Paper formation improvement through the use of new structured polymers and microparticle technology

By F. BROUILLETTE, D. MORNEAU, B. CHABOT and C. DANEAULT

Abstract: In a previous study, we have shown that structured (branched and cross-linked) cationic polyacrylamides (C-PAM) improved retention and drainage over a traditional linear C-PAM in fine paper manufacturing. The improvement was more significant at high turbulence. This study presents the effect of the same structured polymers on sheet formation. Results show that the structured and linear C-PAM provides similar formation. In addition, structured C-PAM dosages required to obtain a specific retention level decrease with increasing turbulence while that of the linear C-PAM must be increased.

Structured polymers are different from linear polymers because they contain several ramifications or branches. Structured polymers with only side-chains attached to the linear backbone are called branched polymers. A cross-linked polymer is a tridimensional network structure resulting from permanent bonds between linear chains, Fig. 1.

Branched and cross-linked cationic polyacrylamides (C-PAM) have already been tested as retention and drainage aids [1], but most of them had inadequate rheological properties (low apparent viscosity or “short” polymer) or had a too high level of cross-linking and were insoluble. More recently, Shin et al. showed that branched polymers improved retention efficiency compared to traditional linear polyelectrolytes [2,3]. In a previous study [4], we have shown that the use of new types of structured C-PAM floculants (Flobind technology) along with bentonite in a microparticulate retention system improved significantly retention and drainage over a traditional linear C-PAM and bentonite combination in fine paper production. The improvement was particularly significant at high turbulence levels, similar to those generated on modern twin-wire formers. However, the impact of the structured C-PAM on formation, the uniformity of fibre distribution, was not studied. Good formation is important in most paper grades to obtain a uniform distribution of ink or coating, but also to prevent breaks on fast manufacturing or converting machines.

Formation can be assessed visually by looking at the light passing through the sheet. Several light and dark spots of various sizes should be visible and distributed uniformly over the sheet. Because of the subjectivity of the visual determination of formation quality, several quantitative methods have been developed: for example, measurement of local differences in opacity or grammage, profilometry and image analysis. Usually, formation quality is reported as a single index such as the formation number and NUI [5]. Image-analysis techniques provide more details on floc sizes and structures [6,7]. In this study, the Kaptra Formation Index (KFI), a measurement based on image analysis, was chosen because it is already used in several mills and experimental results are becoming available [8].

Total retention is an important issue to consider when comparing sheet formation. The validity of the comparison is ensured only if all handsheets are prepared at the same total retention (fibres, fines and ash). In fact, formation is usually inversely proportional to retention. As the amount of flocs in the sheet reduces, less filler is retained. Therefore, the objective of this study was to compare sheet formation obtained with branched, cross-linked and linear C-PAM at the same total retention value.

EXPERIMENTAL

Pulp Furnish: A wood-free paper furnish consisting of 46% bleached hardwood kraft pulp, 31% bleached softwood kraft pulp, and 23% deinked pulp was used for all experiments. The furnish also contained approximately 16% precipitated calcium carbonate (PCC). The pulp was obtained from an Eastern Canada fine paper mill. Samples were taken at the storage chest at a consistency of 3.8%. For experimentation, the pulp was disintegrated in a British Disintegrator in 50°C water for 5 minutes and the consistency adjusted at 0.27% using 50°C tap water. PCC concentration was also increased to 20% to simulate headbox conditions. The pH of the pulp suspension was adjusted at 8.6.

Retention Programs: Two structured C-PAM floculants (branched and cross-linked) having a medium charge density and a high molecular weight were compared to a standard linear C-PAM. The structured C-PAM were emulsion polymers, and the linear C-PAM a solid powder. Sodium bentonite montmorillonite was used as the microparticle component in each system studied. Table I. Polymer and microparticle solutions were prepared from concentrated chemicals using deionized water. Floculants and microparticles were diluted at 0.1% and 0.3%, respectively. All polymer solutions were subjected to vigorous agitation before they were injected into the pulp suspension.

Handsheet Preparation: Test sheets having a basis weight of 75 g/m² were prepared using a modi-
fied handsheet machine. The original tank was replaced with a 14-cm deep plastic tank and a Dynamic Drainage Jar (DDJ) was placed on top of the tank, Fig. 2. Each experiment was repeated four times. The pulp (0.27% consistency) was fed into the DDJ and stirred for 30 seconds. Then, the flocculant was injected and the suspension mixed for another 60 seconds. Finally, the microparticle was added and mixed for another 20 seconds. At the end of the mixing stage, the drainage valve was opened for 2 to 3 s to drain all the pulp from the DDJ. The time between the opening of the drainage valve and the application of the vacuum was held constant at 5 s to minimize the time when the pulp is left without mixing in the handsheet tank.

Table II summarizes the experimental conditions studied. Rotational speed was varied between 1,100 and 2,500 rpm to determine the effect of turbulence level on formation. Polymer dosages (as active material) were determined based on previous results [1] to obtain similar first-pass total retention (FPR) values at each turbulence level. Microparticle concentration was held constant at 1 kg/t. For each rotational speed studied, a blank run was made without any chemicals.

Formation Analysis: Sheet formation was first evaluated globally with the Kaptra Formation Analyzer. Formation was then compared to C-PAM type. Hence, similar retentions were not significantly different according to C-PAM type. This result could be explained by two factors. First, the efficiency of the cross-linked polymer increases steadily with turbulence. Consequently, it was more difficult to determine dosages required to reach a specific retention value. It is also known that the efficiency of the cross-linked polymer increases steadily with turbulence.

Effect of Polymers on Retention: Figure 5 shows that the experimental FPR values obtained are higher than those of the previous study [4]. These high retention values are caused by the smaller openings of the standard handsheet machine wire (125 mesh) compared to the usual DDJ wire (60 mesh) used for retention experiments [9]. As the rotational speed was increased, floc formation is reduced with linear and branched C-PAM. The reduction was more important in the 1,000- to 1,800-rpm range. The FPR was much less affected in the case of the cross-linked C-PAM. This result could be explained by two factors. First, the efficiency of the cross-linked C-PAM did not change much with dosage at low turbulence. Consequently, it was more difficult to determine dosages required to reach a specific retention value. It is also known that the efficiency of the cross-linked polymer increases steadily with turbulence.

Effect of Polymer Program on Formation: Formation was first evaluated globally with the KFI, Fig. 6. Comparison of blank and polymer runs shows that the retention

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**TABLE I. Retention aids used in the study.**

<table>
<thead>
<tr>
<th>Program</th>
<th>Flocculant</th>
<th>Microparticle</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Linear C-PAM</td>
<td>Bentonite</td>
</tr>
<tr>
<td>2</td>
<td>Branched C-PAM</td>
<td>Bentonite</td>
</tr>
<tr>
<td>3</td>
<td>Cross-linked C-PAM</td>
<td>Bentonite</td>
</tr>
</tbody>
</table>

**TABLE II. Experimental conditions.**

<table>
<thead>
<tr>
<th>Rotational speed (rpm)</th>
<th>Polymer dosage (kg/t)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 100</td>
<td>0.179</td>
</tr>
<tr>
<td>1 800</td>
<td>0.196</td>
</tr>
<tr>
<td>2 500</td>
<td>0.200</td>
</tr>
</tbody>
</table>

**FIG. 1. Schematic representation of polymers.**

**FIG. 2. Modified handsheet machine.**

**FIG. 3. Limits and average spot size for each category measured by the Kaptra Formation Analyzer.**

**FIG. 5.**

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**RESULTS, DISCUSSION**

It is obvious that the formation indexes and DLR shown here cannot be representative of an actual mill sheet. The experimental device used to make handsheets cannot simulate the orientation of fibres obtained on a real paper machine. In addition, the experimental pulp consistency is lower than the actual paper machine headbox consistency. However, variations in floc and void sizes produced by the different polymer programs can be identified. Figure 4 shows the Kaptra reconstructed images of a typical laboratory handsheet and an actual copy paper. It has been determined that laboratory handsheets give on average 50% less spots (both dark and light) than the mill sheet. The maximum area covered by the spots on the experimental handsheets is around 16%, whereas actual copy paper is around 23%. This higher flocculation of the copy paper could have been caused by a lower turbulence on the paper machine than in the experimental device, which is unlikely, or by a higher polymer dosage.

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**POLYACRYLICS**

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**FIG. 6. Comparison of blank and polymer runs shows that the retention**
points gained with retention aids impair formation. The average KFI for blank runs is 17, while that of polymer runs is located between 27 and 56. As expected, formation is generally improved at higher turbulence because of the lower retention. Even though the correlation between FPR and formation index values is quite high ($r^2 = 0.69$, Fig. 7), changes in FPR cannot explain all the variations in formation quality. Polymer structure also has a significant effect on the formation. The formation improvement is particularly significant in the case of the structured C-PAM. They are less effective (higher KFI) than the linear C-PAM at 1,100 rpm, but they provide a similar formation at 1,800 and 2,500 rpm.

In addition, it must be considered that polymer dosages decrease with increasing turbulence for the structured C-PAM. On the other hand, the dosage of the linear C-PAM must be increased to maintain or slightly improve formation at high turbulence. Structured polymers are thus more effective at improving formation at high turbulence and low dosage. This effect is rather unexpected but it can be explained by the fact that flocs formed by linear polymers are broken irreversibly at high turbulence, while structured C-PAMs have the ability to reflocculate because of their particular molecular structure.

In order to provide a more detailed analysis of formation, the amount and size of flocs and voids in the handsheets must be considered. It can be observed that the use of polymer programs have a dramatic effect on the number of dark and light spots in the sheet, Figs 8 and 9. All distribution curves obtained with polymers show the same pattern. The 0.55-mm$^2$ category has more spots (200 to 250), the 1.60-mm$^2$ around 50 and the 4.20-mm$^2$ less than 30. The last three categories (9.25-mm$^2$ and larger) were generally below 10 spots. However, even a small amount of these large spots can have a significant effect on formation. In fact, larger spots have a strong effect on the KFI while the contribution of small spots is almost negligible.

No sheet showed signs of over-flocculation, even in the case of the cross-linked C-PAM. There was also no correlation between polymer type and the amount of large spots (9.25 mm$^2$ and larger) were generally below 10 spots. However, even a small amount of these large spots can have a significant effect on formation. In fact, larger spots have a strong effect on the KFI while the contribution of small spots is almost negligible.

FIG. 4. Kaptra reconstructed images of a typical laboratory handsheet and of an actual copy paper showing dark (black) and light (light grey) spots.

FIG. 5. Average FPR for each set of experimental conditions.

FIG. 6. Effect of turbulence level on the Kaptra Formation Index (KFI).

FIG. 7. Correlation between the First-Pass Retention (FPR) and the Kaptra Formation Index (KFI).

Finally, we have compared the DLR for the three polymers studied. Only the four smaller categories of spots were considered because the number of spots in the other categories was too low for accuracy. As Fig. 10 shows, the relative error becomes important for the 9.25-mm$^2$ category. Figure 10 also shows that the more balanced sheets, regardless of the polymer used, are obtained at 1,800 rpm. In fact, the DLR values for all polymers are located between 80 and 100% for the 0.55-, 1.60-, 4.20- and 9.25-mm$^2$ spot categories.

Differences between polymers occur at 1,100 and 2,500 rpm. At 1,100 rpm, the structured C-PAMs produce similar DLR for all size categories. However, the cross-linked produced a more balanced sheet. This behaviour could have been caused by a lower retention obtained at this turbulence level. The linear, and to a lesser extent, the branched C-PAM produced much more light than dark areas which indicates a too high polymer dosage. It should have been expected that at low turbulence level, the polymers would promote more flocculation.

At 2,500 rpm, the loss in retention translates into more voids and a more porous sheet for all polymers. This effect is particularly evident for the 4.20-mm$^2$ category, where the DLR for the linear C-PAM is less than 50%. However, the
branched and the cross-linked C-PAM still provide an adequate balance between flocs and voids.

**CONCLUSIONS**

Sheet formation obtained with structured (branched and cross-linked) and linear C-PAM retention and drainage aids was compared at three FPR levels. The evaluation of global sheet formation by the Kaptra Formation Index and the analysis of dark and light spot distributions showed that all polymers give similar formation for the same dosage. Structured C-PAM can also provide a formation similar to that of the linear C-PAM at a similar FPR value. However, structured C-PAM dosages required to obtain a sheet formation similar to that of linear C-PAM decrease with increasing turbulence while that of the linear C-PAM must be increased.

In light of the results presented here and other previous studies, it is now clear that structured C-PAM can significantly improve retention and drainage over a traditional linear C-PAM. In addition, structured C-PAM provides similar formation at much lower dosages in fine paper manufacturing. Polymer dosage reductions could result in substantial savings on chemical costs.
ACKNOWLEDGEMENTS

The authors are grateful to the Natural Sciences and Engineering Research Council of Canada for its financial support and to SNF-Floerger for providing the polymer samples. The authors would also like to thank Lyne Desharnais, Cindy Geoffroy, and Marisol Tanguay for their technical assistance.

LITERATURE


Résumé: Dans une étude précédente, nous avons démontré que des polyacrylamides cationiques (C-PAM) structurés (ramifié et réticulé) améliorent la rétention et le drainage par rapport à un C-PAM linéaire traditionnel dans la fabrication de papier fin. L’amélioration était plus importante à haute turbulence. Cette étude présente l’effet des polymères structurés sur la formation. Les résultats obtenus montrent que les C-PAM structurés et linéaire produisent une formation similaire. De plus, les dosages de C-PAM structurés requis pour obtenir une rétention spécifique diminuent avec l’augmentation de la turbulente alors que le dosage de C-PAM linéaire doit être augmenté.


Keywords: POLYACRYLICS, ACRYLAMIDE, CATIONIC COMPOUNDS, FORMATION, TURBULENCE.