TO CENTIMETER
Figure III
IGT PICK vs. %BENTONITE

- 14% SOLIDS
- 12% SOLIDS
- 10% SOLIDS

IGT Pick (inches)

% Bentonite
occur, or because machine calendering had fractured the bentonite film leaving flaws where premature picking could occur.

The other tests were inconclusive regarding the use of bentonite. Brightness showed only that the coated paper was not as bright as the blank. This is probably attributable to the fact that the starch that was used was not as bright as the furnish. Smoothness showed very little change. It appeared that applying a starch coating to the sheet yielded a slight increase in smoothness, and that addition of bentonite gave inconsistent results. The increase in smoothness with increasing solids might be the result of the starch bonding loose fiber ends to the sheet surface to provide a smoother surface. It would be difficult to say whether bentonite helps or hurts smoothness, as evidenced by the data.

Opacity showed a decrease with increasing starch solids, and that part of this decrease might be partially counteracted with low levels of bentonite. The decrease with increasing solids was possibly a result of the starch filling in the sheet and thereby reducing its scattering coefficient. A slight counteracting of this decrease with a low level of bentonite might be caused by the difference between scattering coefficients of the bentonite and the starch-filled sheet. The fact that opacity appeared to decrease with higher levels of bentonite could possibly be caused by the formation of a more continuous layer of bentonite on the sheet which could thus reduce scattering coefficient, a phenomenon which has been observed with coating applications of other pigments when the level of the pigment is increased to a sufficiently high concentration.
IGT gloss showed a tendency to increase slightly both with increasing starch solids and with increasing levels of bentonite. This could be attributed to both the starch sealing the sheet surface and the bentonite film sealing the sheet surface to make the sheet more impenetrable to the ink.

K and N ink holdout showed the possibility of increased ink holdout at low bentonite levels, but then the holdout appeared to fall off with higher levels of bentonite. The response at low bentonite levels might be due to the bentonite film working in conjunction with the starch to seal the sheet surface to penetration, since the sheets with starch alone had better holdout than did the blank. The fact that holdout was poorer at higher bentonite levels suggests the possibility that either the thicker bentonite film absorbed the test ink or that the film had been broken by the machine calender which would then allow the ink to penetrate the film. It should be noted that the inked portion of the sheet showed no unusually noticeable patterning.

The results of the Hercules coating holdout test are difficult to interpret. Most evident was that the blank had better holdout than did any of the coated samples. This, more than likely, was due to internal sizing in the sheet. As coating solids increased, the sheets showed a decline in coating holdout until 14% solids was reached, and as bentonite increased the coating holdout showed virtually no change until high bentonite levels were reached, in which case holdout improved. However, sample 14-8 was the exception to this trend. The reason for this test showing the results it did is difficult to ascertain without studying the test in more
detail. It is possible that the starch on the sheet surface was especially receptive toward the coating, in which case the test coating would be absorbed more quickly than if the sheet had not been size press treated. The behavior at high bentonite levels could be attributed to the bentonite film swelling, since bentonite is hydrophilic, to form a better seal on the sheet surface. The behavior of sample 14-8 could be caused by breakage of the bentonite film due to machine calendering which would then allow the test coating, or at least the water and dye in the coating, to be rapidly absorbed.

The burst test showed an increase with increasing starch solids, but rather inconsistent results for bentonite. The increase with increasing starch solids was probably due to internal strengthening of the sheet through penetration of the applied starch into the sheet structure. Addition of bentonite in the 10% solids coatings caused an increase to a point and then a slight decrease, in the 12% solids coatings the strengths increased but all were weaker than the control sheet which contained no bentonite, and the same was true with the 14% solids coatings. It is difficult to explain the behavior of the sheets with bentonite, but a possible explanation is that the bentonite may hinder the penetration of the starch into the sheet, which would explain the lower burst, while at the same time the bentonite film may provide some resistance to bursting, which would explain the increasing burst with increasing levels of bentonite.
CONCLUSIONS

From the results and discussion, it is seen that maximum pick strength can be attained with a relatively small amount of bentonite. Also, any level of bentonite will help porosity. A small amount will help ink holdout while a high amount appears to aid ink gloss, but at the expense of pick strength and burst. Therefore, it is difficult to say that one particular level of bentonite is best since one level of bentonite may be beneficial for one property yet deleterious to other properties, while another level of bentonite may be beneficial for some other property.

In conclusion, then, it is felt that bentonite can be applied at the size press to yield an improved base stock. However, it is recommended that more work be done with the bentonite-coated base stock. Specifically, the paper should be pilot coated to determine the coating the coating response to the different levels of bentonite at the different levels of total solids, as applied at the size press. Also, more work should be done with the Hercules coating holdout test and the test coating to determine what factors affect replication of test results.
LITERATURE CITED