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The Effect of Drying Delay Time on Paper Coatings

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THE EFFECT OF DRYING DELAY TIME ON PAPER COATINGS

By

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ABSTRACT

There are many variables which impact the final properties of coated paper. One of the major variables is the drying of the coating. Drying delay time is a significant factor which affects coated sheet properties. Delay times of 0, 5, and 10 seconds were used in this trial.

The cylindrical laboratory coater (CLC) was used to apply coating to paper stock, and the coated paper was tested to determine the effects of increasing the time interval between application of the coating colour to the point when the IR dryer was turned on.

It was found that increasing drying delay time affects both starch/latex and CMC/latex (carboxymethyl cellulose) coating colours. There is notable effect on roughness, porosity, pick, and optical properties.

Porosity, roughness, and K & N ink brightness reduction all experienced maximum values at 5 seconds of delay time. Opacity and brightness values were also greatest at 5 seconds delay time. Gloss measurements revealed lowest vlaues at 5 seconds delay time due to high roughness of the sheet. The general trend of pick strength as measured by the wax pick test was a decrease in pick strength as delay time was increased. This was due to the loss of binder near the surface of the sheet as delay time was increased.

INTRODUCTION

The purpose of this thesis was to determine the effects of drying delay time on coated paper properties. Drying delay time refers to the time between application of the coating on the sheet, and drying of the coating. The cylindrical laboratory coater was used to apply all of the coatings. Two formulations were used which differed only in binder content. One contained starch and latex, and the other CMC and latex. Each coating was applied at 3 different delay times, 0, 5, and 10 seconds. In addition, for each delay time the coating application was repeated with the identical formulation, but using a new coating batch.

The coated sheet properties test results are found in the results section and interpreted in the discussion section. A brief summary is presented below.

Porosity and roughness values were found to be greatest at the 5 second delay time. When the coated sheet exhibited greater roughness, higher porosity values corresponded.

Opacity and brightness tests both yielded maximum values at 5 seconds delay time. Peak optical performance was obtained from the pigment in the coatings at this delay time. It appears that the amount of binder required to retain pigment particles near the coating surface is achieved at this delay time.

Gloss was found to be lowest at the 5 second delay time. This result is best explained by noting that the highest roughness values are also found at 5 seconds of delay time, and the realization that a rougher sheet will affect gloss by lowering it.

Brightness reduction was greatest at the 5 second delay time. Porosity values are highest at this delay time also, so the brightness reduction results are logical.

Wax pick values decreased with delay time due to less binder content near the coated sheet surface with increased delay time. An exception to this was noted with the starch/latex coating where a minimum wax pick value was found at 5 seconds of delay time.

BACKGROUND INFORMATION

Coating of certain paper grades is common practice in the paper industry. The focus of this thesis is to survey the effects of drying on coated sheet properties. It is therefore appropriate to discuss the phenomena which are thought to occur during the drying and pre-drying stage of coating the sheet. First, a general discussion of coating basics is in order.

Coating the paper surface has several advantages. Some of the main benefits of coating the sheet are:

1. Increased smoothness (provides better ink transfer)
2. Increased gloss
3. Improved ink gloss holdout
4. Increased brightness
5. Print detail improvement
6. Mottle control (1)

Some of the key factors that influence coated sheet properties are:

1. Base sheet (surface smoothness, porosity, mottle).
2. Coating formulation (pigments, binders, additives).
3. Coating application system (rod, blade, air knife).
4. Coating drying (drying method, dryer type, drying intensity).

As soon as the coating is applied to the base sheet water begins to transfer to it. Conditions under which the water is transferred will dictate much about the characteristics of the coated sheet. (2)

Evenness of the mass distribution throughout the coating layer is affected by compressibility of the sheet, and blade pressure. Compressibility of the paper is largely determined by blade pressure and water pick-up of the base sheet that occurs between the applicator and blade. The more compression the sheet experiences under the blade, the more even the mass distribution of the coated layer will be. The greater the rate of water pick-up (which enhances compressibility), the greater will be the evenness of the mass distribution. As sizing of a sheet increases, the rate of water penetration decreases. This being true, it may be said that as sizing increases, sheet compressibility decreases and therefore evenness of the coating layer mass distribution will decrease with increased sizing. (3)

Concerning beveled blade coating, an increase in blade pressure will enhance the evenness of the mass distribution of the dried coating structure. It is thought that the tip of the beveled blade rides on the peaks of the paper surface during coating. This method of doctering off excess coating from the sheet tends to fill in the valleys between the peaks on the substrate surface. The greater the pressure the more compression experienced by the sheet during coating. This compression causes the hills and valleys to be "leveled" to a degree, and this results in a more even water and binder migration through the sheet during coating, leading to a more even mass distribution throughout the dried coating structure. Blade pressure is influenced by water pick-up in this manner: the greater the amount of water picked up by the sheet, the greater the compressibility of the sheet under the blade pressure experienced. (4)

Smoothness is heavily influenced by how the water from the wet coating interacts with the base sheet. There is an inverse relationship between mass distribution of the coating layer and surface smoothness of the coated sheet. The greater the smoothness of the coated sheet surface, the less the evenness of the mass distribution. (4)

When a beveled blade is used and machine speed is increased, surface roughness and uniformity of the coating structure will experience an increase as well. Surface uniformity corresponds with gloss distribution of the coated surface, which is heavily influenced by the mass distribution of the dried coating layer. Mass of the dried coating layer tends to be more evenly distributed as blade pressure increases. Increased solids in the coating colour will increase blade pressure. (5 & 6)

There are three fundamental stages in which water may be picked up by the base paper. The first is between the applicator and blade. The next stage is between the blade and dryer. The third stage is from the dryer to the FCC (first critical concentration) when the coating solids are immobilized. Most of the water is picked up by the base sheet in the second zone, between the applicator and the dryer. This stage occurs over the longest time interval out of the three stages. The distance between the forming unit and the dryer then has a major impact on the amount of water that transfers to the base sheet before immobilization occurs. As previously stated, this water absorption has a major impact on mass distribution, and thus binder distribution in the coated sheet. (7 & 8)

In summary, drying delay time (time between coating blade and dryer) will decrease the evenness of the mass distribution of the coating structure, and a greater amount of binder migration will occur also. Also, the longer the period of delay time, the deeper the penetration of the binder into the base sheet. (9)

EXPERIMENTAL DESIGN

Purpose

The experiment was designed to measure the effect of drying delay time on coating properties. This was done by applying coating to paper at three different delay times and testing the coated paper properties. Delay time is defined as the time interval between application of the coating to the point at which heat from the dryers comes in contact with the coated sheet.

General

All coated samples from each of the 12 coating runs were super-calendered under the following conditions.

1. 4 nips of super-calendering.
2. 30 psi nip pressure.
3. 130 degrees F roll temperature.

Substrate

A single substrate was used for every trial run of this experiment. An uncoated base paper was used. The sheet is characterized as follows.

1. Basis weight of the uncoated sheet was 69 g/m^2.
2. Sheet sizing was 124 seconds on the Hercules Size Test.

Cylindrical Laboratory Coater (CLC)

Variable settings:

1. 2000 feet/minute
2. Beveled blade coater used (45 degree blade angle)
3. I.R. drying intensity: 100%
4. Delay times: 0 seconds, 5 second, and 10 seconds

Operation:

Coating was applied with the CLC at The Department of Paper and Printing Science and Engineering, Western Michigan University. This laboratory coater has many features which made it a valuable tool for this coating trial. Important features of the coater that were utilized during this coating trial are as follows:

1. Dryer delay time (delay distance)
2. Beveled blade coater head
3. Infra-red dryer
4. Variable speed

The CLC is computer controlled. Speed and delay distance can be entered on the control panel. The CLC has *no delay time function*. Instead the delay time must be indirectly controlled by adjusting the delay distance. Delay distance simulates the distance the web would travel between applicator blade and the coater dryer. The delay distance which corresponds to the required amount of delay time must be calculated and this distance must then be entered into the control panel of the CLC. This was done to achieve the delay times that were tested in this trial.

The coater head contains the pond which holds the coating colour. The blade is affixed at the bottom of the coater head, fed by the coating pond. When the CLC is ready for a coating trial (all parameter settings have been entered in and the base stock affixed to the drum) the drum starts rotating. Once the drum speed is at the set speed, the heater is turned on to preheat the sheet. The heater shields, which separate the I.R. dryer from the sheet on the drum, are automatically removed once the sheet is preheated.

When the web has been preheated and the appropriate delay time is reached, the coater head begins to traverse the web. As it does the pond gate is lifted and a 6-inch wide strip of coating is applied to the base sheet in a spiral pattern across the length of the web as the coater head travels across in the machine direction of the web.

<u>Formulations:</u>

Formula # 1
1. 60 % coating colour solids
2. # 2 kaolin clay
3. Binder:
   7.5 parts hydroxyethylated starch (Penford Gum 280)
   7.5 parts styrene butadiene latex (Dow 620)

Formula # 2
1. 60 % coating colour solids
2. # 2 kaolin clay
3. Binder:
   15 parts styrene butadiene latex (Dow 620)
   0.7 parts (sodium) carboxymethyl cellulose (thickener)

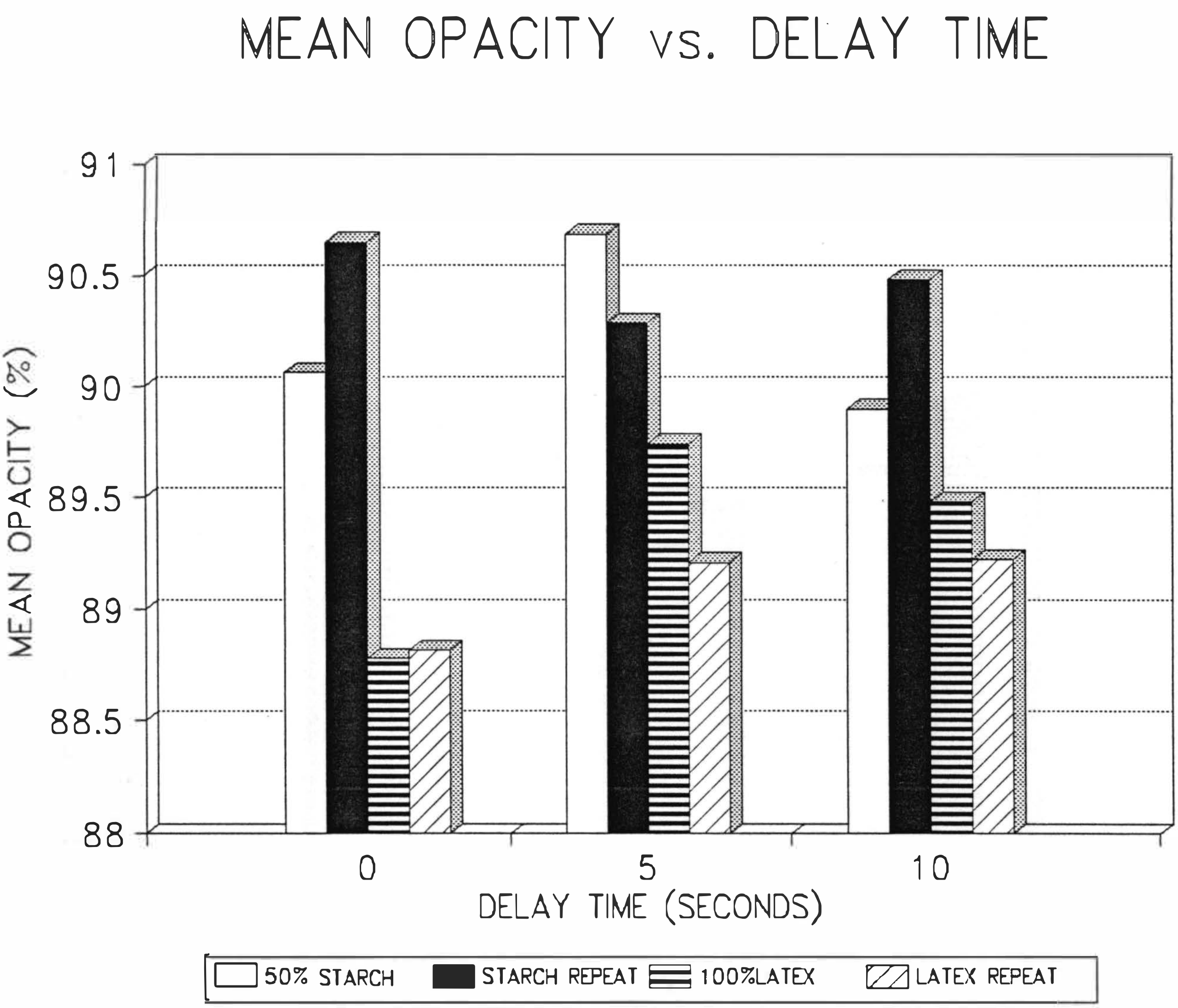
Formula # 1 and # 2 were each run in duplicate and at the three listed delay times.

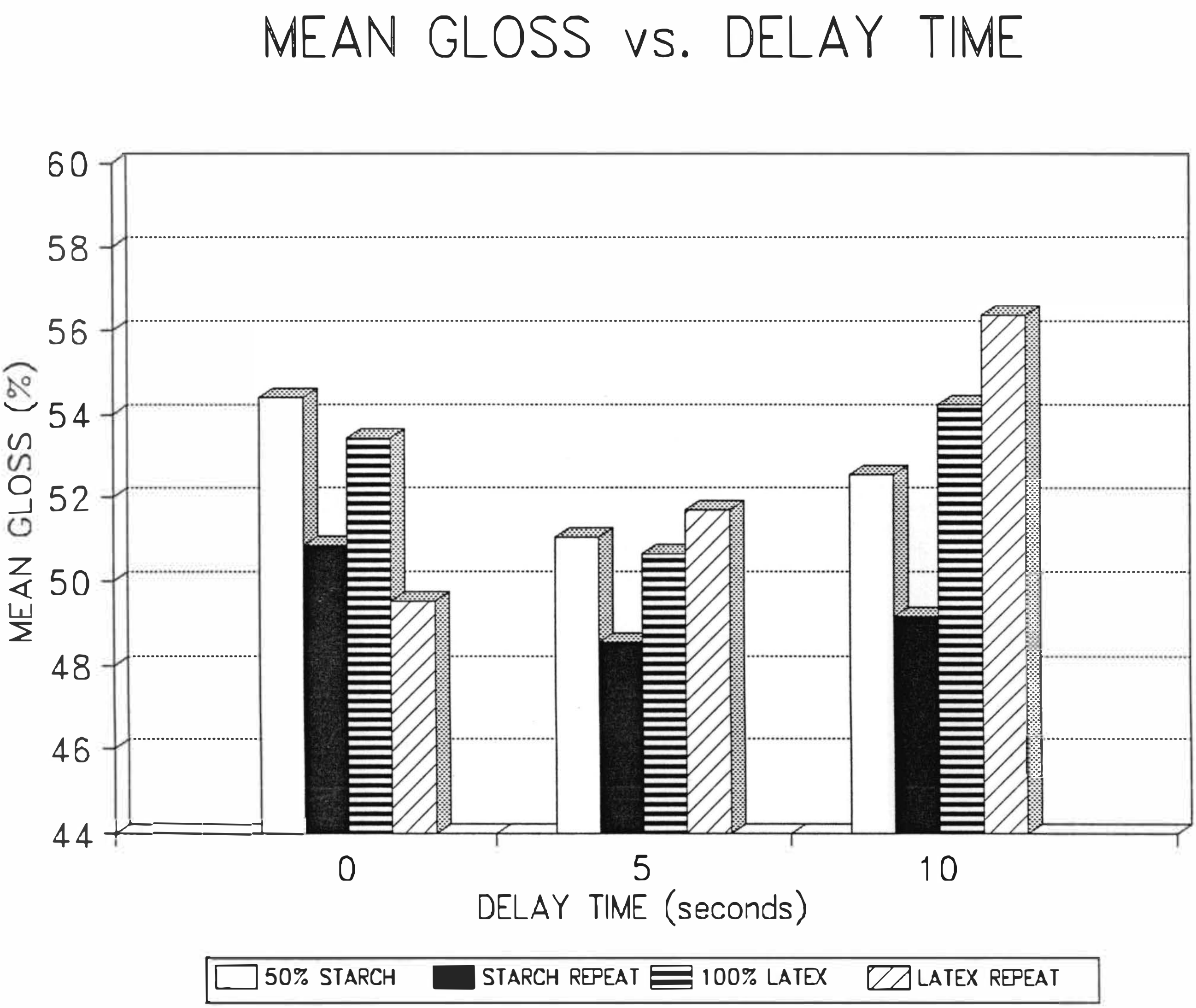
Total runs = 12 = (2 formulas)(2 duplicates)(3 delay times).

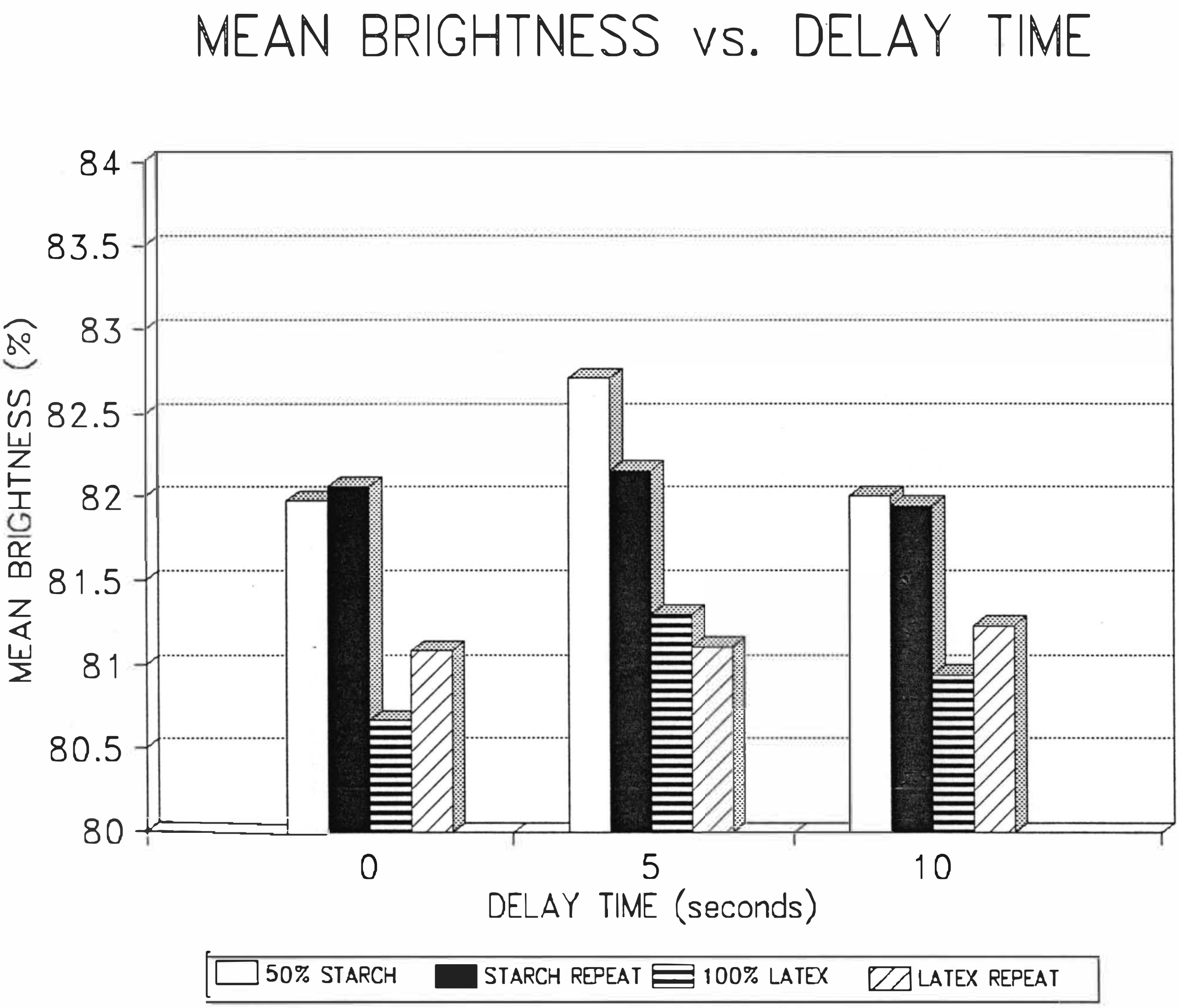
<u>Tests performed on the coated sheet:</u>

1. Brightness
2. Brightness reduction (K & N ink test)
3. Opacity (Tappi)
4. Gloss (75 degree)
5. Porosity (Parker Print Surf)
6. Roughness (Parker Print Surf)
7. Wax pick

	50/50 STARCH/LATEX						LATEX and CMC					
Delay time	0 Seconds		5 Seconds		10 Seconds		0 Seconds		5 Seconds		10 Seconds	
Run	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd	1st	2nd
Gloss-% mean	54.40	50.90	51.10	48.60	52.53	49.17	53.40	49.50	50.70	51.70	54.20	56.37
std	3.57	3.96	3.71	4.08	5.21	3.37	4.55	3.21	5.16	4.02	4.20	3.56
Brightness-% mean	82.03	82.11	82.70	82.15	81.90	81.95	80.86	81.07	81.11	81.30	80.99	81.28
std	0.22	0.36	0.46	0.26	0.45	0.34	0.37	0.30	0.31	0.22	0.45	0.46
K & N ink-% loss	14.10	12.65	15.13	15.12	14.45	14.12	3.84	4.96	5.67	5.23	6.12	5.24
Opacity-Tappi %	90.06	90.94	90.63	90.23	89.98	90.48	88.78	88.82	89.74	89.21	89.40	89.22
Porosity-% mean	3.49	3.02	4.82	5.30	4.46	5.09	0.45	0.73	0.75	0.61	0.71	0.58
std	0.84	0.46	0.98	1.37	1.30	1.01	0.23	0.28	0.26	0.13	0.28	0.09
Rough-microns mean	1.68	1.27	1.64	3.04	1.74	2.69	1.41	1.22	1.72	1.30	1.60	1.19
std	0.54	0.23	0.68	0.33	0.77	0.73	0.70	0.18	0.74	0.67	0.72	0.43
Wax pick	11.00	11.00	10.00	10.00	11.00	11.00	13.00	13.00	12.00	12.00	11.00	11.00

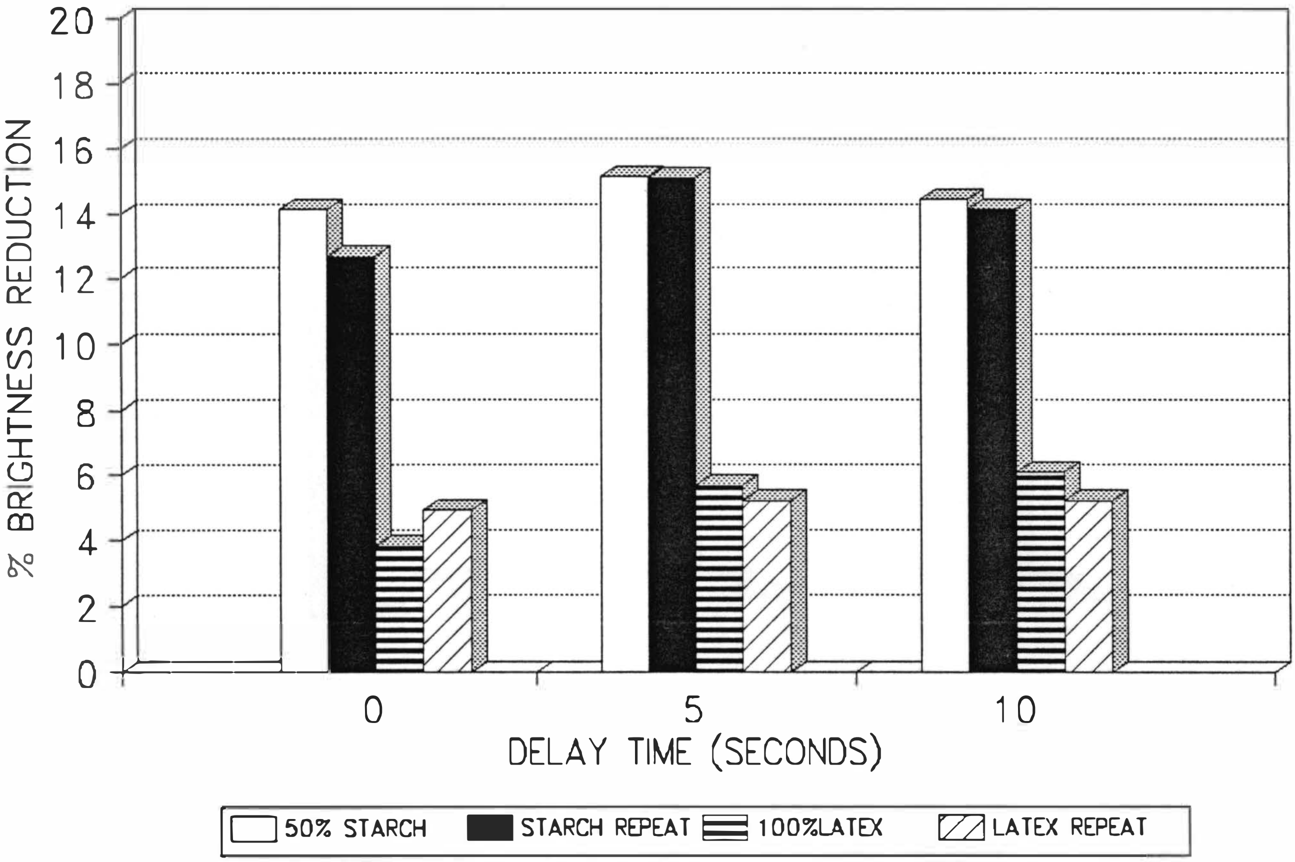

MEAN OPACITY vs. DELAY TIME
91
90.5
90
89.5
89
88.5
88
MEAN OPACITY (%)
0
5
10
DELAY TIME (SECONDS)
50% STARCH
STARCH REPEAT
100%LATEX
LATEX REPEAT


MEAN GLOSS vs. DELAY TIME
60
58
56
54
52
50
48
46
44
MEAN GLOSS (%)
0
5
10
DELAY TIME (seconds)
50% STARCH
STARCH REPEAT
100% LATEX
LATEX REPEAT

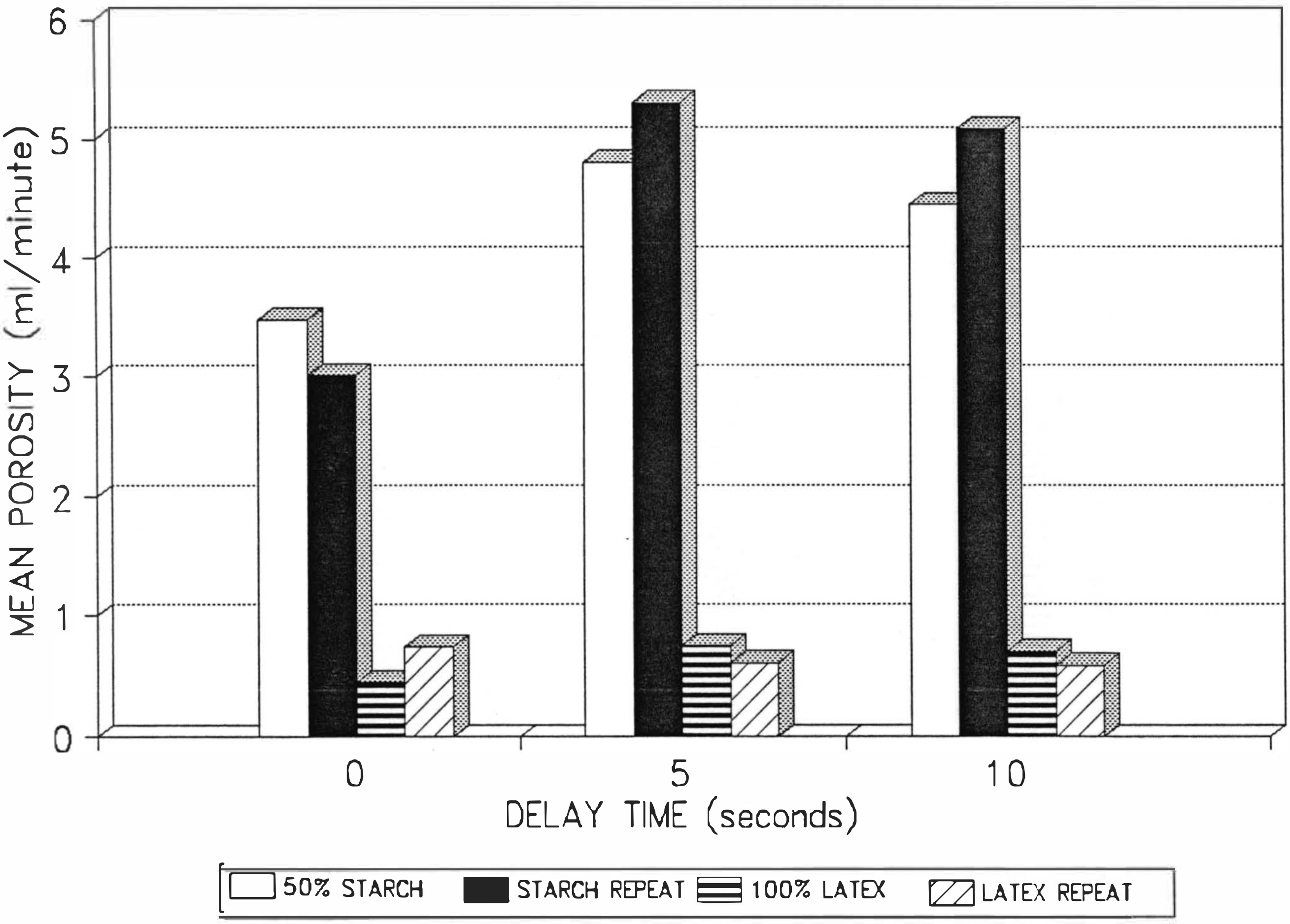


MEAN BRIGHTNESS vs. DELAY TIME
84
83.5
83
82.5
82
81.5
81
80.5
80
MEAN BRIGHTNESS (%)
0
5
10
DELAY TIME (seconds)
50% STARCH
STARCH REPEAT
100% LATEX
LATEX REPEAT

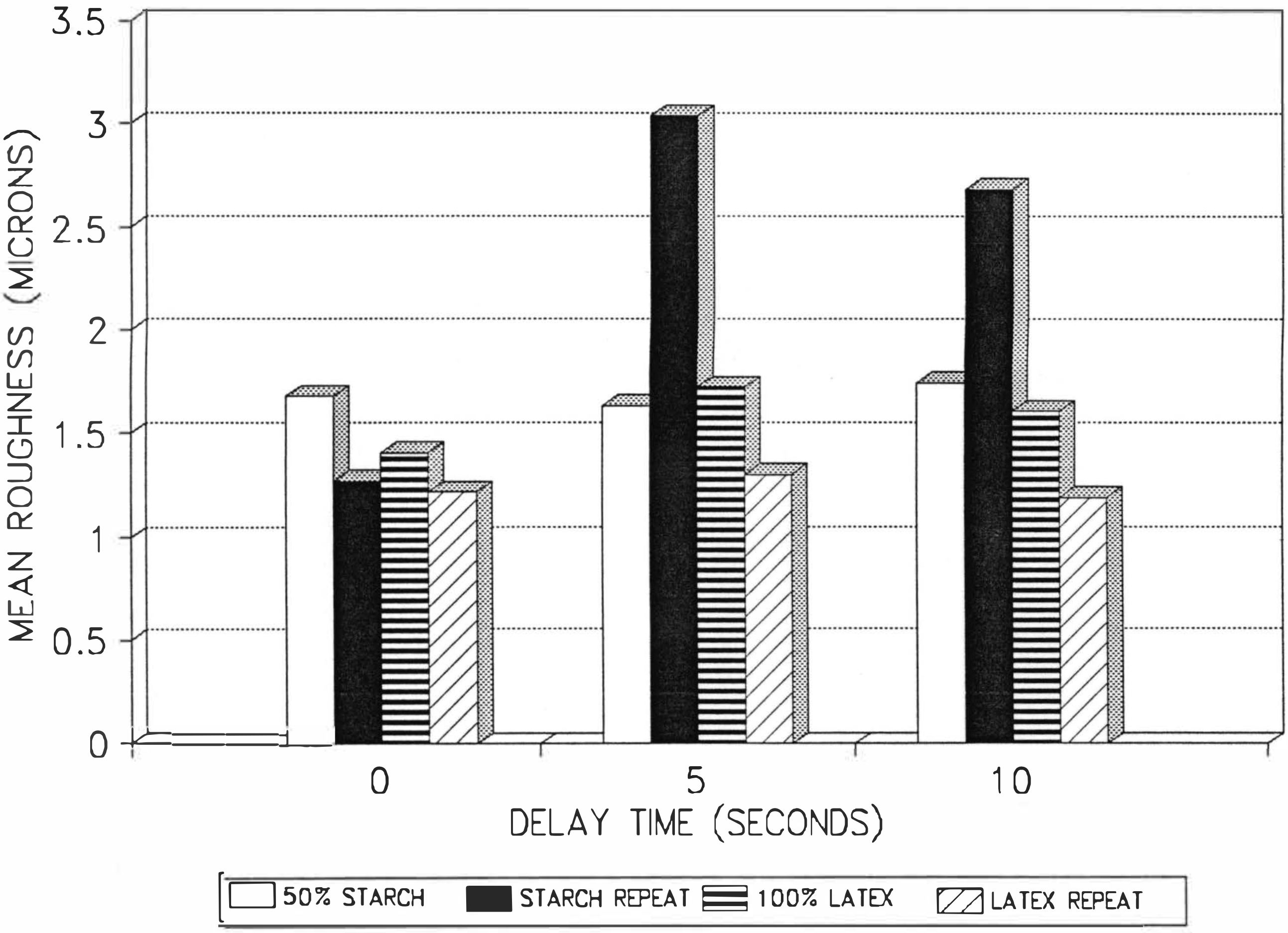
% BRIGHTNESS REDUCTION vs. DELAY TIME
(K & N INK TEST)



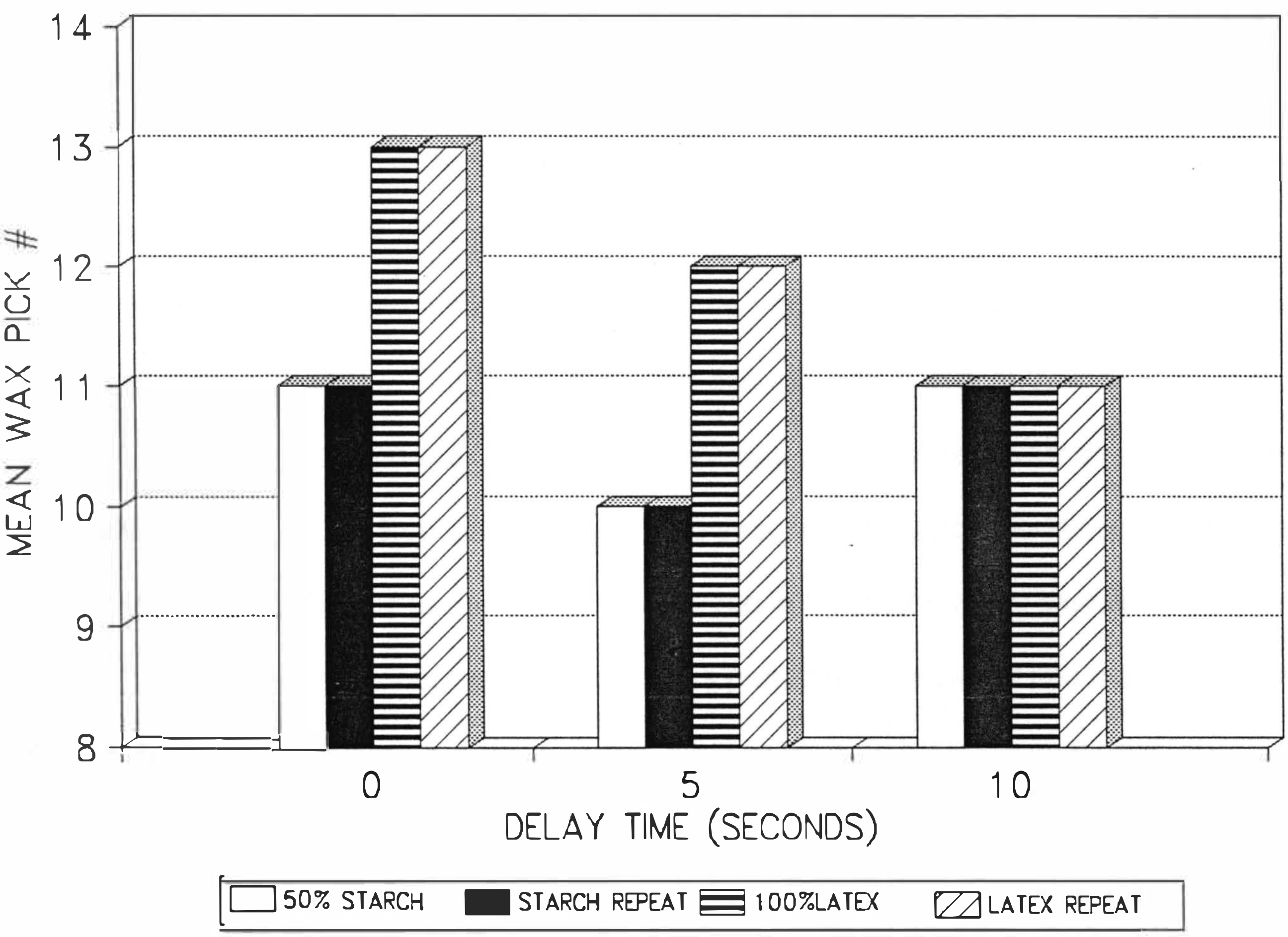
MEAN POROSITY vs. DELAY TIME



MEAN ROUGHNESS vs. DELAY TIME



MEAN WAX PICK # vs. DELAY TIME



DISCUSSION

Note: In this section the results are discussed in terms of mean values. Test values for the initial and repeated runs of the three delay times tested were averaged to enable the results to be discussed in terms of trends.

Porosity

It is well known that once the coating colour is applied to the web, binder migration occurs along the same path that water follows into the interstices of the base sheet. When the solids level reaches 75 % solids, water stops transferring to the base sheet. This is known as the first critical concentration (FCC). Until 90 % solids is reached the water and binder can still migrate through the interstices of the sheet and the coating structure. This is known as the second critical concentration (SCC). (2)

Porosity is reported in ml/minute. Porosity values were lowest at 0 second delay time and peaked at 5 seconds delay. At 10 seconds delay porosity dropped off again. It is theorized that the porosity trends observed in this trial may be explained as follows.

As delay time increases so also does penetration of binder into the base sheet. At 0 second delay time binder migration into the base sheet is minimal because evaporation of water from the surface of the coating begins almost instantly. Since dryer heat is applied immediately after coating application, the FCC and SCC are reached quicker than at 5 and 10 seconds of delay time. A dense layer of binder should be found close to the surface of the coating structure. This binder film near the surface of the coating layer impedes air flow, reducing porosity. (2)

At 5 seconds delay time the binder has more time to migrate further into the base stock. The binder is more evenly distributed throughout the top layer of the base sheet and the coating structure. This creates a more porous coated sheet because there is no formation of a dense layer of binder in the coating structure, as occurs with the 0 second delay time coated sheet.

Allowing 10 seconds of delay time between coating application and drying causes the binder to travel deep into the sheet. When heat from the dryer is applied, evaporation begins. The binder, however continues traveling into the base sheet until the FCC is reached. The binder then travels through the interstices of the sheet and the coating layer until the SCC is reached. The binder distribution in the coated sheet is more dense in the base paper. The interstices and pores of the base sheet are much larger, on average than those of the coating structure, because fibers are much larger in length and diameter than clay, latex, and starch particles. Since there is a high amount of binder in the base sheet, it is expected that porosity values would be lower than porosity of the 5 second delay sheet because the binder has filled many of the interstices in the fiber network of the sheet.

The fact that porosity of the 10 second delay sheet is higher than that of the 0 second delay sheet may be explained by noting the dense film formation in the 0 second delay time coating. The binder film effectively decreases porosity in the coated sheet. Whereas filling interstices of the base sheet with binder also decreases porosity (as with the 10 second delay sheet), the binder in this case is distributed more broadly throughout the z-direction of the sheet. This allows for a greater amount of interstices and pores in the sheet, which translates to higher porosity values.

Roughness

Roughness is reported in microns of surface variability. A small section of a sample is tested and the instrument then calculates an average roughness value for that particular area tested. What is actually being determined is the average distance from the peaks to the lows of the coated sheet within the measuring orifice area. The result is reported in microns of roughness.

Results show that peak roughness values are found at 5 seconds delay time. This corresponds well with porosity data, as porosity peaked at 5 seconds delay as well. A possible explanation is the difference in pore size of the sheets. It is feasible to expect larger pore size to correlate with higher porosity values. Again it is plausible to argue that if pore size increases, so also will the average distance from "peak to valley" in the coated sheet, resulting in an increase in roughness. This is what is believed to have occurred in this trial.

Opacity

Opacity is a function of scattering coefficient. In general the more small particles in a paper system, the higher the opacity. Opacity comparisons reveal that peak opacity was found at 5 second delay time.

A possible explanation for this follows closely the argument made for porosity. At 0 second delay time the film formation near the surface of the coating layer probably covers over many of the surfaces that would otherwise contribute to diffuse reflectance of light, and thus decrease opacity.

At 5 seconds delay time there is sufficient binder to retain clay particles, which increases opacity by increasing scattering coefficient. There is not an excess of binder concentration in the coating structure, which if present would decrease opacity by decreasing scattering coefficient.

At 10 seconds delay time the sheet has more surfaces exposed to light. This creates a higher scattering coefficient of the coated sheet. It is possible that opacity is lower at 10 seconds delay time compared to 5 seconds because the clay particles were not retained as well near the coating surface as they were with 5 seconds of delay. This might be explained by the theory that more binder traveled deeper into the web with 10 seconds delay time, leaving less binder for actual binding of the coating pigment structure.

Gloss

Gloss is lowest at 5 seconds delay time. Coated sheet roughness was greatest at 5 second delay time. Gloss and roughness results are in agreement with each other. It is expected that as sheet roughness increases, gloss should decrease. Since gloss is a measure of specular reflectance of light (at a 75 degree angle of incidence), the greater the surface smoothness is, the greater the gloss of that sheet.

Sheets coated at both 0 and 10 second delay time are smoother than that coated at 5 seconds delay time, and correspondingly their gloss values are higher than that of the 5 second delay sheet. Trial results for smoothness explain fairly simply the gloss results.

Brightness

Brightness peaked at 5 seconds delay time. This corresponds well with other optical property trends.

At 0 seconds delay time the dense binder layer is located near the surface of the coated sheet. This detracts from the brightness as the binders (both starch and SBR latex) are well known to cause brightness values to diminish.

At 5 seconds, where brightness was found to be at peak values, the binder is better distributed through the sheet and coating layer. It is thought that binder density is not as high near the surface of the coating structure, as in the case of the sheet coated at 0 seconds delay time. Brightness is therefore higher because more pigment surface area is exposed at the surface of the sheet, yielding higher brightness values.

The sheet coated at 10 seconds delay time has lower brightness than the sheet coated at 5 seconds delay time. Here is a possible explanation. The coating components were free to move within the fluid coating system during the delay time period. As previously stated, this resulted in deep penetration of water and binder into the base sheet. It is proposed that pigment may also have traveled in the direction of the base sheet. Pigment mobility would be expected to be less than that of water and binder. Still, the long delay time allowed for enough particle mobility to create a densely populated layer of pigment particles around the base sheet/coating structure interface. This caused a decrease in the amount of pigment near the surface of the coated sheet, thus causing a brightness reduction from 10 seconds delay time, to 5 seconds of delay time.

Brightness reduction (K and N ink test)

Brightness reduction is a measure of the degree of brightness loss of the coated sheet after application of the test ink. A standard ink is used in the test. Time between application of the ink and removal of the excess ink is also standardized at 2 minutes. Brightness of the stained sample is compared to brightness of the unstained sample, and the result is reported as % brightness reduction.

Brightness reduction was highest at 5 second delay time. This indicates a higher degree of ink absorption into the sheet. Porosity values correlate well with this, as porosity is also highest at 5 second delay time. Larger pore size and a greater number of interstices in the coated sheet caused the increased porosity. Brightness reduction was highest at 5 second delay time for the same reasons.

At 0 and 10 seconds delay time the coated sheets exhibited less brightness reduction for the same reasons that these two delay times had lower porosity values: smaller pore size and fewer interstices.

Wax pick test

Wax pick is a test devised to give an indication of the level of tack that will cause picking on the surface of the coated sheet. Wax sticks are numbered, with a number of

1 corresponding to the lowest level of tack. The tip of the wax stick is heated until the wax melts. The hot wax is then applied to the sheet and allowed to solidify so that it adheres to the sheet. The paper is then secured and the wax sticks are removed perpendicularly from the sheet. If a particular wax (for example, # 13 wax) causes picking, but the wax of immediately prior to this wax (# 12 wax) does not cause any picking, then the value reported as wax pick is the wax number at which picking first occurs (in this example, wax pick would be reported as # 13).

Wax pick values showed different trends for the coating containing starch and the one containing CMC. The starch coating pick was lowest at 5 seconds delay time, and the CMC containing coating steadily decreased to the lowest pick value at 10 seconds delay time. The CMC coating followed a reasonable trend. It stands to reason that the pick should decrease due to the decreasing binder content near the coated sheet surface, as delay time increased. However the reason for the increase in pick of the starch containing coating at 10 second delay time is not understood.

Conclusions

1. Maximum porosity values were found at 5 second delay time. It is thought that this is due to a more even distribution of binder throughout the base stock and the coating layer than with 0 or 10 seconds delay time.

2. Roughness peak values are found at 5 seconds delay time. As this corresponds with peak porosity, the high roughness at 5 seconds delay time appears to be due to the higher number of interstices and larger pores in the sheet.

3. Opacity is highest at 5 seconds delay time. It is possible that this results from having the proper amount of binder to retain pigment particles. There is no excess binder near the coated sheet surface to mask over the pigment, and neither is there an insufficient amount of binder which would cause loss of pigment particles.

4. Gloss is lowest at 5 seconds delay time. This is what is expected, as the peak porosity and roughness values were found at 5 seconds delay time also, which would obviously yield lower gloss values.

5. Brightness is at peak value at 5 seconds delay time. It is believed that this is due to a higher amount of pigment surface area than 0 or 10 seconds delay time sheets. The same reasoning that was used in the opacity argument holds true here also.

6. The highest amount of brightness reduction was experienced at 5 seconds delay time. This corresponds well with porosity and roughness values at 5 seconds delay time. If the sheet is more porous, then it should experience more ink absorption, thus causing more brightness loss under inking conditions.

7. Wax pick values decreased with increasing delay time. This result is expected because less binder should be present in sheets with higher delay time. The pick results for the starch based coating experienced a minimum at 5 % seconds delay time, and the author does not have a theory for this pick behavior exhibited.

Recommendations

1. A follow-up thesis sound be done in which different delay times are used between 0 and 10 seconds. Also more delay time intervals should be used to verify trends observed in this thesis.

2. More variations of coating formulations should be tested in the same manner as was done in this thesis. The formulas should be "standard" coating colour formulations.

3. More samples should be tested if future work is done. The purpose would be to reduce deviation to determine observable trends with a higher degree of confidence.

4. A thesis could be done very similar to this one, only taking into account the effects of delay time on coated sheet strength properties as well as optical properties.

LITERATURE CITED

1. Engstrom, G., “Forming and consolidation of a coating layer and their effect on offset print mottle”, TAPPI Notes, 1993 Advanced Coating Fundamentals, 1993.

2. Engstrom G. and Rigdahl, M., “In-situ studies of water drainage from wet coating layers”, Tappi, 69 (1), 1986.

3. Salminen, V.J., “Water transport into paper - the effect of some liquid and paper variables”, Tappi, 71 (9), 1988.

4. Eriksson, U. and Rigdahl, M., “Differences in consolidation behavior and properties of Kaolin-based coating layers induced by CMC and starch”, 1993 Advanced Coating Fundamentals, TAPPI Notes, 1993.

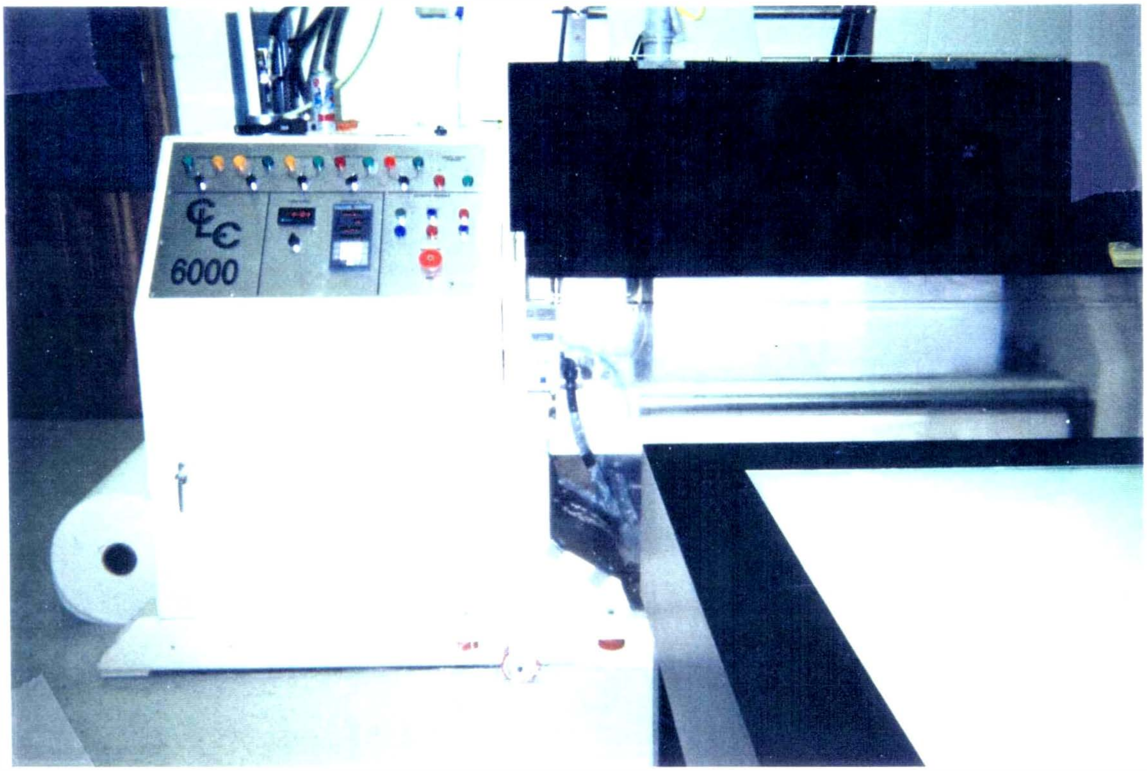
5. Bliesner, W.C., “Basic Mechanisms in Blade Coating”, Tappi, 54 (10), 1971.

6. Windle, W. and Beazly, K.M., “The Mechanics of Blade Coating”, Tappi, 50 (1), 1967.

7. Chen, K.S.A. and Scriven, L.E., “Liquid penetration into a deformable porous substrate”, Tappi, 73 (1), 1990.

8. Herbet, A.J., “A single method for measuring immobilization using the surface gloss technique”, Tappi, 73 (11), 1990.

9. Triantafillopoulos, N.G., Miller, C.E., and Carmichael, J.E., “Effect of coating application temperature on end-use properties of paper”, TAPPI Proceedings, 1994 Coating Conference, 1994.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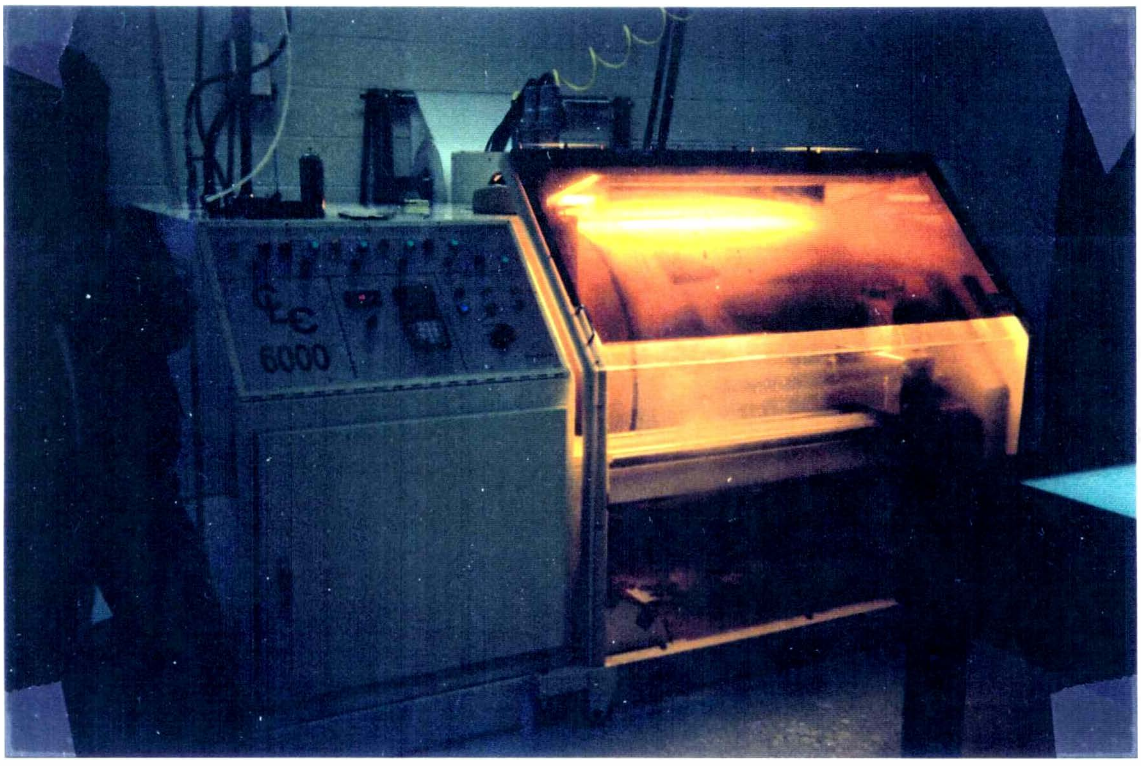
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