The effects of polymeric additive on papermaking

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ABSTRACT I determined the effect a cationic polyacrylamide has not only on pulp slurry drainage rate but also on web vacuum dewatering response, web behavior during wet pressing, web drying rate, and sheet tensile and burst strengths. Various amounts of polyacrylamide were used with a 51%-yield red oak kraft fiber furnish to form 273- and 205-g/m² webs. As polyacrylamide level was increased, the drainage rate of the pulp slurry increased, and web dryness decreased in response to vacuum. Over the levels studied, polyacrylamide had no effect on web behavior during wet-press dewatering. Polyacrylamide did, however, reduce the web drying rate and sheet burst index at the higher concentration (0.25%) of polyacrylamide. At a lower level (0.10%), web drying rate and sheet burst index were not affected. Sheet tensile index was not affected by polyacrylamide at either level.

KEYWORDS Additives Dewatering Drainage Drying Paperboard Polyacrylamide Water removal Wet pressing

A considerable amount of information has been reported on how various polymeric additives affect drainage rate and fines retention (1–9). When used as a drainage aid, polymeric additives can overcome slow drainage of fiber furnish containing high-yield pulps such as stone groundwood, hardwood pulps, and recycled fiber furnish (3–6,10). In addition, these additives improve the drainage of high-basis-weight paperboard furnishes and the drainage of paper machines that are drainage limited (11).

The effects of different polymeric additives, their concentrations, molecular weight distributions, and charge densities, have been studied as they relate to both drainage rate and retention (12–17). In addition, the effects of shear rate on polymer floc stability and the mechanisms by which the differing types of polymeric additives work have received attention (18–21). Some recent work shows that polymeric additive drainage aids may adversely affect web dewatering response on vacuum elements (6–7).

Because there is a lack of published information on how polymeric additives affect the rest of the papermaking operation, my objective was to determine the effect a cationic polyacrylamide drainage aid has not only on pulp slurry drainage rate but also on web vacuum dewatering, web behavior during wet pressing, web drying rate, and the sheet tensile and burst strengths. This objective was accomplished using various levels of polyacrylamide with a 51%-yield hardwood (red oak) kraft fiber furnish when forming 273- or 205-g/m² webs. The pulp slurry drainage rate and the web vacuum dewatering response were measured using an off-line drainage tester (22). Web behavior during wet pressing was determined by feeding machine-made webs of known moisture content through a wet press. Drying rate was determined by passing machine-made and wet-pressed webs over felted dryer rolls and measuring evaporative water removal. Burst and tensile indices were measured on restraint-dried sheets.

Results and discussion
Drainage and vacuum dewatering
As measured by an off-line drainage test device (22), the drainage rate of the oak kraft pulp in forming 273-g/m² webs increased as polyacrylamide levels increased. Near 0.2% by weight, the highest drainage rate was achieved (Fig. 1A). Addition of more polyacrylamide did not increase the drainage rate further.

Web dryness in response to a 33.8-kPa vacuum was also measured using the same drainage device. Measured web dryness after vacuum decreased with increasing levels of polyacrylamide. The measured decrease in web dryness was about 1%. Web moisture content increased as polyacrylamide levels increased (Fig. 1B). Therefore, the use of polyacrylamide can yield a web leaving the wire with a slightly higher moisture content, even though polyacrylamide has increased the pulp slurry drainage rate. The reason for a
higher web moisture content may be that polyacrylamide flocculates the fiber, resulting in a web with a larger pore structure (5). These pores would allow easier passage of air through the web, thereby reducing the effectiveness of vacuum dewatering. Another reason for higher web moisture content could be that fiber flocs hold more water, giving the web a higher moisture content.

**Wet pressing dewatering**

The effect of polyacrylamide on web behavior during wet-press dewatering was determined using 205-g/m², machine-made webs. Specifically, the effect on the two web properties that control web pressing response was measured. The web properties are dewatering time constant, \( \tau \), and apparent compressive modulus, \( C' \) (23, 24). For paperboard grade webs, these two web properties are related to wet pressing through the following relationship:

\[
\frac{\Delta MC}{MC_{in}} = (\frac{P}{C})(1 - e^{-\frac{t}{\tau}})
\]

where

\[
MC = \text{web moisture content, g water/g fiber}
\]

\[
\Delta MC/\Delta MC_{in} = \frac{\text{web fractional change in moisture content, } MC_{out} - MC_{in}}{MC_{out}}
\]

\[
MC_{in} = \text{web moisture content entering the wet press, g water/g fiber}
\]

\[
MC_{out} = \text{web moisture content exiting the wet press, g water/g fiber}
\]

\[
P = \text{average press pressure, MPa}
\]

\[
t = \text{nip residence time, ms}
\]

\[
C' = \text{web apparent compressive modulus, MPa}
\]

\[
\tau = \text{web dewatering time constant, ms}
\]

By measuring web moisture content changes for different wet-pressing conditions, the effects of polyacrylamide on the web parameters \( \tau \) and \( C' \) were determined.

Web moisture content entering the wet press had a larger effect on \( \tau \) and \( C' \) than did polyacrylamide level. As the initial web moisture content decreased, \( \tau \) and \( C' \) increased (Fig. 2). Over the ranges studied for press pressures (1.7–3.7 MPa), nip residence times (2–2.5 ms), web moisture contents, and polyacrylamide level, polyacrylamide did not have either a positive or negative effect on web behavior during wet-press dewatering.

Despite polyacrylamide reduction of web vacuum dewatering (i.e., higher web moisture content, Fig. 1B), web behavior during wet-press dewatering appears to be unaffected. In fact, it appears that wet-pressing can compensate for increased web moisture content leaving the paper machine wire. This is possible because webs with higher moisture content generally have lower values of \( \tau \) and \( C' \) (24). According to Eq. 1, this results in greater dewatering for a given set of pressing conditions—assuming crushing does not occur. Even if the web moisture content differences are not eliminated after the first pressing, by going through multiple press nips, web moisture content differences will be reduced to the point at which there would probably be no discernible differences.
Drying

Only at the 0.25% level did polyacrylamide have an effect on the drying rate of the 205-g/m² machine-made webs pressed to nominal moisture contents of 2.4 and 1.5 g water/g fiber (29.4% and 40% dryness, respectively) (Fig. 3). Compared to webs produced with 0% or 0.10% polyacrylamide, the webs containing 0.25% polyacrylamide had a lower drying rate. The difference in drying rate was largest when web moisture contents were highest. As drying proceeded and web moisture contents decreased, the difference in drying rate also decreased.

The observed difference in drying rate may be related to the action of the 0.25% level of polyacrylamide in promoting the presence of fiber flocs. These flocs could alter (a) the effectiveness of web contact on the steam-heated dryer roll, (b) the moisture distribution throughout the web, making it less uniform, (c) the thermal conductivity within the web, or (d) the web diffusion characteristics for water vapor leaving the web (25).

Sheet tensile and burst strengths

The effects of polyacrylamide on sheet tensile and burst strengths were measured on the 205-g/m², machine-made webs restraint-dried in the x-y direction. Sheet tensile index was not affected by polyacrylamide level over the range of conditions used (Fig. 4). However, for sheets produced at the higher polyacrylamide level (0.25%), burst index was reduced. This reduction in burst index may be related to formation. By flocculating fiber and fines, sheet formation may be adversely affected by polyacrylamide, thereby reducing burst index (26).

Overall, burst and tensile indices correlated well with sheet density. At a given polyacrylamide level, sheets having equivalent density also had comparable strengths despite having achieved that density through differing combinations of press pressures and nip residence times. Press pressure and nip residence times were the most important variables in sheet density development (Fig. 5). Sheet density development was relatively unaffected by polyacrylamide level. Even though different levels of polyacrylamide were used, comparable sheet densities would be expected from webs pressed at identical press pressures, nip residence times, and similar web moisture contents.

Conclusions

A cationic polyacrylamide used as a drainage aid in forming paperboard-grade webs from a 51%-yield red oak kraft pulp furnish can affect papermaking subsequent to drainage on the wire. Polyacrylamide, viewed strictly as a drainage aid, increased pulp slurry drainage rate. Therefore, polyacrylamide can give a web leaving the wire with a higher moisture content, even though polyacrylamide has increased pulp slurry drainage rate.

Polyacrylamide did not affect web behavior during wet-press dewatering, as determined by the measurement of web apparent compressive modulus and the dewatering time constant. In fact, it appears that wet pressing can compensate for increased web moisture content leaving the paper machine wire. Web drying rate was reduced by the addition of 0.25% polyacrylamide. At the lower 0.10%
level, no effect was observed. Sheet tensile index was unaffected by polyacrylamide level, while burst index was reduced at the higher 0.25% level. Therefore, when using a drainage aid such as polyacrylamide, other effects on the papermaking process apparently need to be considered besides drainage rate.

**Experimental procedure**

**Furnish**

Red oak (*Quercus borealis*) kraft pulp was produced at the U.S. Forest Products Laboratory. The 51%-yield kraft pulp was produced in a 0.4-m$^2$ rotating digester. The pulp was refined to a nominal freeness of 550 mL CSF at 2-3% consistency using a 300-mm-diameter, single-rotating-disk, pump-through refiner.

A commercially available cationic, high-molecular-weight, low-charge-density polyacrylamide was used. The same additive was used in independent off-line drainage measurements as well as in producing machine-made webs on the FPL experimental paper machine. Polyacrylamide was received as an emulsion at about a 5% consistency and was used over the range of 0-0.375% based on fiber weight.

**Drainage and vacuum dewatering**

A modified Britt water release analyzer was used for measuring off-line drainage rate and vacuum dewatering response (5, 22). A complete description of the device and procedures used can be found elsewhere (6, 22). Parameters selected to approximate conditions on the paper machine were: a basis weight$^*$ of 273 g/m$^2$, 0.23% consistency, pH 5.5, a contact time of 30 s between polyacrylamide and the fiber furnish, a shear rate of 5 rev/s (as determined by stirrer speed), a 4.22-kPa vacuum during web formation, and a 33.8-kPa vacuum after web formation to determine web dewatering response. Tap water was used in all experiments rather than distilled or deionized water because tap water was used in making machine-made webs.

**Machine-made webs**

Machine-made webs produced on the FPL paper machine were used for measurements of both wet pressing and drying rate. Continuous 330-mm-wide webs at 205 g/m$^2$ were produced at 6 m/min. Webs having a polyacrylamide content of 0%, 0.10%, and 0.25% were produced. The polyacrylamide levels were selected on the basis of off-line drainage measurements (Fig. 1A) and cover the range of drainage rates measured. Polyacrylamide was added to the fiber furnish at the fan pump prior to being pumped into the headbox. The pH of the white water was measured and adjusted to 5.5 using hydrochloric acid.

Webs varying in moisture content were obtained as follows. In the first instance, 0.6-m-long sections were removed after the couch roll without pressing at a nominal moisture content of 3.4 g water/g fiber (22.7% dryness). In the second instance, 1.3-m-long sections were removed after being pressed in the first wet-press to nominal moisture contents of 2.4 and 1.5 g water/g fiber. After marking the machine direction, the 0.6- and 1.3-m-long webs were cut into smaller webs measuring 100 × 140 mm. These smaller webs were used for the wet pressing and drying rate measurements.

**Wet pressing**

Web wet-pressing dewatering behavior was determined by hand feeding the 100-mm × 140-mm, machine-made webs through the first wet press of the FPL paper machine. The press could be operated at a variety of press pressures and nip residence times. Pressing pressure ranged from 1.7 to 3.7 MPa, and nip residence time ranged from 2 to 215 ms. From changes in web fractional moisture content ($\Delta MC/MC_{im}$) vs. nip residence time for differing press pressures, the web dewatering time constant could be determined for webs at a given moisture content and polyacrylamide concentration (23, 24, 27). By using Eq. 1, web apparent compressive modules, $C'$, was determined once $\tau$ was known. After wet pressing, the webs were restrained in the $x$-$y$ direction and dried in a platen press maintained at 177°C. These dried sheets were used for measuring burst and tensile indices after conditioning at 23°C and 50% relative humidity. Burst index and tensile index were measured according to TAPPI Methods T 403 and T 404, respectively.

**Drying rate**

Drying rates for the machine-made and pressed webs (100 × 140 mm) at nominal moisture contents of 2.4 and 1.5 g water/g fiber were determined by hand feeding them over a felted dryer roll on the FPL paper machine at a machine speed of 6 m/min and a

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$^*$A basis weight of 273 g/m$^2$ was selected to use in the drainage tester because it gave better precision in measuring drainage rate. The slightly higher basis weight will not alter the trends obtained for drainage or vacuum dewatering response (22).
roll temperature of 121°C. Web weight was measured initially and after each successive pass. By knowing the time of web contact with the dryer roll, the contact area, and the amount of water removed with each pass, drying rates were calculated. Each point on the drying curve (Fig. 3) is an average of 20 webs.

**Literature cited**

2. 1980 Retention and Drainage Seminar Notes, TAPPI PRESS, Atlanta.