

RETENTION AIDS FOR HIGH-SPEED PAPER MACHINES

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FIFTH-GENERATION MICROPARTICLE CHEMISTRY KEEPS FAST MACHINES IN THE GROOVE.

GAP FORMERS AND DILUTION-CONTROL HEADBOXES HAVE become the standard for high-speed papermaking. Poor dewatering in roll and blade gap formers has been overcome, except for formers producing heavy grammages or production beyond machine design specification. Indeed, the new generation of paper machines has shifted the focus from dewatering to an emphasis on retention and formation.

To achieve good retention at these high-shear conditions, a retention system with greater floc strength is essential. Fifth-generation microparticle retention programs are producing superior retention while maintaining aesthetic sheet properties. This paper highlights the benefits of this novel chemical system and explains how it works.

MICROPARTICLE DEVELOPMENT

Colloidal silica microparticles for use in papermaking were developed and introduced in the early 1980s (1). The first generation of the novel microparticle system was based on a colloidal anionic silica in combination with cationic starch (2). At that time, the system was applied mainly in the fine paper and board segments, where high filler and virgin fibers were used and strength was important. These mills were running either the original microparticle system or a later microparticle development based on anionic bentonite clay and cationic polyacrylamide (3). These initial systems were successful because they provided higher retention levels (especially filler), better drainage, and increased strength. The improved drainage resulted in better formation, higher shear resistance, and a more homogenous sheet (less two sidedness), providing a clear advantage over the single polyacrylamide or dual polymer systems in use at that time.

Today, there are about 300 machines using colloidal silica microparticle (CSM) systems in 25 countries. Most customers are in the fine paper or virgin-board/sack-paper segments. However, during the past 3-5 years, a

broader range of papermaking segments has benefited from the advantages of this technology. Expansion in the range of potential users has been achieved through intense product R&D, application development, and a better understanding of wet-end chemistry and the mechanism of these patented microparticle retention and dewatering systems. The discovery of second-, third-, fourth-, and fifth-generation anionic silica sol molecules has advanced the technology, along with the development of alternative cationic components such as guar gum, polyacrylamides, and highly cationic starches. These advances have opened the door to applications in more difficult papermaking systems, such as LWC (lightweight coated), SC (supercalendered), recycled test liner, and recycled corrugating medium.

MICROPARTICLE MECHANISM

In a CSM system, it is the cationic component (starch, guar gum, or polyacrylamide) that provides the flexibility and the fiber-bonding ability to the system. Thus it is important to have the correct charge prior to the addition of the anionic microparticle. An overly anionic system will suffer bridging problems, while an overly cationic system will be contaminated with unadsorbed cationic components that consume microparticles for no efficient purpose and can even cause deposits.

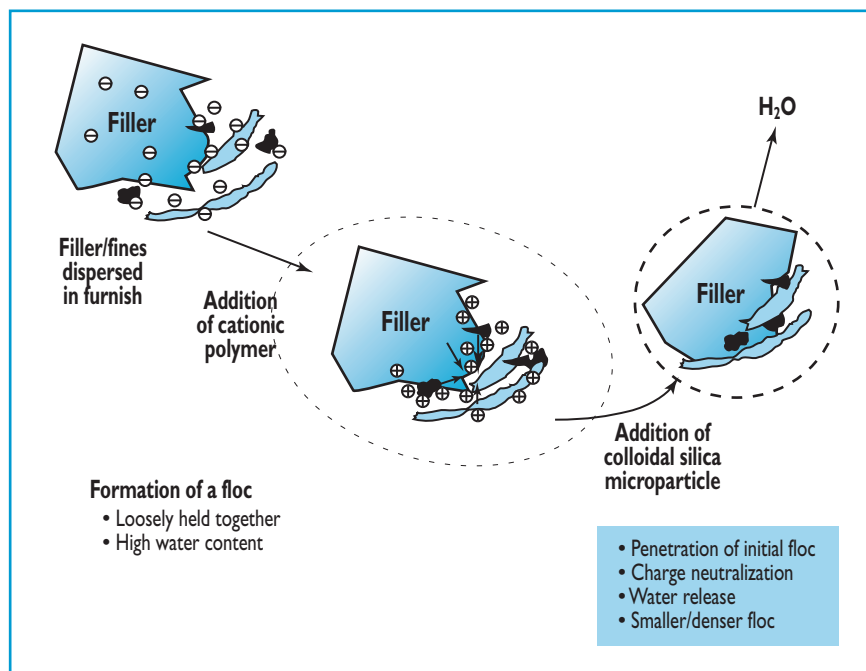
To achieve the full microparticle effect, it is important to find the charge balance in each papermaking system. In most cases, this is easily accomplished, but a full wet-end survey will provide a better understanding of the best application for maximum effect. The starch, polymer, or anionic trash catcher (ATC) is added to the furnish prior to addition of the CSM (4). However, it is often the case that the addition point and the type of starch, polymer, or ATC are more important than the amount added. It is usually possible to achieve an excellent microparticle effect simply by adding enough starch to attain the desired sheet strength. If sheet strength is not an issue—or if the papermaker chooses not to add starch—then the cationic donor should be a cationic

polyacrylamide. Ensuring the optimum chemical addition points and sequence of addition will lead to a favorable adsorption on the fiber and filler surface and a good microparticle effect. Occasionally, an early addition of an ATC is needed to control cationic demand. The choice of ATC is based on the results of laboratory screening and is often an organic polyamine or an inorganic polyaluminum hydroxy chloride.

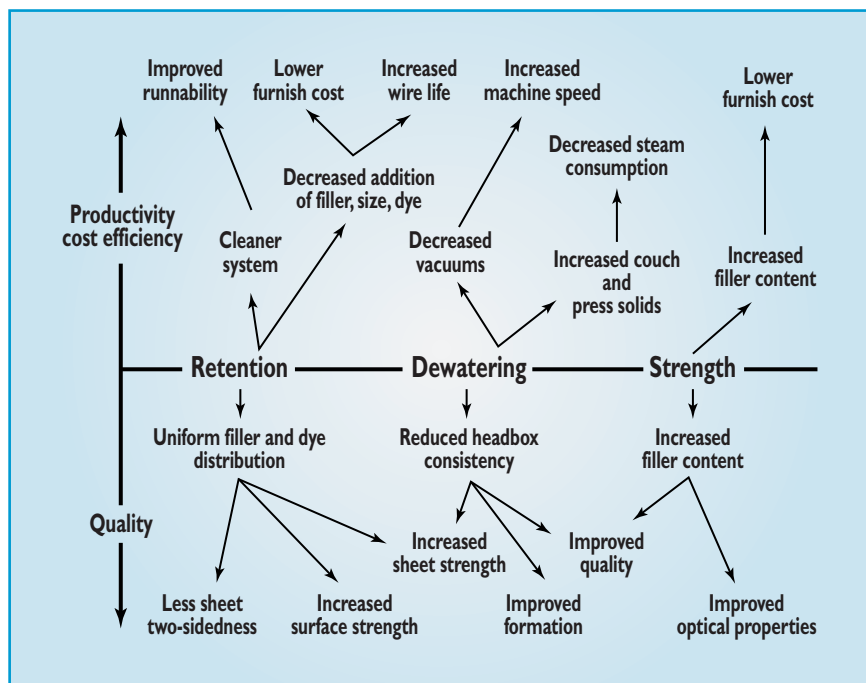
The ATC addition is followed by the addition of cationic starch or polyacrylamide, usually prior to the fan pump or screens, which results in the primary flocculation of fiber, fines, and filler. These initial flocs are broken down when subjected to shear in the pumps and screens, mainly through breakage of starch/polymer chains. These dispersed flocs then react with the anionic silica particles, effecting a rapid consolidation and dewatering of the floc, resulting in smaller, denser, and much stronger flocs. This flocculation process is illustrated in **Fig. 1**.

Microparticle systems have the ability to reflocculate on the wire and in the white water. This is one of the main strengths of microparticle systems, resulting in high shear resistance at high turbulence. The ability of this system to reflocculate will improve the efficiency of water cleaning systems on the paper machine. The reflocculation will also give a wet web with a higher microporosity, making it easier to press and dry. The mechanism that yields the higher microporosity also provides the papermaker with tools to improve formation or sheet strength mechanically. With faster drainage through the wire, the papermaker can increase the level of refining or reduce the headbox consistency, steps that improve strength or formation, respectively. The dewatering power of this microparticle retention system can increase pressing efficiency, often by lowering the couch moisture and through greater water removal in the presses. These features often lead to improved runnability in the press section.

The ability to positively influence retention, dewatering, and strength are fundamental to the significant pro-



1. Initial floc formation with cationic polymer followed by rapid consolidation and densification upon reaction with colloidal silica microparticles

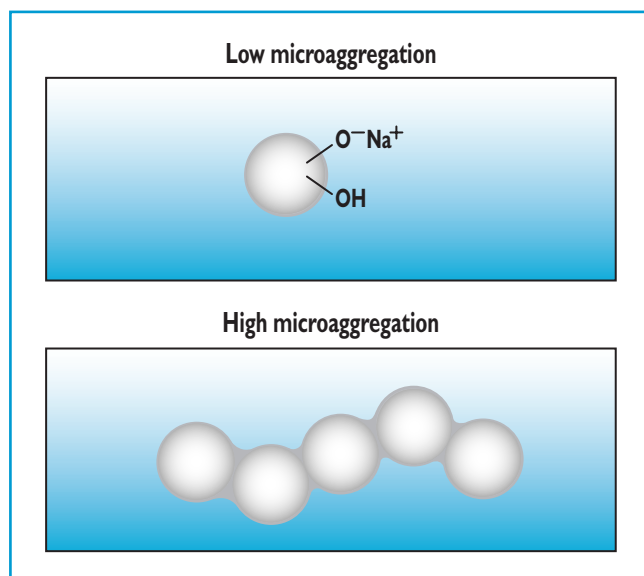


2. Benefits obtained with CSM systems

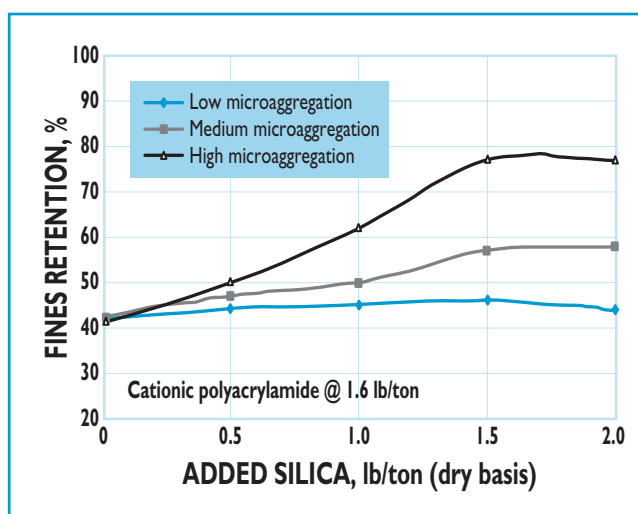
ductivity, cost efficiency, and quality benefits that are commonly realized by papermakers who use the microparticle system. **Figure 2** illustrates the benefits of CSMs in high-shear papermaking systems.

NEW COLLOIDAL SILICA PARTICLE SYSTEM

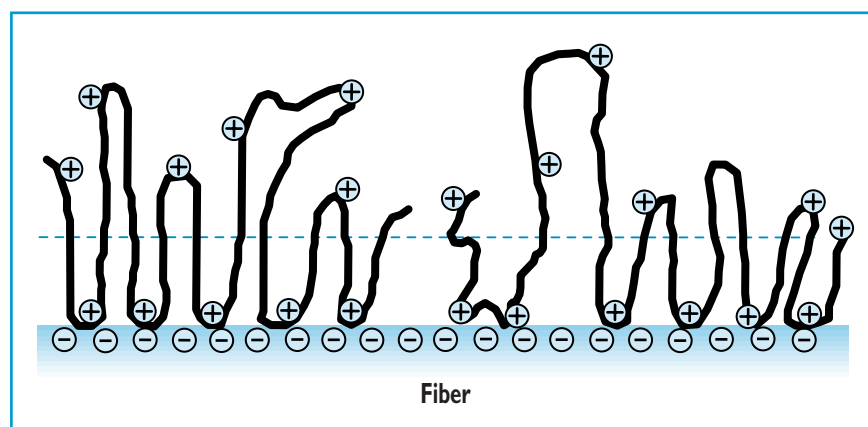
In the original microparticle system, the colloidal anionic silica and cationic starch were applied in combination. In 1992, new types of specially designed structured colloidal silica (high microaggregation) were developed for



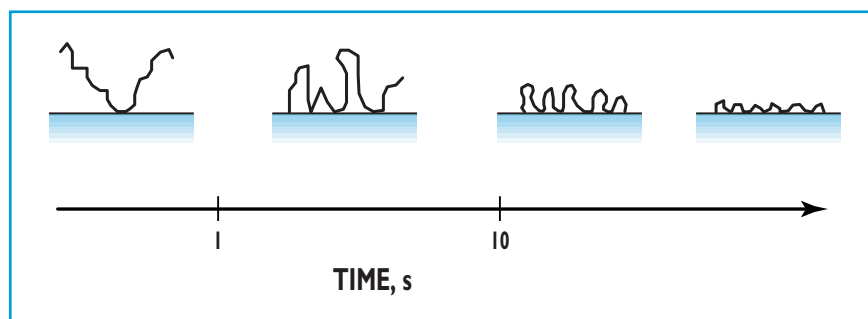
3. Low and high microaggregation of silica



4. Effect of CSM aggregation on reactivity with cationic polyacrylamide



5. C-PAM in active configuration



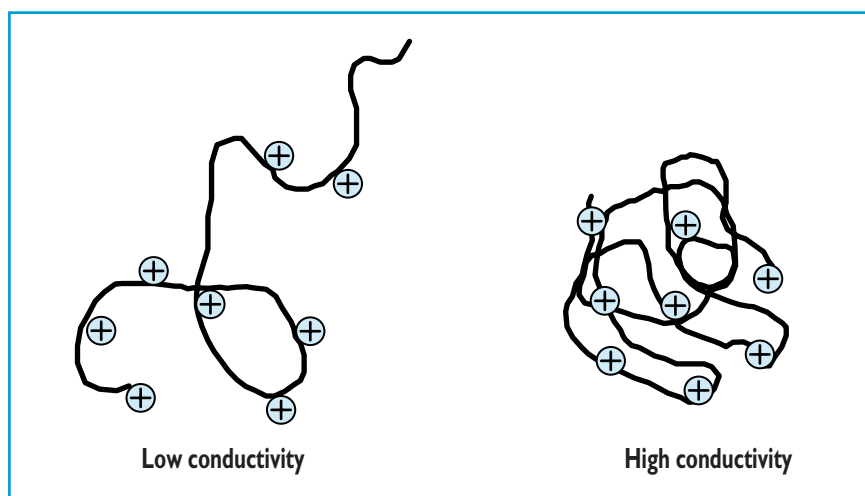
6. Change in C-PAM configuration over time

use in combination with synthetic cationic polyacrylamide (C-PAM). **Figure 3** illustrates the original colloidal silica sol molecules with low aggregation and the more recently developed highly aggregated molecules.

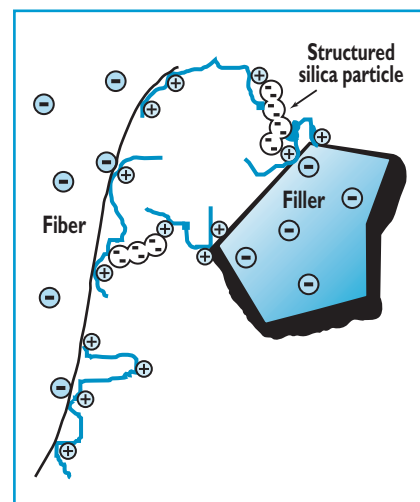
These patented, highly aggregated colloidal silica sol molecules were found to react significantly better in a microparticle system when C-PAM was the other reactive component (5). **Figure 4** shows the reactivity between C-PAMs and CSMs of low, medium, and high aggregation. The primary particle size for the highly aggregated silica is in the order of 2–3 nm with a surface area around 900 m²/g. The bonds between the silica spheres are covalent siloxane bonds that are strong enough to resist breakage by the shear on the paper machine (6).

The synthetic C-PAM has a molecular weight of 4–15 million dalton and a charge density of 2–30 molar percent. Both parameters are of importance when choosing the correct polymer for optimal performance. The level of charge density and molecular weight required by the chosen C-PAM to remain in an “active” configuration depends on the conductivity of the system, the amount of anionic disturbing substances, and its addition point relative

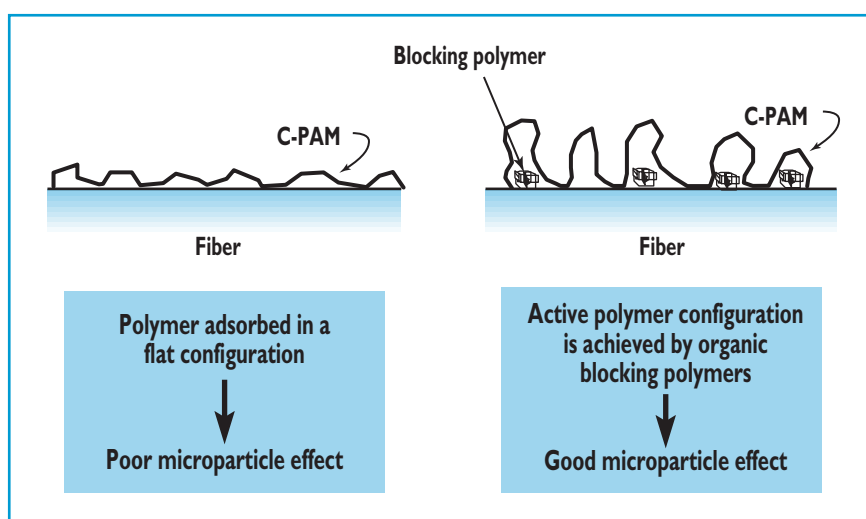
to points of shear in the paper machine approach flow. The higher the speed and shear of the system, the higher is the required molecular weight to counter the increasing interference with the polymer chains, which reduces the possibilities for a good primary bridging flocculation.



7. C-PAM conformation at low and high conductivity



9. Colloidal silica microparticle floc (C-PAM and silica)



8. C-PAM configuration with and without a blocking agent

POLYMER CONFIGURATION

To achieve an effective microparticle flocculation, it is important to have the C-PAM in an “active” configuration. This is optimal when there are many tails and loops extending from the fiber surface, as seen in **Fig. 5**.

The time scale for adsorption onto fiber and filler is less than one second. Following this is a reconfigurative state that can take several seconds, ending with a flatly adsorbed C-PAM, as seen in **Fig. 6**. The flatly adsorbed C-PAM is ineffective for bridging and flexibility. In the time scale of a few minutes, the polymer will be lost through penetration into fiber pores. The preferred configuration can be achieved by manipulating three key factors:

1. Charge density on C-PAM
2. Conductivity of wet end
3. Fiber surface charge.

Under high conductivity conditions, the C-PAM will have a more coiled conformation with a more flat

adsorption, as seen in **Fig. 7**. This can be cured by using a C-PAM with a higher charge density to further increase the interrepelling forces within the molecule.

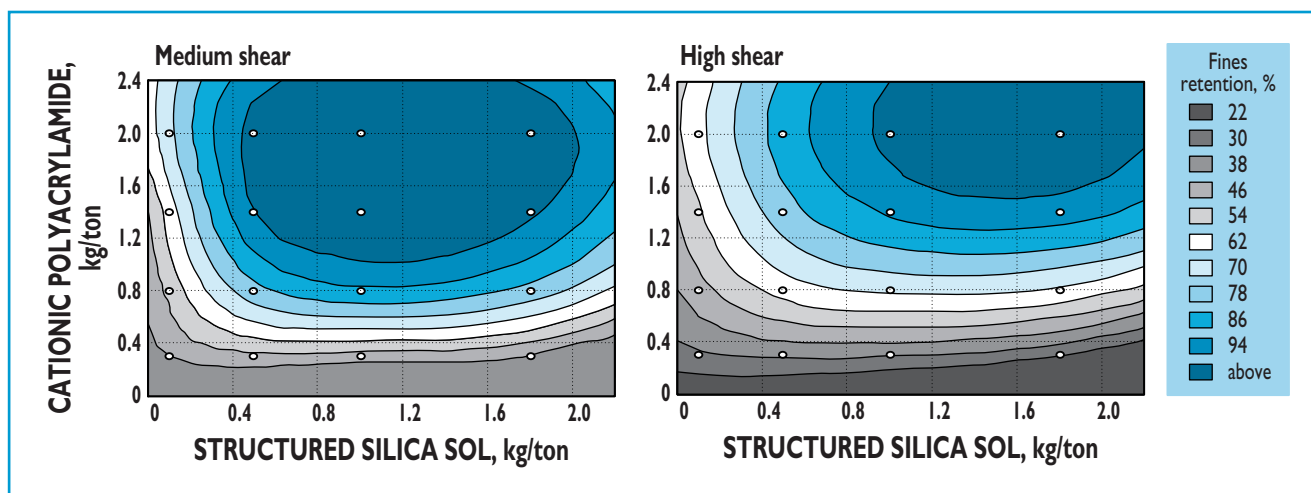
If the fiber charge is too high, a blocking polymer is needed to reduce the electrostatic attraction between the fiber and the C-PAM. The blocking polymer is best suited if it is a highly charged, low-molecular-weight cationic polymer. This use of the blocking agent improves the C-PAM configuration, as seen in **Fig. 8**. When the C-PAM is in an active configuration, the flocculation is more effective, as seen in **Fig. 9** (7).

SHEAR RESISTANCE PROPERTIES

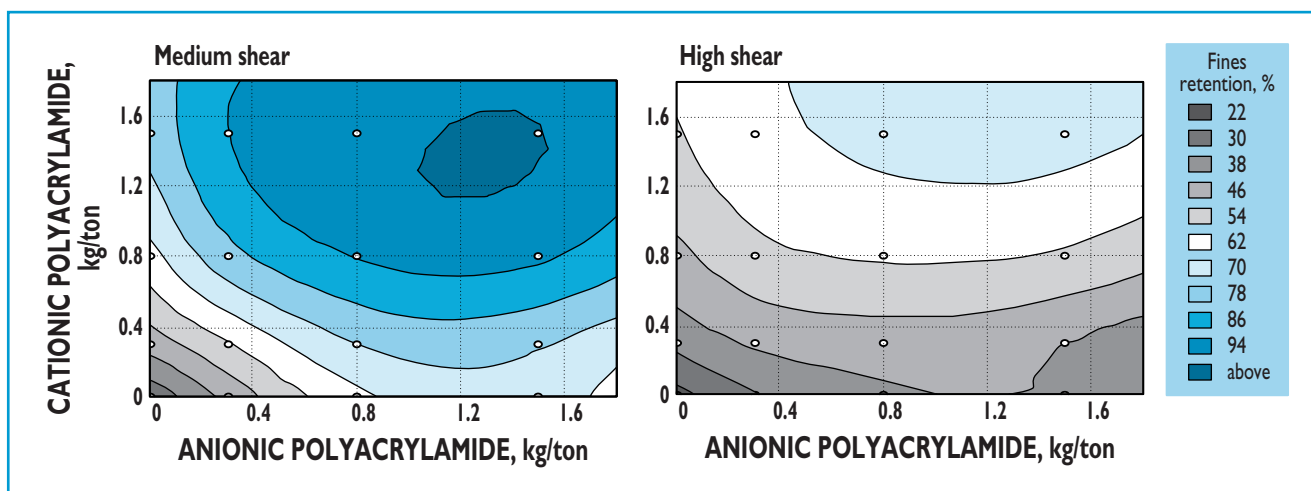
The highest shear and pulses are created in the blade section of the gap former. To simulate and explore the behavior of the new CSM system in the laboratory, floc strength was tested using a Britt dynamic drainage jar (DDJ). Two rotation speeds were used to simulate medium and high shear for a fine paper furnish containing 30% ground calcium carbonate (GCC). The results were expressed as fines fraction retention. **Figure 10** shows the results for the C-PAM/CSM system, and **Fig. 11** shows the results for a dual polymer system consisting of C-PAM and anionic polyacrylamide (A-PAM). Good floc strength is represented by a deep red coloration, while green indicates poor floc strength. The CSM system reveals a much stronger floc strength at high shear.

CASE STUDIES

The following five case studies are all machines with gap forming units running at speeds above 3000 ft/min (three fine paper applications, one waste liner, and one LWC). Cases 1–4 are applications of the new polymer-based CSM system, while Case 5 is a starch-based CSM system.



10. Fines retention (floc strength) for C-PAM and colloidal silica



11. Fines retention (floc strength) for C-PAM and A-PAM

Case 1: Fine paper made from market pulp

Case 1 illustrates some of the possible advantages of the CSM system over a bentonite-based microparticle system. The machine runs at 3200–3900 ft/min to produce many different GCC-filled grades from a furnish of eucalyptus and pine. These grades include printing, copy, and base paper in the range 30–80 lb/3300 ft². Wet-end conditions are pH 7.3, conductivity 900 μ S/cm, Ca²⁺ 40 ppm.

The reference microparticle system consisted of C-PAM in combination with bentonite. Cationic starch and AKD (alkylketene dimer) size were also added to the furnish. This reference system resulted in unstable filler retention and poor runnability. The only change to the reference system was to substitute colloidal silica for the bentonite. The substitution of CSMs produced several important benefits:

- Major reduction in consumption of optical brightening agents (OBA)

- Very good runnability/stability
- Reduction in consumption of C-PAM
- Maintained or improved formation and retention, with first-pass retention (FPR) of 75% and filler first-pass retention (FFPR) of 35%–40% for sheets with grammages of 27–34 lb/3300 ft². FPR and FFPR were 90% and 60%–70% for heavier sheets with grammages of 54–61 lb/3300 ft².
- Reduction of starch in white water.

The OBA consumption for the Case 1 reference system was 1.0 kg/ton at a brightnesses of 90% ISO and 2.5 kg/ton at 94% ISO. With the replacement CSM system, OBA consumption dropped to 0.4 kg/ton at 90% ISO brightness and 1.2 kg/ton at 94% ISO.

Case 2: Fine paper made from market pulp

This machine produces GCC- and clay-filled multipurpose papers from eucalyptus and pine at speeds of 3200–3600

ft/min. Grammage is in the range 40–60 lb/3300 ft². Wet-end conditions are pH 7.5, conductivity 800 µS/cm, Ca²⁺ 70 ppm. The reference microparticle system used a C-PAM in combination with bentonite. Cationic starch and AKD size were also added to the furnish.

The former was having problems with low and unstable FPR and FFPR. A low level of refining was required for runnability reasons, resulting in poor formation. The only change to the reference system was to substitute colloidal silica for the bentonite. The substitution of CSMs produced several important benefits:

- Full refining to excellent formation without runnability problems
- Consistent FPR and FFPR
- Higher filler levels in the finished sheet
- Steam savings of 20–25%.

Sheet ash was 10% for the Case 2 reference system versus 16% for the CSM systems (grammage=50 lb/3300 ft²). Formation went from 70% to 86% (Kajaani).

Case 3: Liner made from mixed waste and OCC

This machine produces liner from mixed waste and old corrugated containers (OCC). The system represents an extreme case, since the wet end is fully closed. About 100–130 gallons of water per ton of liner must be added, which leads to very high levels for COD and conductivity. This creates a very challenging environment for any retention–drainage systems.

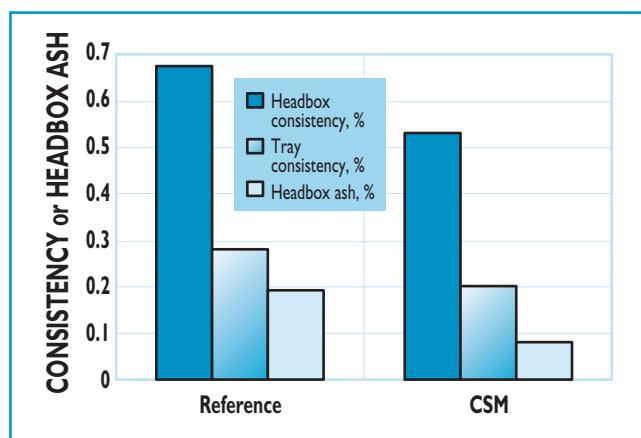
The new colloidal silica retention system combined the microparticle with a blended C-PAM and polyamine. This combination was found to be excellent in lab investigations. The laboratory results translated directly to paper machine performance, providing a solution both technically and economically. The modified retention system provided the following benefits:

- Increase in FPR (from 40% to 70%)
- Better formation because of lower headbox solids
- Improved sizing
- Increased production (runnability and drainage).

For the Case 3 reference system, FPR was 40% and headbox solids were 18 g/L. With the CSM system, FPR went up to 70% and headbox solids went down to 15 g/L.

Case 4: LWC made from SGW

This twin-wire fourdrinier produces LWC from stone groundwood (SGW) and clay at a speed of 3750 ft/min. The reference additives in this acid system were cationic starch, alum, C-PAM, and bentonite. Changes to both the C-PAM type—molecular weight and charge density—and



12. Headbox and tray solids for Case 4 reference system and CSM system

microparticle type were decisive in achieving significant performance benefits:

- 25% reduction in wet-end breaks
- Increased FPR and FFPR
- Increased Scott bond at 20% lower starch addition
- Improved saveall, solids reduced by 45%
- 60% reduction in headbox ash.

Selected results for the Case 4 reference system and the replacement CSM system are presented in Fig. 12.

Case 5: Uncoated fine paper

This is a case with the traditional CSM system based on starch and colloidal silica. The paper machine is a gap former with a speed of 3550 ft/min. Despite the high shear and turbulence, the cationic starch is performing well.

Uncoated fine paper at neutral pH has long been produced on slow fourdrinier paper machines using retention systems containing cationic starch and A-PAM. However, this approach was not up to the task on the gap former.

The successful approach was to replace the A-PAM with a low aggregated colloidal silica sol. The introduction of polyaluminum chloride (PAC) boosted colloidal retention and stabilized the system charge. In this case, the benefits were:

- Increased speed
- Increased stability/runnability
- Increased filler level (from 9% to 15% on 35 lb/3300 ft²)
- Reduced consumption of ASA (alkene succinic anhydride) and cationic starch
- Improved formation
- Production records
- Increased FPR and FFPR.

Machine speeds for the Case 5 reference system varied from about 3330 ft/min to 3380 ft/min, depending on grammage. With the CSM system, machine speed increased by about 100–170 ft/min.

CONCLUDING REMARKS

Field results show that retention systems consisting of C-PAM and a new anionic structured colloidal silica sol can perform well at the high shear conditions on today's modern gap former machines. Moreover, advances in colloidal silica technology have made it possible to use starch-silica systems on high-speed gap formers. However, it is essential that mills evaluate the use of an anionic trash catcher and blocking agent prior to application of the selected C-PAM. With the right charge conditions prior to the silica addition, optimal performance can be obtained. **TJ**

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