

Alkenyl Succinic Anhydride (ASA)

JEROME M. GESS AND DOMINIC S. RENDE

Alkenyl succinic anhydride (ASA) was added to the agents that would increase the resistance of cellulose fibers to the adsorption of water under neutral/alkaline conditions (at pH's in the range of 7.5-8.5) in the 1960's by O. Wurzburg and E. Mazzerella of the National Starch and Chemical Company [1]. The sodium salt of ASA can be complexed with alum in a similar manner to resin acids to size in acid papermaking. Furthermore, commercial ASA products are also being used in acid papermaking, pH 4.5-6.5, in the manufacture of recycle linerboard, fine paper, roofing and molded products. The development of ASA gave papermakers an alternative to AKD (alkyl ketene dimer), a product that had been developed by C. Weissgerber of Hercules Chemical Company [2].

Both materials are applied to cellulose fibers in the form of cationic dispersion prior to the fibers being formed into a web, pressed and dried. The two sizing agents have helped papermakers make the transition from acid papermaking using clay as the primary pigment to neutral/alkaline papermaking using calcium carbonate.

Note: This paper is Chapter 9 from *The Sizing of Paper, Third Edition*, edited by J.M. Gess and J.M. Rodriguez.

BACKGROUND AND THEORY

O. Wurzburg had developed the use of a C-8 version of ASA to prepare a hydrophobic starch with the trade name "dry-flo". ASA itself had originally been developed and marketed as a water absorbent addition to transformer oils as it reacted readily and rapidly with water and active hydrogens. The reaction converted the ASA into a di-acid containing the water (Figure 1). The di-acid that was formed was oil soluble. Thus the water was therefore removed from the transformer oil without hurting the transformer insulating qualities of the oil.

The original version of ASA was the product of the ene reaction of maleic anhydride with a mix of wax cracked olefins with a range of C-15 to C-21 (not less than 95% by mass) carbon chain length (Figure 2). All of the ASA products are water insoluble liquids and are normally emulsified with cationic starch immediately before its addition to the papermaking system. Other emulsification systems have been tried. Emulsification systems with cationic synthetic polymer are available. They are a commercially viable alternative to starch and they are used where cationic starch technology is neither available nor economical to sustain [14].

It is a known fact that ASA, when applied to cellulose fibers, will impart a measure of resistance to the sorption of water when the treated fibers are made into paper. There are two important theoretical questions to be asked regarding the use of a size emulsion such as ASA in the papermaking process:

The mechanism of the distribution of the ASA through the cellulose fibers in a papermaking furnish. The initial reaction of a cationic ASA emulsion with cellulose leads to an ionic attraction of the ASA droplets onto the cellulose fibers and other furnish components in a non-dispersed form as clumps of discrete particles. The ASA must then be uniformly distributed through the cellulose and react with the cellulose for it to be an effective sizing agent.

The mechanism by which the ASA reacts with and is oriented on the cellulose fibers to impart sizing or the resistance of the cellulose fibers to water.

THE DISTRIBUTION OF ASA THROUGH A PAPERMAKING SYSTEM

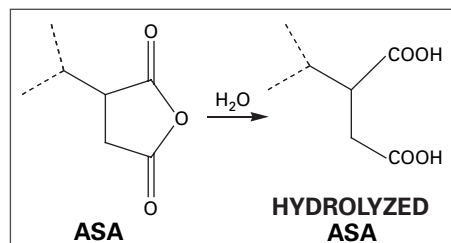
It has been hypothesized that those sizing agents (rosin acid, ASA and AKD) that have been deposited onto fibers from an emulsion

distribute themselves through a mass of papermaking fibers (a web that will become paper upon pressing and drying) via a process that has been called, "sintering" or melt and flow [3]. This hypothesis states that the sizing agent melts in the heat applied to a paper web in the dryer section of a paper machine and flows from fiber to fiber. As the sizing agent melts and flows, it reacts in a manner that orients the hydrophobic tail of the sizing agent away from the fiber. In the case of solid sizing agents such as rosin acid and AKD, it was assumed that the key to the re-distribution of the sizing agents was the glass transition temperature of the sizing agents. The lower the glass transition temperature of the sizing agent, the greater was the probability of the sizing agent melting and flowing to a uniform distribution through the papermaking web.

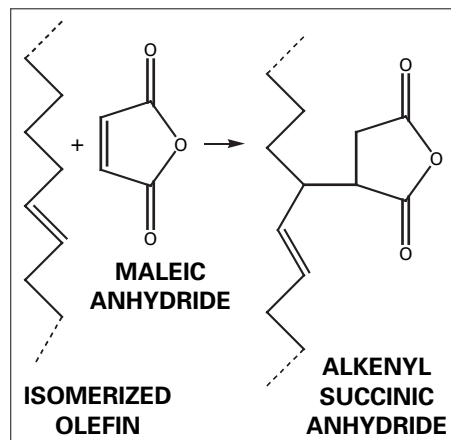
ASA, unlike rosin acid or AKD (alkyl ketene dimer-alkyl-based products) is a liquid at room temperature. Therefore the melting part of the "sintering" hypothesis did not apply, but it was assumed that the flow part of the hypothesis did apply.

However, when Gess found rosin in the hood of at least one paper machine [4], and there was another report of ASA in the hood of a paper machine [5], the "sintering" hypothesis became untenable. As there was a gap between the papermaking web and the hood, there was no way for the size to "flow" from the fibers to the hood. One argument that did have some validity was that the sizing agents had been deposited on cellulose fines and these fines migrated out of the web by the pocket ventilation and vacuum system in the dryer section of the paper machine. When this occurred, changes in the airflow decreasing the release and flow of fines to the hood decreases the amount of rosin in the hood. This accounted for some of the rosin found in the hood of a paper machine, but it did not account for that rosin found unassociated with cellulose fines. Therefore, the rosin/fines hypothesis did not account for all of the rosin that was found in the hoods of paper machines.

An alternative hypothesis was proposed by Gess [6]. In this hypothesis, it was proposed that the sizing agent migrated via either the vapour phase or via steam distillation (i.e., on particles of water). It was hypothesized that the sizing agent



1. The hydrolysis of ASA.



2. The preparation of ASA by the ene reaction between an isomerized olefin and maleic anhydride.

could go into the vapour phase and re-deposit on another fiber. The lower the vapour pressure of the sizing agent, the faster would it migrate through a papermaking web. Therefore, in this hypothesis, the rate of migration of a sizing agent through a papermaking web would depend on:

- The vapour pressure of the sizing agent.
- The bond energy between the sizing agent and the substrate.
- The distance the sizing agent would have to travel to achieve a uniform deposition through the fiber mass.
- The energy available for this process to occur.

Some positive evidence for this hypothesis was shown in a study carried out by Gess [7] with rosin acid. His work indicated that the aluminum moiety of alum formed a stronger bond with the sizing agent (rosin) than did the cationic centers in high cationic charge density, low molecular weight polymers. Hercules corroborated this to some extent by their use of cationic, hi-charge density, low molecular weight polymers to accelerate the development of sizing of AKD.

In another study, Gess [8] studied the loss of sizing with time in a butt roll of paper, where the fibers had been treated with ASA. The HST (Hercules Size Test) of the paper was 15 seconds. He found that the outer layers of the roll had zero sizing. However, as he cut into the layers of the roll, sizing increased. At the fifteenth layer, sizing was normal. One possible explanation for this was the migration of the sizing agent out of the roll. An alternative explanation was that the moisture in the air, broke the bond between the ASA sizing agent and the cellulose fibers and it was this that led to the loss of sizing in the surface layers. The deeper the layer, the less was the potential for the reaction of moisture.

The advantage of ASA over the other available sizing agents is the fact that it develops 80%+ of its sizing before the web comes to the size or metering press of the paper machine. This allows the papermaker to bring the web into the size or metering press at moisture levels in the range of 4-8%. This can be important for it decreases the amount of energy used in the dryer section of a paper machine and this decrease can be taken either as an increase in production rate or as steam savings.

THE REACTION OF A SIZING AGENT WITH THE CELLULOSE SUBSTRATE

The development of sizing in a papermaking web is a two-part process. The uniform distribution of the sizing agent through a web of paper is but the first part of this process. After or while the sizing agent is re-distributing itself through the paper web, it must react with the elements of the papermaking furnish in a manner that causes the hydrophobic tail of the sizing agent to orient away from the cellulose.

It had been hypothesized that ASA reacts with the cellulose to form an ester as is shown in **Figure 3**. The primary evidence for the formation of the ester is the work of Roberts at U.Mist [9]. Robert showed that ASA formed an ester with one of the hydroxyl groups of the glucose moieties of the furnish. Glucose is a component of cellulose. The problem with this work is that the ASA used in the studies was emulsified with cationic starch. Cationic starch also contains glucose. More important, the glucose in the

starch helix is easier to react than is the glucose in the cellulose helix. Therefore, although the evidence does show the reaction with glucose, the source of the glucose (starch or cellulose) is not identified.

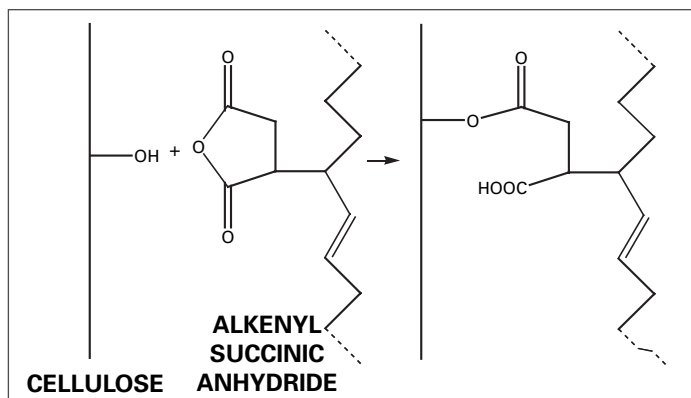
The available evidence relating to the possible reaction of ASA with cellulose can be summarized:

The work of Wurzburg at National Starch and Chemical Company as was noted earlier. He found that the addition of a C-8 ASA (the ASA used in papermaking is a C-16 to C-18, C-18, C-20 to C-24 or C-20 olefin based material,) to starch produced a starch that repelled water. This starch, known as "Dri-Flo" is marketed. Wurzburg assumed that the ASA reacted with the starch to give the ester.

The work of Cuculo [10]. Cuculo, at North Carolina State University, attempted to react succinic anhydride with cellulose. He was attempting to make a material that could be used in place of CMC (carboxy methylcellulose). He found that high temperatures were required for this reaction to occur. The temperature required would cause the cellulose to deteriorate. He was able to lower the temperature by converting the anhydride to an amic acid. However, even this required a temperature that was higher than that available in the dryer section of a paper machine.

ASA self-emulsified in water, hydrolyses rapidly as is shown in **Figure 4 and 5**. This emulsion becomes unusable as a sizing agent within 5-10 minutes. Further that ASA deposited from an emulsion onto cellulose that is not retained and is re-cycled hydrolyzes rapidly.

ASA emulsified in cationic starch has a definite shelf life. The exact length of this shelf life is not known, but in one documented instance at the Dryden Paper Company in Dryden, Ontario, the ASA/cationic starch emulsion was viable after sitting in a tank for 12 hours [11]. The mill was unable to discard the tank of the ASA/cationic starch emulsion and therefore used it in the production of paper. The efficiency was not measured, but the use of the emulsion did produce a paper that was resistant to the sorption of water. Therefore, there would appear to be a difference between the ASA in a cationic starch emulsion and ASA that is not in close contact with cationic starch.



3. The esterification reactions of ASA with cellulose.

The evidence would tend to indicate that:

- ASA will react with the glucose moieties in paper.
- However, the glucose moiety that reacts with the ASA may not be that from cellulose.
- The potential reaction of ASA with a glucose moiety in paper is that with the glucose moiety of starch.
- The cationic starch reacted with the ASA deposits and coats the surface of the fibers with the hydrophobic tail of the ASA oriented away from the fibers.

Again, the mechanism by which sizing occurs is in dispute. What is not in dispute is the fact that fibers treated with ASA and formed into a web and dried come to the reel of a paper machine "sized". This is all that a papermaker needs to know. The mechanism is potentially interesting, but the result is a known and is used by papermakers.

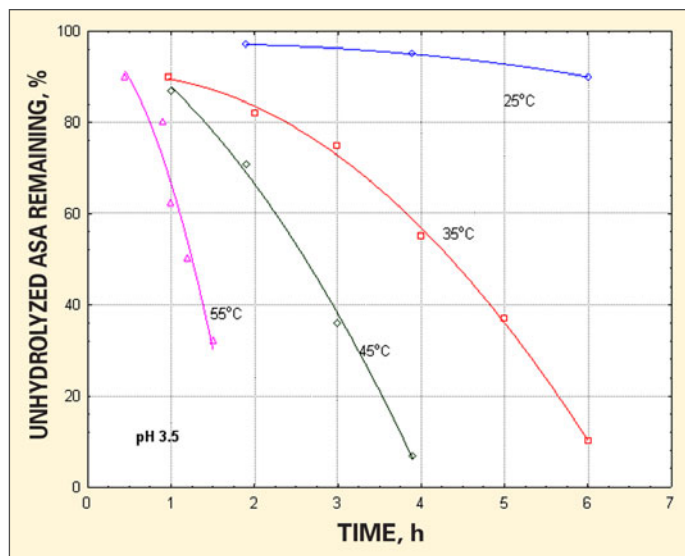
THE USE OF ASA

The Purchase and Storage of ASA

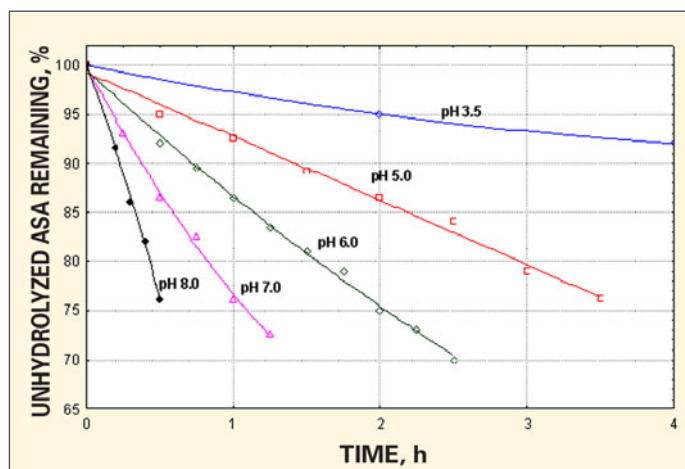
Two basic varieties of ASA are available at the present time:

- An ASA that is primarily composed of linear C-16 isomerized carbon chains.
- An ASA that is a mix primarily of C-16 to C-18 partially branched and isomerized carbon chains
- An ASA that is primarily composed of C-18 carbon isomerized chains.
- An ASA that is primarily composed of linear C-20+ isomerized carbon chains.

Both products are liquids and are sold and received as 100% solids products. The C-18 product is preferred where a mill has problems with the potential steam distillation of the ASA in the dryer section of a paper machine. The C-18 product has a lower vapour pressure than does the mixed product and thus will have less of a tendency to steam distill. A mill has a potential steam distillation problem when the web coming into the dryer section of a paper machine has a high moisture content and the mill wishes to remain at a relatively high production rate. In this situation, the mill generally, increases the use of steam in the first dryer section of the paper machine and this increases the potential for the steam distillation of the ASA. Recent advances in ASA technology have commercially introduced a C-20 to C-24 olefin-derived ASA with potential advantages in both vapour



4. The effect of temperature on the hydrolysis rate of ASA emulsions at an initial pH of 3.5 [13].



5. The effect of pH on the hydrolysis rate of ASA emulsions at 25°C [13].

pressure reduction and sizing performance improvements.

A mill that prefers for one reason or another to come to a size or metering press at close to zero moisture may also want to investigate the use of C-18 ASA in place of the mix.

An advantage of ASA is that it is supplied in essentially a 100% active form. This saves the mill the cost of transporting and storing large quantities of water. Most of the ASA supplied today does contain a small amount of surfactant to make it easier to emulsify, but it is a small amount and can be discounted.

ASA must be protected at all times from moisture. The hydrolysis reaction is apparently auto-catalytic and once started will rapidly consume all the material in a tank. Therefore, precautions must be taken to keep moisture away from the ASA until it is emulsified.

Generally, ASA is stored in a tank that has dry air or nitrogen over it. The dry air or nitrogen is kept at a small positive pressure to help in keeping moisture away from the ASA.

When there are problems with sizing, a mill should first check the quality of the ASA. Hydrolyzed ASA is soluble in the starting ASA product. The hydrolyzed ASA is more viscous and may have a tendency to density separate to the bottom of the storage vessels. Testing should begin at the vessel bottom and be compared to the top. The amount of hydrolyzed ASA can be quantitatively determined by infrared technique.

The Emulsification of ASA

ASA and Cationic Starch. ASA has been emulsified with cationic polymers [14]. The ASA/cationic polymer emulsion system was developed originally for use in those mills not using cationic starch. This emulsion technology is used extensively on very successfully in the manufacture of gypsum liner, carton and container boards, molded products, and newsprint grades. Some other mills trying this type of emulsion in the manufacture of fine writing and printing papers have reported excessive deposits.

ASA has been emulsified with cationic starch. Almost all of the mills successfully using ASA use cationic starch as the emulsifying agent. The ASA/cationic starch emulsion has been shown to be significantly more stable than is the self emulsified ASA. As was noted, it is not known at the present time why the ASA/cationic starch emulsion is relatively stable. The manufacturers of ASA give explicit instructions on the cationic starch viscosity needed for emulsification of the ASA. There are questions as to the degree of the cationization of the cationic starch to be used as well as whether one would use a quaternary or a tertiary cationic starch or whether one would want to use a potato or a corn starch. The degree of the cationization of the cationic starch that is needed tends to be a function of the conductivity of the water in the mill at the point where the ASA/cationic starch emulsion is to be added. The higher the conductivity of the system, the higher is the degree of cationicity in the starch that is needed in order to optimize the reaction of the emulsion with the anionic fibers.

There is also a very strong relationship between starch solids and starch temperature and the quality of ASA-emulsion that are formed using either turbine or cavitron emulsifying systems. Generally, greater starch solids will promote ASA-emulsification. Higher starch temperature can also induce emulsification but creates concern over ASA-hydrolysis.

Both quaternary and tertiary starches have been used. The original ASA/cationic starch emulsions used a tertiary cationic starch as the emulsifying agent and no problems were noted. Again, experience has indicated that the tertiary starches are effective up to a pH of about 8.5. Above that pH, a quaternary cationic starch is generally required. However, the majority of the starch producers are manufacturing quaternary starches today and changed their commercial offering when North America fine paper industry converted to alkaline papermaking. Potato, tapioca and various types of corn starches (to include waxy maize and amphoteric derivatives) have been used to emulsify ASA. Many of these starches have been acidified with alum, citric or adipic acids designed to produce a pH 4.0 at 4% starch solids in bicarbonate laden mill waters. The manufacturers of starches have put forth their arguments and both have their points. Suffice it say that many types of starches have been used successfully. It is incumbent upon the starch and ASA suppliers to choose proper chemistries and emulsification operating parameters.

The critical parameter in the starch would seem to be the amount of calcium in the starch. The bi-product in the manufacture of the tertiary cationic starch is hydrochloric acid and starch. Some studies have shown that the presence of lime in the cationic starch decreases the stability or rather the effective life of an ASA/cationic starch emulsion. Today, essentially all of the cationic starch used in the emulsification of ASA is neutralized with caustic. However, it is recommended that those planning to use a locally manufactured cationic starch (that not manufactured in the United States or Europe specifically for the emulsification of ASA) have the starch analyzed for the presence of calcium. The presence of calcium decreases the life of the ASA/cationic starch emulsion and increases the potential for the formation of deposits (calcium resins) in the papermaking system.

Emulsification Techniques. Three basic techniques have been developed for manufacturing ASA/cationic starch emulsions:

1. A venturi system [12].
2. A turbine system.
3. A cavitron system.

The turbine system is by far the most widely used system for preparing ASA/cationic starch emulsions. The venturi system is simple and has very few moving parts. It has been used successfully in the past. The weakness of this latter system was:

- It was necessary to add an emulsifying agent to the ASA (one part chemical emulsifier in 17 parts ASA).
- The particle size of the emulsion produced tended to be larger than 1 micron.

The cavitron emulsifying pump is used widely in Europe along with turbine-based pump designs. Almost all of the ASA suppliers offer their own turbine systems and all seem to work without problems. However, the turbine systems, unlike the venturi may require a significant amount of maintenance.

Initially, the addition of a surfactant to the ASA might have caused someone to expect that this would decrease the hydrophobicity of the final product or perhaps to increase the potential for foam. However, a significant percentage (if not all of the ASA currently supplied) does contain some surfactant, approximately 1% by mass. Therefore, if there is a desire to use a venturi for the emulsification of the ASA, one should check to be sure if it contains some surfactant. This would decrease the need for additional surfactant.

The Use of ASA/Cationic Starch Emulsions

There are two philosophies for adding ASA/cationic starch to a papermaking system:

1. The addition of the emulsion to the thick stock at the stuff-box accepts. This philosophy notes that by adding the emulsion to thick stock, it minimizes the percent of the ASA that will deposit on cellulose fines, especially if the majority of the filler is added to the thin stock. Therefore, this philosophy states that it improves the potential for the retention of the ASA as most of the ASA is deposited on cellulose fibers by this mode of addition. This philosophy further states that the time between the addition of the emulsion to fibers and the formation of a web is short and will not

effect hydrolysis and the loss of sizing efficiency. For stuffbox addition to be optimum, the ASA should be added immediately after the thick stock has passed through the basis weight or thick stock flow valve and before it comes into contact with the white water used for stock dilution.

2. The addition, of the emulsion as close to the headbox as possible (generally to the accepts coming from the primary centrifugal cleaners). This philosophy states that it is necessary to add the ASA as close to the headbox as possible to minimize the potential for hydrolysis. Mill systems that are very hot, >50°C, or have the majority of their filler base loaded to thick stock are examples that warrant a feed forward dosing strategy. This philosophy feels that hydrolysis or ASA association with the filler may be problematic and therefore prefers to deal with fines retention rather than hydrolysis.

Both have been used successfully. Therefore the papermaker has to decide which philosophy to follow. The addition of the ASA/cationic starch emulsion to fibers at the stuffbox accepts has the advantage that it minimizes the potential for the variation in the retention of the ASA in the web that will be formed because theoretically most of the ASA will be on the cellulose fibers rather than on the cellulose fines.

One supplier has stated that this mode of addition increases the potential for the hydrolysis reaction to occur preferentially. Therefore, he feels that hydrolysis is a greater potential problem than is retention. The problem with the so-called "thin stock" addition is that it places importance on the uniform retention of the cellulose fines. One has only to look at the thick stock flow/time to see the variation in retention with time. If the variation in retention with time (the variation in thick stock/time) is greater than plus or minus 2%, the papermaker might want to opt for thick stock addition over thin stock addition. In practice, the majority of fine paper mills today dose ASA into the thin stock.

The potential deposition of the ASA/cationic emulsion on the calcium carbonate pigment used in the neutral/alkaline papermaking process is generally not a problem. The precipitated form of calcium carbonate (PCC) has a positive zeta potential. Therefore there is but a small probability that the cationic ASA emulsion will come into contact with and react with the cationically charged PCC particles. The ground forms of calcium carbonate and chalk are anionic, but they too tend to react as if they were cationic to some degree. Therefore, as a general rule, PCC, at least, can be added to a furnish prior to the addition of the ASA/cationic starch emulsion.

The primary problems with ASA are:

- The retention of the ASA in the web that is formed. The ASA that has been precipitated onto the cellulose fines and not retained in the web that was formed will hydrolyze, as the cellulose fines containing the ASA are re-circulated. The hydrolyzed form of ASA, as was noted, is readily dispersible in water, but it is not soluble in water. This is a resin acid and it can form deposits through the piping, chests and on the foils of the former. Surprisingly, calcium carbonate is one of the best scavengers for anionic materials and will therefore adsorb with and tie up the hydrolyzed ASA. Therefore, up to a point, the calcium carbonate will adsorb

any ASA that was not retained. But if too high a percentage of the ASA containing fines are not retained, the amount of ASA may overwhelm the ability of the calcium carbonate to minimize deposit formation. It is therefore important to analyze foil deposits to determine that ASA:calcium carbonate ratio. In addition, as was noted, if the thick stock flow variation/time is greater than 2%, the papermaker has to determine either why his thick stock flow/time varies as it does or go to thick stock addition of the ASA (if he is using thin stock addition of the ASA/cationic starch emulsion).

- It has been found that in systems with open presses, the ASA/cationic starch system can affect the material of a press roll. It is not a problem where the presses are double felted, but it can be a problem where the presses are single felted. Therefore, when contemplating a shift to neutral/alkaline papermaking and the use of ASA on a paper machine with open presses, the papermaker should contact the manufacturer of press rolls to be sure that this type of problem will not occur.
- Again, on a paper machine without double felted presses, there is a tendency for the adhesion forces between the web and press roll to be greater than is seen in acid papermaking. Therefore, there is a stronger tendency for the web to stick to the second press. Generally, this is not a problem, but if it is, it can be easily eased by applying water alone or water containing some phosphate to the top roll of the second press via a flexible dam (and sewerage the water).
- Overdrying the paper can also cause some potential problems. This is both an advantage and a potential problem. It is an advantage in that the papermaker can save a significant sum by decreasing the amount of energy required to dry the paper prior to coming to the size or metering press. It has to be remembered that drying a web from 8% to 0% moisture can add 20% to the cost of the energy required to dry the web. However, if there are CD web moisture problems (streaks, etc.), it may not be possible to come to a size or metering press at 4-6% moisture. Therefore, if ASA use is high under this circumstance, the papermaker might want to go the higher molecular weight ASA (the so-called, C-18 product).

The primary problems faced by papermakers are not going from one size to another, but rather in going from acid to neutral/alkaline papermaking and from the use of clay to the use of calcium carbonate. As was noted, the clay pigments are and react as if they were anionic. Calcium carbonate is either or reacts as if it were cationic. Therefore, the papermaker has to have an entirely new retention aid system. Several are available from the suppliers of ASA, but each type available has their pluses and minuses. Therefore, problems in sizing at the neutral/alkaline pH's may not be related to the size used, but rather to the change in the system from acid to the neutral/alkaline pH's.

The basic problems faced in going from acid to neutral/alkaline papering are:

- **Deposit control.** Non-ionic resins (resin esters) coming from a pulp mill/bleach plant can be controlled at the acid papermaking pH's. They are difficult to control at the neutral/alkaline pH's. Therefore, if there is a problem in deposits and they are found to contain resin esters, the papermaker has

to work closely with the pulp mill/bleach plant of his mill to find out why resin esters have come onto the paper machine. These same resin acids can reduce sizing efficiency and promote a loss of sizing response with time, a phenomena commonly referred to as size masking.

- **Retention.** This has been quickly noted, but neutral/alkaline papermaking requires a combination of cationic and anionic retention aids for optimum retention of the cellulose fines and the calcium carbonate pigments. When using a dual polymer (a combination of cationic and anionic polymers), the papermaker has to carefully control the zeta potential of his system. The greater the degree of the anion-icity of his system, the greater is the potential for slowing the drainage of his furnish at the former. The anionic polymers used will slow drainage if they are used in too high a quantity. One should operate around a zeta potential of -5 when using the dual retention aid systems.
- **The control of microorganisms.** Generally, having 1-2ppm of chlorine dioxide residual at the headbox of the system can control microorganisms. Some mills have also used sodium hypochlorite for this. The problem is the potential reaction of anionic retention aids with either the chlorine dioxide or the sodium hypochlorite. Therefore, the papermaker has to query the supplier of his retention aid to have assurances that the anionic retention aid will not react with the biocide. There are retention aids that have a low order of reaction with chlorine dioxide or sodium hypochlorite and this is not a problem with the right retention aids. With the wrong retention aids, the papermaker can lose both retention (because of the oxidation of the retention aid) and biological control (because of the reaction of the biocide with the polymer instead of the microorganism).

CONCLUSIONS

- ASA is a viable sizing agent for use in the neutral/alkaline papermaking process.
- It has many advantages in that it is supplied on a 100% solids basis, saving the papermaker the cost of transporting water. However, it is emulsified immediately before use and this requires equipment.
- The actual life of an ASA/cationic starch emulsion is not known. All of the studies involving the life of ASA in the papermaking process is based on adding a self-emulsified ASA. Nothing has been published regarding the life of ASA/cationic starch emulsions.
- ASA has been emulsified with cationic polymers. Over 30% of the ASA consumed globally is emulsified in synthetic polymers.
- Most of the problems faced by papermakers when going to ASA are problems related primarily to the conversion from acid to neutral/alkaline papermaking. **TJ**

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NOTE TO READERS

This paper is Chapter 9 from *The Sizing of Paper*, Third Edition, edited by J.M. Gess and J.M. Rodriguez. It is available through TAPPI Press.

Since 1989, when the second edition of *The Sizing of Paper* was published, most paper mills have converted to neutral or alkaline pH wet end conditions. Therefore, this edition reflects the experiences and technologies that have developed with the new application. Covers topics like the chemistry of aluminum, soap size vs. dispersed size, fluorochemical sizing, and surface sizing additives, to name a few. The size press surface sizing section is expanded from the last edition to accommodate the new interest generated by the technology. Useful for paper mill technical personnel, students, chemists, and mill engineers.

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