Flocculants for precipitated calcium carbonate in newsprint pulps

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ABSTRACT

The retention of precipitated calcium carbonate (PCC) in newsprint pulp (15 wt.% semibleached kraft + 85 wt.% peroxide-bleached mechanical) using polymeric flocculants was investigated. Both commercially available and experimental polymeric flocculants were evaluated, and the combination of cationic polyacrylamide and bentonite was found to be the most effective commercial retention aid. However, the experimental poly-(AM/MPEGMA), a copolymer of acrylamide and methoxy poly(ethylene glycol) methacrylate, when used in conjunction with phenolic resin (PFR), was the most effective retention aid. The retention of precipitated calcium carbonate by the PFR/poly-(AM/MPEGMA) system was further increased by pretreatment of the pulp furnish with Na_2CO_3 or by using acid-tolerant PCC instead of conventional PCC. Both Na_2CO_3-treated pulp and acid-tolerant PCC have lower equilibrium concentrations of Ca^{++} ions.

Application:

Laboratory results provide some guidance to the types of commercial retention aids that may be effective for PCC retention in newsprint. Ca^{++} ion sensitivity, displayed by some retention aids, is an important issue.

POLYMERIC FLOCCULANTS (retention aids) are routinely used in paper manufacture to enhance the deposition (retention) of inorganic pigments onto wood fibers. In 1980, Pelton and coworkers published the results of a laboratory investigation of retention-aid effectiveness in newsprint pulp *(1)*. The major finding at that time was that cationic flocculants, effective in fine paper production, were not cost effective in newsprint, whereas very high-molecular-weight poly(ethylene oxide), PEO, showed promise. Since then, however, many things have changed. At that time, essentially no North American newsprint operations were regularly using retention aids, whereas now retention aids are routinely used *(2)*. Newsprint furnishes have evolved from mixtures of stone groundwood and chemical pulps to thermomechanical pulp (TMP) and chemithermomechanical pulp (CTMP), with increasing amounts of deinked pulp. Furthermore, in an effort to upgrade paper quality, there has been increasing use of fillers, including clay, ground calcium carbonate, and precipitated calcium carbonate (PCC).

The chemical suppliers have also been very active in the last 15 years in bringing new products to the marketplace. Some of the most commonly used newsprint retention aids include bentonite+polyacrylamide *(3)*, phenolic resin+PEO *(4)*, and polyethyleneimine *(5)*.

Newsprint and related paper grades are particularly challenging applications for polymeric retention aids, because the paper machines usually have very turbulent drainage and rapid dewatering, which can destroy polymer flocs *(6)*. Furthermore, the action of cationic additives is inhibited by high levels of dissolved and colloidal substances, DCS, (sometimes called anionic trash), which are carbohydrates, lignin residues, resin, and fatty acids originating from the wood *(5, 7)* or from the bleaching process *(8)*. Retention-aid components that do not have positive charges, such as PEO, bentonite, and phenolic resins, are usually not deactivated by the DCS.

A new experimental copolymer that has been developed in our laboratory shows promise as a retention aid. The copolymer structure, shown in **Fig. 1(a),** consists of a long polyacrylamide backbone (molecular weight > 10^6) bearing about 1 mole% pendant PEO side chains containing 9–23 ether oxygens *(9)*. Previous laboratory work has shown that the copolymer is an effective retention aid for newsprint fines while offering the additional advantages of being more robust than PEO with respect to mechanical and chemical degradation *(10)*.

The objectives of this work were to compare the retention and flocculation efficiency of our copolymers with the leading commercial retention aids. For this work, we chose a peroxide-bleached mechanical pulp with a particularly troublesome DCS fraction, and we focused on retention of PCC, a filler offering many potential advantages *(11)*

EXPERIMENTAL

Polymeric flocculants

The commercial polymers were obtained from four suppliers and were used as received without further purification (see **Table I**). The novel experimental polymers prepared in this and previous work *(9, 10, 12)* consisted mainly of nonionic flocculants based on the copolymerization of acrylamide (AM) and methoxy poly(ethylene glycol) methacrylate, (MPEGMA). Terpolymers consisting of (acrylamide/acrylic acid/MPEGMA), [poly-(AM/AA/MPEGMA)], and [acrylamide/3-(methacryloylamino) propyl]trimethyl ammonium chloride MPEGMA] [poly(AM/MAPTAC/-MPEGMA)] were also synthesized

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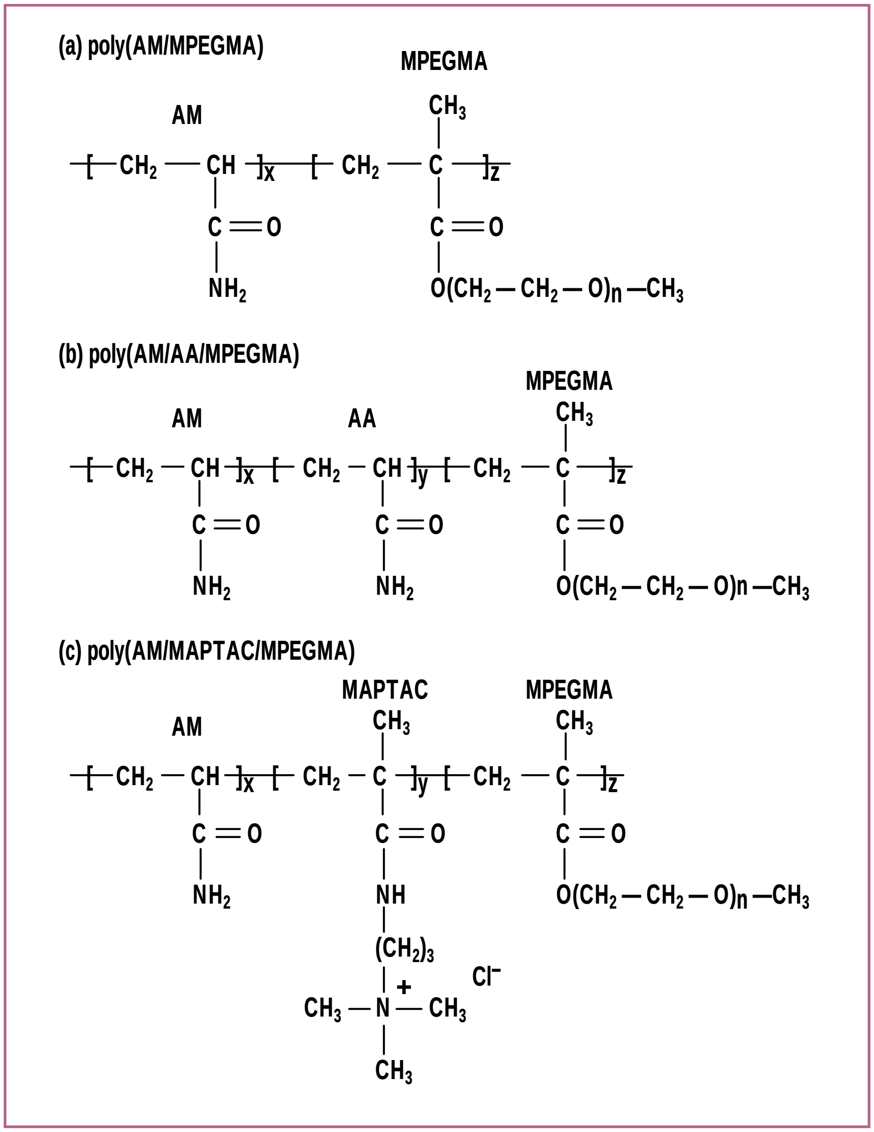


1. Chemical structures of experimental polymers

(Fig. 1). The synthesis involved the dissolution of the monomers (see **Table II**) in water, which was then purged with ultra-pure N_2 for approximately 30 min before the addition of the initiator (potassium persulfate). Polymerization was subsequently carried out at 25°C for approximately 5 hours, after which time the products were diluted to 0.1–0.01 wt.% polymer using water. The cofactor used in conjunction with the above novel experimental polymers was a low-molecular-weight phenolic resin herein designated PFR (see Table I).

Copolymers of N-isopropylacrylamide (NIPAM) and DADMAC were prepared by free-radical polymerizations. Details of polymer preparation *(12)* and flocculation properties *(13)* have been published.

Newsprint pulp

The newsprint pulp used in this work consisted of a mixture of 15 wt.% semibleached kraft pulp and 85 wt.% peroxide-bleached mechanical pulp (which was made up of 60 wt.% CTMP + 40 wt.% stone ground pulp). According to the pulp supplier (MacMillan Bloedel), obtaining good PCC retention in this pulp was particularly challenging.

Precipitated calcium carbonate (PCC)

Three undispersed PCC samples exhibiting scalenohedral or hexagonal prismatic habits (for characterization data, see **Table III** and **Fig. 2**) were supplied by Specialty Minerals Inc. Acid-tolerant scalenohedral PCC was also provided by Specialty Minerals Inc.

Retention characterization

Precipitated calcium carbonate [20 wt.% based on oven-dried (o.d.) pulp] was added to the pulp (final pulp consistency=0.5 wt.%), and the pH of the furnish was adjusted to 7.5 by the addition of H_2SO_4. The furnish was then dispersed in a dynamic drainage jar (DDJ) *(14)* at 1000 rpm for 60 seconds. Known quantities of polymeric flocculants were added; the first-pass white water (100 mL) was collected 10 seconds after the addition of the final polymeric component.

The first-pass retention was evaluated from the difference between the amount of PCC present in the DDJ before polymer addition and the amount of PCC present in the white water. PCC concentrations were obtained by dissolution of $CaCO_3$ in HCl (0.3 mL of 12 N HCl per 100-mL sample), after which the soluble Ca^{++} concentration was measured by an automated EDTA (ethylenediaminetetraacetic acid) titration apparatus. The endpoint was detected with an Orion Model 93-20 calcium-selective electrode.

RESULTS

PCC retention in a western Canadian newsprint furnish in the presence of commercial and experimental polymeric flocculants was determined by DDJ tests and a paper industry flocculation test *(14)*. This procedure gives the first-pass retention values, which are the fractions of added PCC that deposit onto the wood fibers and thus cannot pass through the 70-μm screen in the DDJ. Both commercial and experimental water-soluble flocculants were evaluated as additives to improve retention.

The designation and suppliers of the commercial polymers are given in Table I, and the compositions of

Code name	Sample	Polymer composition	Molecular weight	Polymer charge	Supplier
CPAM1	PERCOL 455®	Cationic polyacrylamide	High	5% cationic	Allied Colloids
CPAM2	PERCOL 175®	Polyacrylamide	High	Cationic	Allied Colloids
CPAM3	PERCOL 63®	Polyacrylamide	High	Cationic	Allied Colloids
APAM1	Nalco-E®	Acrylamide/sodium acrylate	High	Anionic	Nalco
APAM2	ORGANOPOL®	Copolymer of sodium acrylate and acrylamide	High	Anionic	Allied Colloids
PEO	Polyox-309®	poly(ethylene oxide)	High	Nonionic	Union Carbide
PA1	ALCOFIX 159®	Polyamine	Low	Cationic	Allied Colloids
PA2	ALCOFIX 131®	Quaternized polyamine	Low	Cationic	Allied Colloids
poly DADMAC	Nalco-A®	poly(DADMAC)*	Low	Cationic	Nalco
PFR	PFR C-271®	Phenolic resin	Low	Anionic	Borden Chemicals
CLAY	HYDROCOL O®	Modified bentonite	…	…	Allied Colloids

*DADMAC: diallyldimethyl ammonium chloride

I. Commercial polymeric flocculants used in PCC retention

Polymer	Polymer composition	Polymer charge
poly(AM/MAPTAC/MPEGMA)	n=23; R=1/0.072/0.043	Cationic
poly(NIPAM/DADMAC)	R=2/98	Cationic
poly(AM/AA/MPEGMA)	n=23; R=1/0.0088/0.17	Anionic
poly(AM/MPEGMA)	n=9; R=93/7	Nonionic

*AM = acrylamide
AA = acrylic acid
MPEGMA = methoxy poly(ethylene glycol) methacrylate
NIPAM = N-isopropylacrylamide
MAPTAC = [3-(methacryloylamino)propyl]trimethyl ammonium chloride
DADMAC = diallyldimethyl ammonium chloride
n = repeat units of ethylene oxide
R = mole ratio of monomer feed

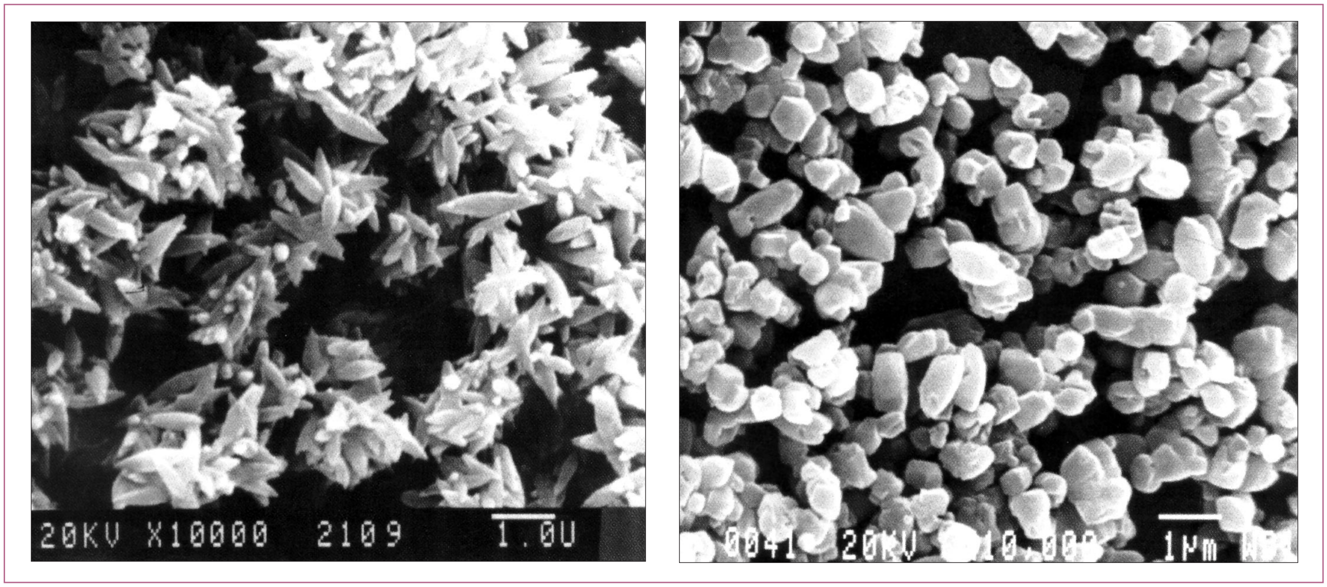
II. Novel polymeric flocculants developed at McMaster University*

the experimental polymers, prepared in our laboratory, are given in Table II. Some of the most effective flocculants involve sequential addition of two additives. To simplify the description of multicomponent systems, a systematic nomenclature was employed; an example is PFR/PEO* (2:1). The order of chemicals reflects the order of addition, and the ratio in brackets is the mass ratio of the two additives used in the flocculation experiment. The asterisk (*) refers to the component used to calculate the dose. Thus, 2 kg/metric ton PFR/PEO* (2:1) means 4 kg PFR was added first followed by 2 kg PEO per o.d. metric ton of pulp suspension.

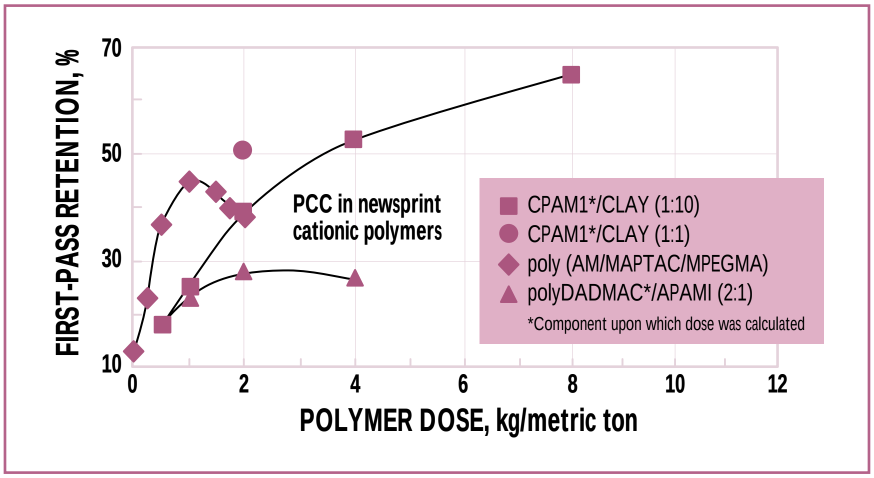
In the following sections, the results are categorized by the charge of the high-molecular-weight flocculant.

PCC retention induced by cationic polymers

Two commercial cationic polymers were compared with an experimental polymer in **Fig. 3**. With no polymer, the PCC retention was less than 15%. The maximum retention was obtained with 8 kg/metric ton CPAM1*/CLAY (1:10). CPAM1 is a high-molecular-weight cationic polyacrylamide with a low charge content, and CLAY is a bentonite. The single point for CPAM1*/CLAY (1:1) indicates that lower ratios of CLAY were more effective. The influence of the CPAM1*/CLAY ratio is illustrated in **Fig. 4,** which shows retention as function of CLAY concentration for a constant CPAM1 concentration. The optimum retention corresponded to a polymer-to-bentonite ratio of (1:1); similar results have been reported in other pulps *(15).*



2. Scanning electron micrographs of PCC



3. PCC retention induced by cationic polymers

Parameter	Dose, kg/metric ton	Albacar HO®	Cloquet Albafil®	Adams Albafil®
Crystal shape	...	Scalenohedral	Hexagonal prismatic	Hexagonal prismatic
Average size, μm	...	1.34	0.8	0.6
Surface area, m^2/g	...	10.6	6	7–8
First-pass retention, %				
CPAM1*/CLAY (1:10)	2	39	31	22
CLAY/APAM2* (10:1)	2	39	35	24
PFR/poly(AM/MPEGMA)* (2:1) in 0.01 M Na_2CO_3	2	46	36	32

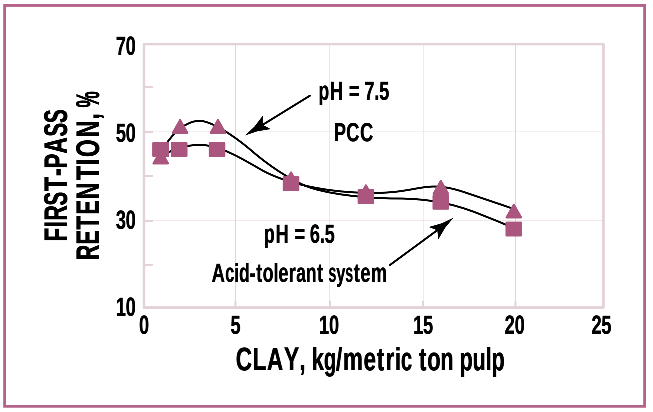
III. Comparison of PCC types by properties and by response to retention aids in newsprint pulp

The acid-tolerant results in Fig. 4 will be discussed in a later section.

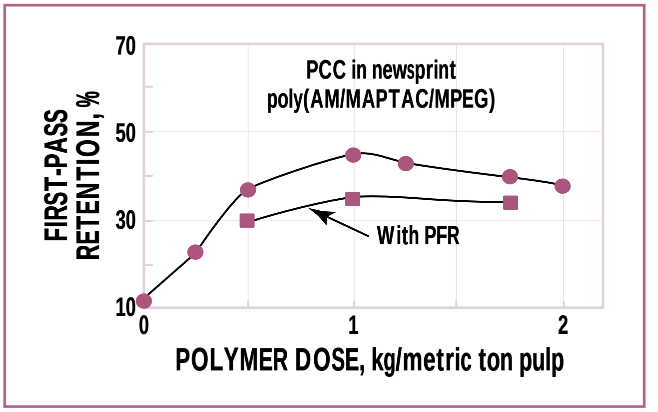
The second commercial system shown in Fig. 3, polyDADMAC*/APAM1 (2:1), is a highly charged poly(DADMAC) coagulant followed by a high-molecular-weight anionic flocculant. PCC retention with this system nearly doubled using a 2 kg/metric ton dose of APAM1 compared with retention in the absence of polymers. Nevertheless, all the other systems in Fig. 3 gave better PCC retention in this pulp.

The experimental poly(AM/MAPTAC/MPEGMA) flocculant was a high-molecular-weight polyacrylamide terpolymer containing 6.5 mole% cationic groups and 3.9 mole% pendant poly(ethylene glycol) chains containing 23 ether groups. Thus, this molecule is capable of both electrostatic interactions via the cationic group and hydrogen bonding interactions through the polyether chain. The terpolymer gave good PCC retention at an optimum polymer dose of 1 kg/metric ton.

Usually, flocculants based on PEO or those that contain pendant poly(ethylene glycol) chains require a phenolic resin cofactor to be effective. **Figure 5** shows PCC retention as a function of terpolymer dose, with and without phenolic resin.



4. The influence of CLAY concentration and the type of PCC on retention in the CPAM1/CLAY system



5. Comparison of poly(AM/MAPTAC/MPEGMA) and PFR/poly(AM/MAPTAC/MPEGMA) (1:1) as PCC retention aids*

The presence of phenolic resin reduced the effectiveness of terpolymer poly-(AM/MAPTAC/MPEGMA).

In previous work, copolymers based upon acrylamide and pendant poly(ethylene glycol) have demonstrated remarkable stability with regard to aging in water. This was not the case for the poly(AM/MAPTAC/MPEGMA) polymer; after 3 months storage at room temperature, the polymer lost virtually all flocculation activity.

The first-pass-retention results obtained using a variety of cationic polymer systems are compared in the first section of **Table IV**. The first three systems involve the initial addition of a highly charged, low-molecular-weight cationic polymer. This is a common approach in industry and is based on the philosophy of sequestering some of the troublesome dissolved and colloidal substances with relatively inexpensive low-molecular-weight cationic polymer before addition of the high-molecular-weight flocculant. The PCC retention for these three systems, however, was low compared with the results shown in Fig. 3.

Poly(NIPAM/DADMAC) is a novel temperature-sensitive copolymer; its preparation and flocculation behavior in clean systems has been described elsewhere *(12, 13)*. However, poly(NIPAM/DADMAC)*/CLAY (1:10) showed little promise as a PCC retention aid for mechanical pulps.

Retention systems	Polymer charge	Dose, kg/metric ton	PCC retention,%
PA2*/CPAM3/CLAY (1:1:2)	Cationic	1.0	29
polyDADMAC*/APAM1 (2:1)	Cationic	2.0	28
PA1*/CPAM2/CLAY (2:1:8)	Cationic	1.5	21
poly(NIPAM/DADMAC)*/ CLAY (1:10)	Cationic	2.0	12
CPAM1*/CLAY (1:10)	Cationic	2.0	39
CPAM1*/CLAY (1:1)	Cationic	2.0	51
poly(AM/MAPTAC/ MPEGMA)	Cationic	1.0	45
CLAY/APAM2* (10:1)	Anionic	2.0	29
poly(AM/AA/MPEGMA)	Anionic	2.0	27
PFR/poly(AM/MPEGMA)* (2:1)	Nonionic	2.0	42
PFR/poly(AM/MPEGMA)* (2:1) with Na_2CO_3	Nonionic	2.0	55
PFR/PEO* (2:1)	Nonionic	2.0	32
PFR/PEO* (2:1) with Na_2CO_3	Nonionic	2.0	43

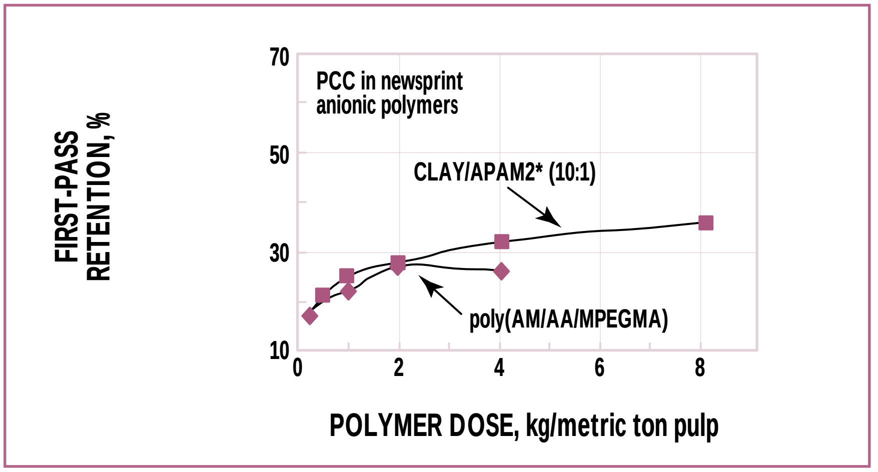
IV. Overall comparison of polymer-induced PCC retention; pH=7.5; pulp: 15% SBK + 85% peroxide-bleached CTPM; pulp consistency: 0.5 wt.%; scalenohedral PCC (20 wt.% on o.d. pulp)

PCC retention induced by anionic polymers

In general, anionic flocculants are not as effective as cationic polymers in papermaking suspensions, because fibers, fines, and fillers are usually also negatively charged. On the other hand, polymers containing carboxylate groups bind calcium ions and adsorb onto PCC *(16)*. Two anionic polymers were evaluated in this work, and the results are summarized in **Fig. 6** and Table IV. Commercial APAM2 is an anionic polyacrylamide that was used in conjunction with bentonite. Poly(AM/AA/MPEGMA) is an experimental terpolymer based on acrylamide, acrylic acid, and PEG macromonomer. At polymer doses less than 2 kg/metric ton pulp, the retention values produced by the two systems were virtually identical. At higher dosages, the CLAY/APAM2 system was more effective. In general, however, retention of PCC using anionic polymers was significantly less than that obtained from the cationic flocculants (Table IV).

PCC retention induced by nonionic polymers

Very high molecular weight PEO homopolymer was compared with a



6. Comparison of the experimental terpolymer with the poly(acrylate-coamide)/bentonite commercial flocculant

Polymer	Dose, kg/metric ton	Retention at 22°C,%	Retention at 50°C,%
CPAM1*/CLAY (1:10)	2	39	35
CLAY/APAM2* (10:1)	2	39	35
PFR/poly(AM/MPEGMA)* (2:1) in 0.01*M* Na_2CO_3	2	46	51

V. PCC retention conducted at different temperatures; pH=7.5; pulp: 15% SBK + 85% peroxide-bleached mechanical pulp; pulp consistency: 0.5 wt.%; scalenohedral PCC (20 wt.% on o.d. pulp)

nonionic experimental copolymer, and the results are shown in **Fig. 7** and Table IV. Both polymers required the addition of PFR, a phenolic resin cofactor that was the first component added. It has been shown previously *(1)* that the high-molecular-weight PFR/PEO system was an effective flocculant for pulp fines in newsprint pulp. The PCC retention results obtained in the present work, however, suggest that this system is not an effective retention aid for PCC (see the lowest curve in Fig. 7). By contrast, the poly(AM/MPEGMA) copolymer produced good PCC retention, and the data indicate that there was significant improvement in retention over the PFR/ PEO system.

The PCC retention was increased further when Na_2CO_3 was used in conjunction with either PEO or the copolymer. Indeed, PFR/copolymer in the presence of Na_2CO_3 was the most effective combination of additives in this investigation. Addition of Na_2CO_3 lowered the free calcium ion concentration from 3m*M* to 0.3m*M*. Furthermore, retention was not dependent on the order of addition of Na_2CO_3 and PCC to the pulp.

Effect of temperature on PCC retention

For convenience, most of the flocculation studies were conducted at room temperature, whereas paper is usually made at about 50°C. The effect of temperature on PCC retention using the commercial cationic CPAM1/CLAY, the commercial anionic CLAY/APAM2, and the experimental nonionic PFR/poly(AM/MPEGMA) systems was investigated. The results (**Table V**) indicated that PCC retention was not significantly affected by an increase in temperature from 22 to 50°C.

Effect of the external crystal habit of PCC on retention

The majority of PCC retention experiments carried out in this work used scalenohedral PCC. Retention of this PCC was compared with that of two hexagonal prismatic forms in the presence of three retention systems. The results, summarized in Table III, showed that, regardless of the type of the polymeric retention system used, the scalenohedral PCC was retained to a greater extent compared with the two hexagonal prismatic forms of PCC.

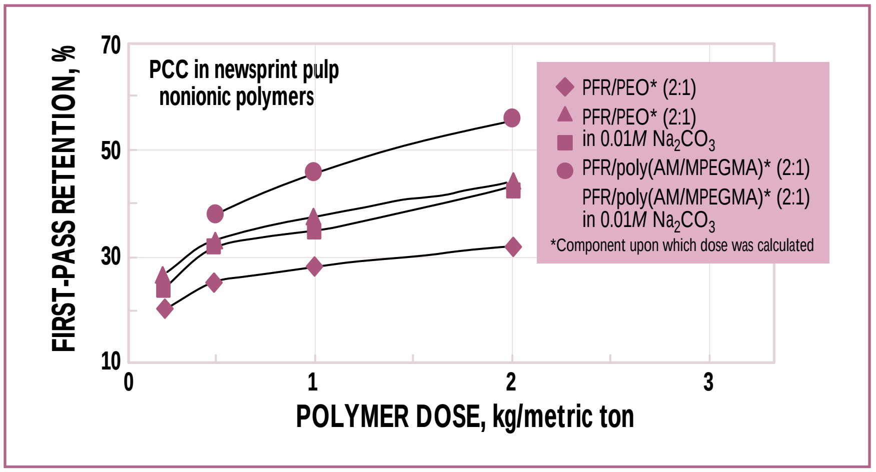
Retention of acid-tolerant PCC

Traditionally, newsprint paper machines operate at pH values less than 6. Neither PCC nor ground calcium carbonate can be used at low pH, since the solubility of these solid phases is too high. Acid-tolerant PCC has been developed to lower the usable equilibrium pH limit for PCC *(17)*. Acid-tolerant scalenohedral PCC was formulated by a proprietary method and tested at both pH 7.0 and 6.5. Retention of both acid-tolerant PCC at pH 6.5 and conventional PCC at pH 7.5 using CPAM1/CLAY was compared, and the results are shown in Fig. 4. The data indicate that when the CPAM1/CLAY system was used, the pH of the PCC did not significantly affect the retention values.

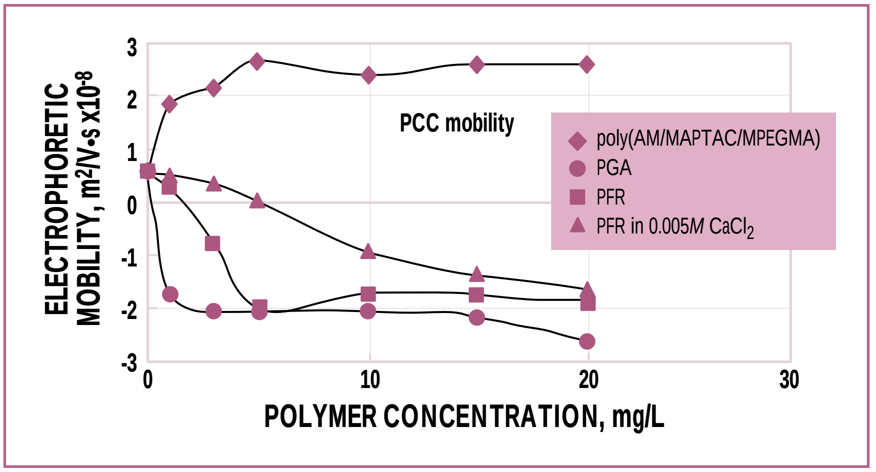
Table VI compares conventional PCC and acid-tolerant PCC retention in the presence of PFR/poly(AM/MPEGMA)* (2:1). The retention of acid-tolerant PCC at pH 6.5 was 10% higher than conventional PCC at pH 7.5. Also shown in Table VI is the retention value for conventional PCC with added sodium carbonate. Retention results obtained using PFR/poly(AM/MPEGMA) in acid-tolerant PCC (pH 6.5) were similar to those obtained using this polymer at alkaline pH (7.5) in the presence of Na_2CO_3. Both acid-tolerant chemistry and Na_2CO_3 give lower concentrations of dissolved calcium ions at neutral pH.

PCC electrophoretic mobility

The electrophoretic mobilities of dilute PCC suspensions in water were measured as functions of the concentration of various additives, and the results are summarized in **Fig. 8**. With no additives, the PCC particles were positively charged. Polygalacturonic acid (PGA), an anionic water-soluble polymer produced during peroxide bleaching *(18),* adsorbed onto the positively charged PCC, causing charge reversal. Phenolic resin cofactor (PFR), which is also an anionic polymer, showed similar behavior. In the presence of added calcium chloride, however, significantly more PFR was required to reverse the PCC charge. Cationic terpolymer poly(AM/MAPTAC/MPEGMA) addition increased the PCC mobility, suggesting that the cationic polyelectrolyte adsorbed onto the cationic particles.



7. Comparison of PEO with experimental nonionic copolymer based on acrylamide and PEG macromonomer



8. The influence of polymers on the electrophoretic mobility of PCC; pH=8.0 and PCC content=0.1 wt.%

System	Dose, kg/metric ton	FIRST-PASS RETENTION, % pH=7.5	pH=7.0	pH=6.5
PFR/poly(AM/MPEGMA)* (2:1)	2	43	45[a]	53[a]
PFR/poly(AM/MPEGMA)* (2:1) in 0.005 M Na_2CO_3	2	55	...	...

[a]Acid-tolerant PCC

VI. Comparison of retention of ordinary scalenohedral PCC and acid-tolerant scalenohedral PCC in the presence of PFR/poly(AM/MPEGMA)* (1:2). Data at pH=6.5 and 7.0 used for acid-tolerant PCC, whereas pH=7.5 used for conventional PCC.

DISCUSSION

Compared with clay, latex, or titanium dioxide, calcium carbonate has unusual colloidal properties. Unlike the former colloids, the surface potential and zeta potential of $CaCO_3$ depend on the ratio of calcium and carbonate ion concentrations in solution *(19).* For example, PCC particles placed in distilled water and equilibrated with air produce a suspension with a pH of about 8.6, and the colloidal PCC particles are cationic. If sodium carbonate is added, the surface potential of the PCC particles becomes negative. The situation is further complicated by the series of carbonic acid equilibria, which result in the complete dissolution of PCC at pH < 6.

In very clean pulps, the natural PCC retention should be high, since pulp fibers are negatively charged and PCC is positively charged—a situation that usually leads to spontaneous deposition. For example, Kamiti and van de Ven *(20)* showed that PCC spontaneously deposited onto bleached hardwood kraft pulp; however, detachment was also significant. By contrast, in newsprint and other mechanical pulps, there are sufficient dissolved and colloidal substances to adsorb onto the PCC particles to render them negatively charged *(21).* Thus, a flocculant system that is not neutralized by the dissolved and colloidal substances (DCS) is required for good PCC retention. The cationic CPAM1/CLAY and the experimental nonionic PFR/poly-(AM/MPEGMA) systems appear to fulfill this role. Although these two systems differ structurally, it is believed that both retain PCC by some form of bridging mechanism.

The experimental nonionic PFR/poly(AM/MPEGMA) system proved to be the most effective polymeric flocculant. It is believed that the presence of the dissolved and colloidal substances originating from the wood pulp induced the cationic polymeric flocculants to precipitate and become inactive. The enhanced retention induced by the nonionic polymer was probably due to the lack of association between these polymers and the DCS.

Retention with PFR/poly(AM/MPEGMA) increased when the calcium ion concentration in solution was lowered, either by the addition of sodium carbonate or by using acid-tolerant PCC. We believe that high calcium ion concentrations interfere with the function of the PFR cofactor. This hypothesis will be explored in a future publication.

This work has shown that first-pass retention values as high as 50% can be achieved by the best commercial and experimental polymers. The utility of our results to the paper industry depends upon two important questions:

- Are the retention tests sufficiently severe to have some relevance to a modern paper machine?
- Is the pulp representative?

The DDJ conditions include highly turbulent stirring (1000 rpm); this means that the pulp was exposed to hydrodynamic forces of the same magnitude as a modern headbox *(22)*. The furnish included CTMP pulp brightened with peroxide, which should render it a very difficult pulp in which to get good retention. Finally, high calcium carbonate concentrations (20% based on o.d. pulp) were used; this also increases retention-aid demand. Thus, we believe that the conditions of this study were conservative, and similar results should be possible in the mill.

KEYWORDS

Acrylamide, bentonite, calcium carbonate, copolymers, flocculants, mechanical pulps, newsprint, polyacrylics, precipitates, retention, retention aids.

CONCLUSIONS

We reached the following conclusions based on the experimental results:

- Maximum PCC retention in a challenging mechanical pulp furnish was achieved by using either the experimental PFR/poly(AM/MPEGMA) system or the commercial CPAM1/CLAY system. Over 50 wt.% of PCC was retained by these retention aids compared with 12 wt.% without polymer addition.
- The experimental nonionic PFR/poly(AM/MPEGMA) copolymer system induced maximum PCC retention when used either with acid-tolerant PCC or with conventional PCC at pH 7.5 in the presence of Na_2CO_3. It is believed that the addition of Na_2CO_3 to the system or the use of acid-tolerant PCC reduced the calcium ion concentration in solution, thus allowing the PFR/poly(AM/MPEGMA) system to be more effective.
- The PFR/poly(AM/MPEGMA) copolymer + Na_2CO_3 system induced on average 10% more PCC retention than high-molecular-weight PEO under similar conditions. **TJ**

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