IMPROVING THE PAPER RECYCLING PROCESS OF OLD CORRUGATED CONTAINER WASTES

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Received October 23, 2013

Recycling of waste paper is a reasonable response to continuity of raw material in the paper industry, as well as to environmental concerns. However, the quality of recycled pulp and the efficiency of the process are of great importance. Benefitting from emerging technologies can be of much help. Recent developments regarding the application of nanotechnology in the pulp and paper industry are suggesting new horizons in this area. A full scale applied example of using nanoparticles in papermaking is the well-established system of nanosilica with cationic starch. This system is now successfully used as a drainage/retention aid in plenty of paper mills using virgin pulps. Applying this system in the paper recycling process, which involves more complicated wet end (i.e. higher cationic demand and conductivity), seems to be less favorable, however results show this system can be useful in increasing fines retention up to 39% and drainage up to 42% in high basis weight recycled paper produced from old corrugated container (OCC), therefore improving machine speed, reducing energy consumption (in press or dryer sections) and increasing the productivity of the whole papermaking system. Moreover, the role of zeta potential as an indicator of system interactions was also monitored. Because of the special characteristics and behavior of nanosilica in this system, zeta potential did not show a direct correlation with system efficiency (drainage/retention).

Keywords: paper recycling, nanosilica, cationic starch, OCC, zeta potential, productivity

INTRODUCTION

Raw material shortage in the paper industry as well as environmental concerns and economical aspects are driving forces toward the continuity of paper recycling.[1] Among various waste paper grades, old corrugated container (OCC) has a considerable share.[2] Nowadays, test-liners are made of 100% recycled OCC pulp. However, there are some problems such as low drainability in high basis weight papers and high percent of fines content in the recycled pulp. A large improvement in drainage will cause a significant increase in machine speed, reduce energy consumption in the press/dryer sections, increase the productivity of the whole papermaking system and, on the whole, will decrease the costs. In view of this, one of the emerging technologies that can be of much help in the future development of the pulp and paper industry is nanotechnology.

Papermaking industry is already a leader in terms of the amounts of nanoparticles used.[3] In this respect, colloidal silica nano-sized particles have been extensively applied in papermaking.

Papermakers employ nanosilica and related products to promote dewatering and fine-particle retention on hundreds of paper machines, and yet there are many areas of this technology that are unknown to papermakers.[4] The cited dimensions of these approximately spherical particles imply that their specific surface area should lie in the range of about 500-3000 m^2g^{-1}, meanwhile highly swollen fiber can have surface areas as high as about 200 m^2 g^{-1}.[3]

The surface of silica can be described as acidic, meaning that protons dissociate from silanol groups, leaving behind a negative charge (Figure 1).

On the other hand, cationic starch is a well-known dry strength additive, which is widely used in the papermaking wet end. It can also act as a part of nanoparticle drainage/retention system. Silica nanoparticles can penetrate the branched amylopectin structure in the starch. The system is also able to initiate a charge neutralization mechanism, resulting in very strong association of the finer material with the fiber to provide excellent drainage and retention.

Drainage improvement is the main observable symptom of applying a nanoparticle system in wet end, especially in the case of paper board machines. Simultaneously, retention is a critical factor to control the cost of raw materials, paper machine runnability, as well as the quality of the end products. Hubbe suggested that retention and drainage increased by addition of micro and nanoparticles to the wet end system.[4] He indicated that microflocculation may be the main reason of this phenomenon. The author proposed two mechanisms for microflocculation: "semi-reversible bridging" and "contraction-deswelling" (Figs. 2 and 3).

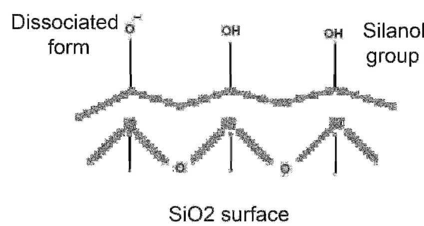

Figure 1: Schematic of the surface of silica particles[4]

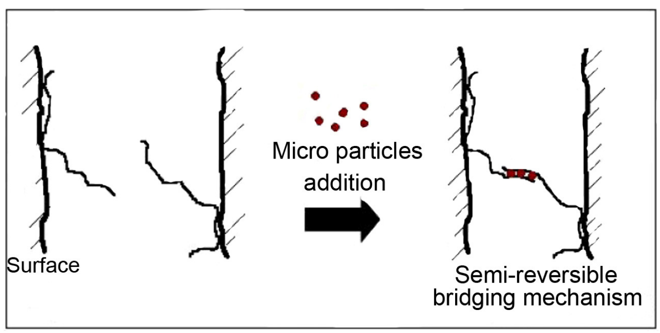

Figure 2: Schematic explaining semi-reversible bridging theory[4]

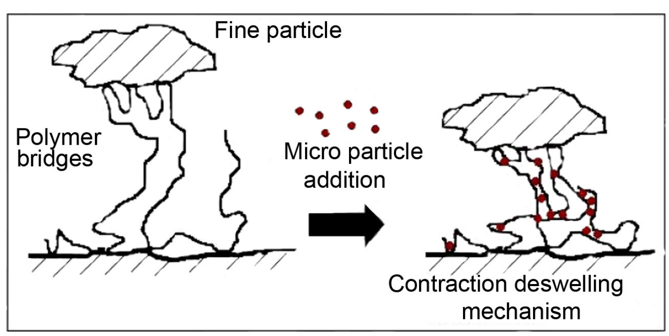

Figure 3: Schematic explaining contraction-deswelling theory[4]

Moberg proposed that colloidal silica is physically small enough to enter the amorphous structure of the cationic starch in solution to neutralize the starch cationic charge, thereby compressing the electrical double layer, a prerequisite for retention.[5] Aloi and Trksak postulated that a proper ionic concentration from anionic microparticles near electrically neutral plane is a precondition for microflocculation (coagulation), thus retention.[6] Solberg and Wagberg proposed that the contraction is based on replacing weak hydrogen bonds with strong ionic bonds, thus collapsing the flocs under its own weight, a reason for enhanced dewatering.[7]

Au *et al*.[8] and Scott[9] indicated that retention is a main factor that is indicative of process efficiency and papermaking machine efficiency. They believed that poor drainage would cause more energy consumption, decreasing productivity and leading to poor formation etc.

On a laboratory scale, various studies focused on applying nanoparticles for formulating the wet end system.[10,11,12,13] Also, at a full scale, many reports discussed the optimum conditions and efficiency of the system.[14,15,16] Carr reported that using silica nanoparticles with cationic starch or cationic polyacrylamide improves the efficiency of the paper machine, even in the case of ground wood pulps containing too much interfering anionic substances.[17]

In this study, a nanosilica-cationic starch system was used in OCC recycling to produce test-liner, which is a high basis weight paperboard mainly made of recycled fiber containing too much fines. Producing a high basis weight paperboard with high content of fines and short fiber fractions surely brings about severe problems with retention and drainage. In this respect, the nanoparticle system is expected to be of much help, although some problematic factors, such as presence of anionic trashes and high conductivity in the furnish which are also affected by the water system closure concept, can interfere with the process.

EXPERIMENTAL

Recovered OCC was collected from Kaveh paper mill in Iran. The OCC samples were cut into pieces and soaked in tap water for 24 hours. Repulping was done with 4% consistency for 30 minutes at 200 rpm in a BALDOR AC INVENTOR repulper. Disintegrating and refining was performed according to SCAN-C 25:76 method in a laboratory VALLEY beater, up to 300 mL Canadian standard freeness (CSF).

To determine the drainage of the pulp, an L&W CSF tester was used according to TAPPI T227 om-99 method. The addition of chemicals and determining fines retention was done in a Dynamic Drainage Jar (DDJ) at 0.54% consistency. For this purpose, firstly polyaluminum chloride (PAC) was mixed at 1000 rpm for 30 seconds, then cationic starch was added at the same mixing rate for 45 seconds. Nanosilica was the last additive, which was dosed at 800 rpm and mixed for 15 seconds. Zeta potential was determined by MUTEK SZP 06. The cationic starch used in this study was modified Tapioca starch (with the trade mark of ExcelCat 110), which was supplied from Siam Modified Starch Co., Thailand. The D.S. of cationic starch was about 0.016-0.020 mol/mol. The anionic nanosilica sol product (NP 882) with high specific surface area and average diameter of 2-5 nm along with polyaluminum chloride (PAC), which is a common anionic trash catcher (ATC) containing 10% Al_2O_3 equivalent, were purchased from Eka Chemical Company. The amount of PAC was constant in all treatments at 0.2% rate. The pH of the pulp was set at 6 before adding the chemicals and the conductivity of the suspension was about 750 µS/cm.

RESULTS AND DISCUSSION

Cationic starch as a wet end component

Cationic starch is an important dry strength additive. As a wet end component, adding cationic starch slightly increased drainability and fines retention (Figures 4 and 5). In wet end chemistry, zeta potential has an important role in the interactions among the particles of a pulp suspension. Monitoring the zeta potential revealed that zeta potential in OCC pulp was about -16.2 mV, but following the addition of 1% or 1.5% cationic starch it was increased to -11.2 and -7.27 mV, respectively. Cationic groups associated with starch, attract the anionic groups available in the pulp suspension (anionic groups on fibers, anionic trashes etc.), thus pushing the zeta potential toward the isoelectric point. The resulted graphs confirmed other investigations.[18]

Note that one of the interfering factors affecting starch attraction is the conductivity of the furnish, which is as an indicator of the amount of ions competing with cationic starch in the attraction to the anions of the fiber surface. On the other hand, high conductivity does not allow cationic starch to spread out well in the suspension for better performance.

Au and Johansson summarized the back water analysis of a typical waste paper mill.[8] They reported that in a waste paper mill with 25 m^3/ton fresh water consumption, the conductivity should be about 520 µS/cm. As it is believed, conductivity will have considerable harmful effects on cationic starch adsorption, when it is higher than 1200 µS/cm.[19] Therefore, it seems that between these two conductivity limits, a wide variety of paper recycling mills are able to get benefits of nanoparticle based wet end systems, which also use cationic starch as a component.

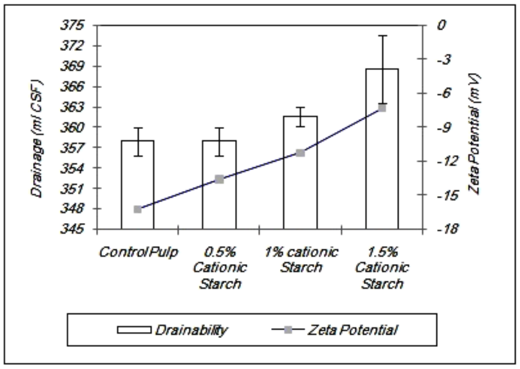

Figure 4: Effect of different dosages of cationic starch on drainage and zeta potential

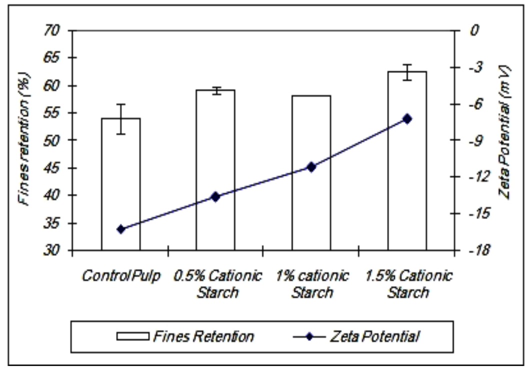

Figure 5: Effect of different dosages of cationic starch on fines retention and zeta potential

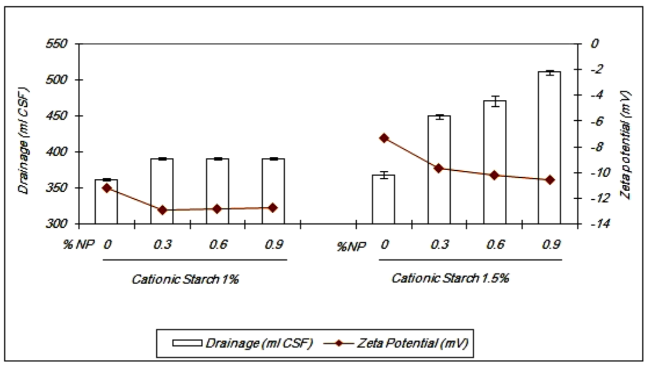

Figure 6: Effect of cationic starch-nanosilica on drainage *versus* zeta potential (NP: nanoparticle dosage)

Drainage gains in nanoparticle system

At a high basis weight paper, such as test liner, drainage improvements yield many advantages for a paper mill, such as increase in machine speed, reduction of energy consumption in the press/dryer sections, increase in the productivity of the whole papermaking system and, on the whole, a decrease of the costs. As observed above, the addition of 1% or 1.5% cationic starch (without nanosilica) into the furnish, only increased the drainage of the control pulp (358 mL CSF) to 362 and 369 mL CSF, respectively (Figure 4), while introducing 0.3% nanosilica to 1% cationic starch increased the drainage to 391 mL CSF. This interaction between nanosilica and cationic starch was able to increase drainage to 511 mL CSF in the case of 0.9% nanosilica to 1.5% cationic starch. This means an about 42% drainage gain for a board mill with back water conductivity of about 750 µS/cm (Figure 6).

Here, there was a point that for 1% cationic starch the drainage did not benefit from higher dosages of nanosilica, whereas in the case of 1.5% cationic starch, there was a considerable difference among 0.3, 0.6 and 0.9% nanoparticle dosages. This indicates that the ratio of nanosilica to cationic starch is a critical factor for the interaction between nanosilica and cationic starch, and thus for the drainage.

It seems that when the components of the system were dispersed due to shear forces, the penetration of nanosilica particles through the floc structure and the interaction with cationic starch may cause reflocculation and result in tiny dense flocs. The relation between this concept and drainage improvement is schematically explained in Figure 7.

A fascinating result was that especially at 1.5% cationic starch, although the zeta potential got more negative, the highest drainage value was achieved. This finding (i.e. the highest drainage gain at farther distances from the isoelectric point) indicates that the interaction between nanosilica and cationic starch seems to be the rule of thumb, rather than the effects of electrical double layer theories. On the other hand, it can be noted that the electrical double layer theories are still proposed as the driving force for many wet end systems that are not based on nanosilica-cationic starch interactions.[18]

Effect of the cationic starch-nanosilica system on fines retention

The recycling process contributes to the generation of more fines. Refining of recycled pulp also adds up to the amount of fines present in the pulp. Therefore, as recycling is repeated in several cycles, fines will constitute the larger part of the furnish.

The retention of fines in the structure of the produced paper will increase the productivity of the paper machine, while preventing a high load on save-all and lower biological oxygen demand (BOD) of the effluents. Also, fines play an important role on the strength of paper due to their sizes, as well as their capability for more binding, especially in the case of secondary fines.[9,20] As previously mentioned, the addition of cationic starch by itself (at the highest dosage of 1.5%) increased fines retention up to 62% (Figure 5), while introducing nanosilica made it possible to improve it as high as 75% (Figure 8).

Dosing of 0.3% and 0.6% nanosilica to 1% cationic starch increased the fines retention from 58% in blank samples to 60% and 64%, respectively; however, a higher dosage of nanosilica was not effective. At 1.5% cationic starch, the more nanosilica was added (up to 0.9%), the more fines were retained, as the maximum retention was observed for a suspension with 1.5% cationic starch and 0.9% nanosilica at 75%. Here, it seems that, as indicated for drainage, in fines retention the ratio of nanosilica to cationic starch is again the critical factor.

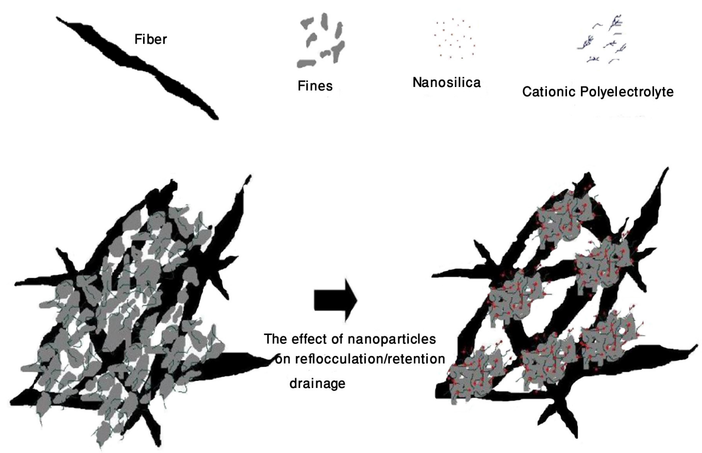

Figure 7: Schematic explanation of how nanoparticles may improve the drainage

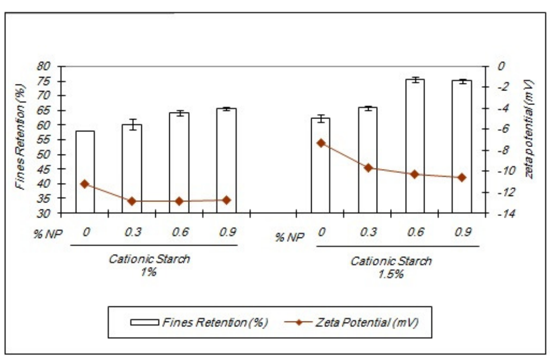

Figure 8: Effect of cationic starch-nanosilica on fines retention *versus* zeta potential (NP: nanoparticle dosage)

CONCLUSION

This study showed that using cationic starch-nanosilica, which is widely used for virgin pulp, can be of much help in producing test liner from OCC, although the conductivity of the pulp suspension is not very low (i.e. about 750 µS/cm).

This system had remarkable effects on some important processing criteria, such as drainage and fines retention. The drainage is especially important for paper products with high basis weight. An improvement in drainage may increase machine speed, reduce energy consumption in the press or dryer sections and increase the productivity of the whole papermaking system. The drainage is the bottle-neck for paperboard machines. This wet-end system was able to improve the drainage up to 42.7% (358 mL in control pulp whereas 511 mL in 1.5% cationic starch plus 0.9% nanosilica).

In the case of fines retention (first pass retention of fine fibrous materials), up to 39% improvement was achieved (53.9% in control pulp, whereas 75.09% in 1.5% cationic starch plus 0.9% nanosilica). This gain means retaining more fibrous material on the wire, which yields in higher productivity while preventing a high load on save-all and lower BOD of the effluents.

For explaining the mechanism, it may be proposed that silica nanoparticles can penetrate the branched amylopectin structure in the starch. The system is also able to initiate a charge neutralization mechanism, resulting in very strong association of the finer material with the fiber to provide excellent drainage and retention (Fig. 7). In this respect, it was observed that the highest drainage or retention was gained with higher dosage of nanosilica, while the zeta potential of the system farther distances from the isoelectric point. This may indicate that the ratio of nanosilica to cationic starch is a critical factor for the interaction between nanosilica and cationic starch, and thus for the drainage or retention.

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