New High Adhesion Creping Technology for Improved Sheet Properties and Machine Productivity

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ABSTRACT

Nalco Company has developed a proprietary creping technology that provides high adhesion over a wide range of creping moistures. Compared to conventional creping chemistries, the new coating is typically more efficient, allowing for up to a 50% reduction in application rates at equal or higher creping moisture. Coating uniformity and softness are also improved. This paper presents laboratory data, demonstrating superior characteristics of the new coating over conventional PAE-based adhesive chemistries. Results from machine trials are also presented, which demonstrate advantages of this new technology with regard to improved sheet properties and machine productivity.

INTRODUCTION

The tissue industry continues to strive for improved product quality and reduced manufacturing cost. Often these two demands are mutually exclusive, i.e., the higher the quality of tissue products, the higher the production cost. Meanwhile, the tissue market in China continues to develop rapidly, with annual increases in production of 8-9% over the past ten years. The expectation is that Chinese production will exceed 5 MM tons in 2010. Many new machine projects are starting up this year, estimated to add 400K tons, or have been announced for 2011, expected to add another 550K tons. Competition is increasing and current utilization rates are estimated at less than 85%. At the same time, the price of tissue paper is increasing as higher quality products are being marketed and purchased by Chinese consumers. Thus, innovations, which allow production of high quality products without a significant increase in cost, are expected to be especially attractive for the Chinese market.

When trying to achieve improved product quality on conventional machines, tissue makers can utilize various mechanical, operational and chemical solutions. Two of the most common solutions are the use of high quality fibers and creping at lower moisture. Virgin hardwood and softwood fibers having low coarseness attributes and can improve sheet characteristics, especially hand-feel softness. However, depending on market conditions, they can also greatly contribute to product cost, thus limiting the extent of using this option to only premium consumer grades. In some cases, such as facial tissue grades, local regulations also require the use of virgin fiber.

Low moisture creping is beneficial for the development of high adhesion between the sheet and the Yankee dryer surface, resulting in a more effective creping process and leading to improved sheet characteristics. However, lower moisture creping is also associated with a higher cost of operation due to an increased energy demand. Moreover, creping at low moisture is known to cause conventional coatings to become hard, resulting in various machine runnability issues. The implications of a harder coating for tissue machine runnability have been reviewed previously. One potential problem associated with a harder coating is blade vibration, which can lead to the phenomenon called chatter. Chatter not only can cause defects in the sheet, but also can damage the Yankee surface.

A softer coating is desired for high temperature/low moisture conditions. Existing coating programs are not always able to function properly under low moisture creping conditions. Conventional polyaminoamide-epichlorohydrin (PAE) resins tend to become too hard under extreme drying conditions, resulting in a loss of adhesion and poor runnability. Non-PAE chemistries, including polyvinyl alcohol (PVOH), polyethyleneimine (PEI), polyacrylamide (PAcAm), have also found use in the Yankee coating applications for conventional creping, but only in limited applications due to either their high moisture sensitivity (PVOH), high cost (PEI) or hard coating characteristics (PAcAm).
The use of humectant modifiers is beneficial for softening a Yankee coating, but a soft PAE coating is often not durable enough to withstand moisture in the nip or shear during blade changes. This results in streaky and non-uniform coating and/or problems with the coating stripping off on blade changes. There have been some recent developments in novel coating technologies more amenable to low moisture creping that take advantage of pre-crosslinked PAE chemistry to reduce runnability issues. However, the high energy consumption still limits the wide use of low moisture creping as a means for improving tissue properties.

Nalco Company has developed a new Yankee coating technology, based on modified vinyl polymer chemistry, and commercially referred to as TULIP creping technology that has a number of attributes beneficial for the creping process. Foremost among these is the high adhesion that can develop between the sheet and the coating to provide more effective creping. This paper presents laboratory data and case studies from industrial trials, demonstrating capabilities of this new coating technology for improving sheet quality, manufacturing cost, and machine productivity.

NEW COATING PROPERTIES

PRODUCT CHARACTERISTICS

The new coating technology is based on proprietary vinyl polymer chemistry, which was modified to alter the viscoelastic and adhesive properties of the coating. The key product characteristics are listed below:

• Non-thermosetting polymer
• Aqueous solution
• Solids 10-20%
• Viscosity 100-1000 cps at 25°C
• pH 6-8
• EINECS/REACH, TSCA, and IECSC compliant
• BfR and FDA approved for indirect food contact
• No VOC
• No organic chlorides

Laboratory measurements of the performance characteristics of TULIP creping technology, based on the Nalco model called Coating Space technology are detailed below.

LABORATORY METHODS

Adhesion – The adhesion performance of films was evaluated using a peel test. This test measures the force required to peel a cotton strip from a heated metal panel. The wet strip was attached to the panel with an adhesive of interest, dried at 105°C and peeled at an 180° angle at a constant speed.

Glass transition temperature – The glass transition temperature (Tg) of different polymers was measured using a differential scanning calorimeter (TA2920, TA Instruments, New Castle, DE). A polymer film was cast at 105°C. The Tg was determined from the second scan using a half-height method.

Shear modulus – The shear storage modulus, G', and the shear loss modulus, G", of the polymers were measured using a rheometer (AR2000, TA Instruments, New Castle, DE). A sample disc of each polymer was prepared by a film-casting technique at 95°C. The film samples were further dried at 110°C under vacuum. An 8-mm parallel plate geometry was used. The frequency sweep measurement was conducted at 100°C and 0.5% strain. The measurements are reported at a frequency of 1 Hz.

Film solubility – Coating film solubility was determined by forming films on cellulosic substrates, drying them at 105°C and solubilizing in water under controlled conditions. The film solubility was calculated from the difference in mass of the product-coated substrate before and after soaking.

LABORATORY DATA

Adhesion – Adhesive properties were evaluated using the peel test method. In this test, a wet strip was applied to a coating film formed on a heated plate. Heating the plate to different temperatures controlled the moisture level in the film, affecting the softness and rewettability characteristics of the film and ultimately the peel adhesion results. Figure 1 demonstrates adhesion data as a function of the film dryness for the new coating compared to conventional PAE products, based on a thermosetting, or active-crosslinking, resin (X-PAE) and a pre-crosslinked, or non-crosslinking, resin (NX-PAE).

For PAE adhesives, the adhesion response to the film moisture content depended on the crosslinking nature of the resin. The crosslinking PAE showed a complete loss of adhesion when the wet strip was applied to a completely dry film, whereas, adhesion of the pre-crosslinked PAE increased when the film was further dried. The TULIP coating provided greater adhesion than the crosslinking PAE when the film was not completely dry. The adhesion remained high even when the film was completely dry.
The temperature and moisture response of the PAE adhesives can be explained by the difference in the crosslinking nature of these polymers, which determines different mechanisms for filmsetting. For active-crosslinking PAE, heating and removal of water promotes additional inter- and intra-molecular crosslinking, resulting in the formation of a harder and less rewettable coating. This coating type tends to set fast and can provide adequate adhesion at relatively high moisture levels. At lower moisture, the coating becomes too hard to form an intimate contact with the sheet, which is needed for development of high adhesion.

The pre-crosslinked PAE resins form films through evaporation of water and material thickening on the metal surface. The filmsetting kinetics and film rheology are largely affected by the molecular weight, the degree of crosslinking and various chemical modifications, all of which are pre-determined by the resin manufacturing process. Normally, a pre-crosslinked PAE coating is more rewettable and, therefore, behaves softer than a crosslinking PAE coating. The laboratory data in Figure 2 indicates that the pre-crosslinked PAE product provided moderate adhesion when the film was not completely dry, but below the adhesion level of the crosslinking PAE product. A possible explanation would be that the pre-crosslinked film did not set completely and partially dissolved in the water introduced from the wet strip; however, as the film dryness increased, the film integrity improved and adhesion increased.

The TULIP coating is non-thermosetting, and was expected to behave similarly to the pre-crosslinked PAE; however, the new chemistry exhibited unique film-forming characteristics and adhesion response with changes in film dryness. The data suggests the relatively wet film withstood moisture from the wet strip, providing good interfacial contact between the strip and the metal panel, which resulted in superior adhesion. Furthermore, the high adhesion was not significantly changed within a wide range of film moistures, dropping only slightly when the film was completely dried. Laboratory data suggests that the advantage of the TULIP coating may not only be that it provides high adhesion, but that it also has less sensitivity to moisture variability across the Yankee dryer, thus maintaining a more uniform adhesion and creping in the cross-direction.

**Coating softness** — As discussed above and reviewed in references<sup>3–7</sup>, coating softness is critical for the development of high adhesion as well as for adequate runnability. On a commercial machine, it is nearly impossible to measure the coating softness directly. Instead, tissue makers must use indirect observations such as edge build up, blade wear, coating recovery on a blade change, and doctor blade loading.

When tissue makers discuss coating product properties, the glass transition temperature (T<sub>g</sub>) is often used to characterize the softness of Yankee coatings. By definition, the T<sub>g</sub> is the temperature, at which an amorphous material transitions from a glassy (hard) to a viscous (soft) state. A T<sub>g</sub> measurement does not provide any quantitative information on how soft the material is. Although Tg can provide useful information on directional changes of film softness upon modifications of the same polymer, comparison of softness of unlike polymers solely based on their T<sub>g</sub> values can be deceiving. For Yankee coatings, the criterion is that the T<sub>g</sub> of the coating should be below the operating temperature of the Yankee surface in order for the coating to be in its viscous state. This allows the coating to form a uniform contact between the sheet and the metal surface. For reference purposes, the T<sub>g</sub> of completely dry PAE films is typically around 50-80°C<sup>4,7</sup>, which can be lowered further by using plasticizing additives<sup>4,5</sup>. The T<sub>g</sub> of dry TULIP films ranges from 20-60°C, depending on modification.

Shear modulus measurement is the more preferred method for evaluating the film softness directly. The shear modulus characterizes the response of a material to an oscillating deformation. The two shear modulus parameters obtained from a single measurement are shear storage modulus (G’) and shear loss modulus (G”), which characterizes elastic and viscous deformations, respectively. It has not been established which of the two parameters is more important for the Yankee coating performance, but in general, a higher shear modulus indicates a harder material.

Figure 2 demonstrates the shear modulus data for PAE and TULIP technology films. Crosslinking PAE

![Figure 1](Image)

**Figure 1** – Peel adhesion data showing the TULIP coating can provide superior adhesion over a wide moisture range.
tends to form harder films than pre-crosslinked PAE, which is consistent with their shear moduli. Based on the $G'$ data, the TULIP technology film appears to be softer than the crosslinking PAE film, but harder than the pre-crosslinked PAE film. Based on the $G''$ data, the TULIP technology and pre-crosslinked PAE films are both very soft. As exhibited by lower shear moduli, using a plasticizing modifier can further soften the TULIP film.

Coating rewettability – A coating must be rewettable at the pressure roll nip in order to become soft and develop good adhesive contact with the sheet. A film solubility measurement is one of the tests performed in the laboratory to evaluate the coating sensitivity to moisture. The less soluble the polymer films are the less rewettable and less moisture sensitive the coating will be.

Crosslinking PAE films are typically less soluble than pre-crosslinked PAE films as demonstrated in Figure 3. The TULIP technology film was mostly soluble under the standard test conditions, suggesting a superior rewettability, a desirable property for low moisture creping. However, a film that is too soluble can lead to potential problems with moisture sensitivity and durability in the wet nip. Countering this concern, is the adhesion data discussed above showing that the TULIP technology coating film was durable even when a wet strip was applied to the wet film. Sufficient durability of the TULIP technology coating was further observed in machine trials. In fact, one of the beneficial features of the TULIP technology coating is its ability to handle cross-direction moisture variability. This ability is demonstrated by the very uniform coating films provided by TULIP technology. The mechanism for rewettability and bonding of the

**PRACTICAL RESULTS**

**CASE STUDY 1**

A tissue maker, using secondary fiber as furnish, to produce a value category bath tissue, wanted to improve both machine productivity and product quality through improved coating stability and coating layer uniformity. The challenge was to meet both the productivity and quality goals at the same time.

**Discussion** – The operating window on this machine was extremely small when using the incumbent PAE-based Yankee coating. Cross-machine moisture variations led to non-uniform coating development that, in turn, led to sheet quality issues. Defects would appear in the sheet consisting of picks and holes that would eventually result in an unacceptably high number of sheet breaks. Previous trials with different types of PAE-based coatings had proven unsuccessful in addressing these problems.

When the incumbent PAE coating was replaced with the TULIP coating, an immediate improvement in coating uniformity was observed on the dryer. Reel building was also observed to level out from a previously uneven condition. The more uniform coating improved protection of the Yankee surface as evidenced by improved blade wear profiles.

The higher adhesion properties of the TULIP technology coating allowed the active coating add-on rate to be reduced by 30%. The crepe structure of the
sheet was noticeably improved which resulted in an improved hand feel. Figure 4 shows a report generated by the Nalco NCAT crepe analysis instrument. Images of the tissue produced with the incumbent PAE coating and the Nalco TULIP technology coating are shown on the left. On the upper right hand side of Figure 4 is the percent frequency distribution of feature (crepe) sizes in the image, and on the lower right hand side the statistics associated with that distribution. The frequency distribution was shifted to smaller (less coarse) crepe structures as evidenced by the increased crepe count/inch and the increase in the percent of fine crepe structures.

Outcome – Improved Yankee coating uniformity was observed, despite the lower coating add on, indicating a superior moisture tolerance of the TULIP technology coating. Increased adhesion resulted in improved product quality – finer crepe structure and improved hand feel. Due to the improved sheet quality, operations in converting showed a 10% efficiency improvement. Overall line production (tissue machine plus converting) increased by 4.5%.

CASE STUDY 2
A tissue maker, using a virgin fiber furnish wanted to improve sheet softness characteristics by making changes to the Yankee coating package. The goal was to improve sheet quality without negatively impacting machine productivity or reducing creping moisture.

Discussion – On this tissue machine, the incumbent PAE-based Yankee coating package allowed for good machine runnability and production of paper within targeted quality specifications.
However, as the tissue maker was interested in improving softness as much as possible, the incumbent PAE-based Yankee coating was replaced by TULIP technology. Based on the high adhesion properties of TULIP technology, the add-on of adhesive material was reduced by 50% and the release add-on was slightly increased. An increase in stretch was observed, which allowed for an increase in reel speed, and a resulting increase in productivity.

Crepe structure during the TULIP creping technology trial was finer than with the incumbent package. The sheet softness was also improved. Based on the initial promising results, it was decided to increase creping moisture by 0.5% moisture points. Coating add-on was increased by 25% in combination with this increase in moisture. Sheet softness remained on target and was maintained throughout the blade life, as shown in Figure 5.

**Outcome** – An improvement in relative sheet softness was observed when using TULIP technology coating, even at higher creping moisture. Machine runnability improved when using the TULIP technology coating with an increase in productivity being reported. The increase in creping moisture offers the potential for energy savings. Reduced coating add-on should also improve drying efficiency.

**CASE STUDY 3**

A tissue manufacturer wanted to improve profitability of a premium tissue grade by substituting a lower cost fiber source for purchased eucalyptus pulp, while maintaining the high quality this premium bath tissue demanded.

**Discussion** – This producer was running a premium fiber furnish consisting of 50% eucalyptus and 50% of a HW/SW on-site produced slush pulp plus broke. An improvement in grade profitability could be realized if the proportion of slush pulp was increased while maintaining softness targets. The incumbent PAE coating provided good machine efficiency when using the premium furnish blend, but efforts to substitute more slush pulp resulted in an unacceptable loss in product quality.

The TULIP technology coating was used in place of the PAE, and after optimization of the program, resulted in a 40-50% reduction in total coating (adhesive plus release) add on. Coating uniformity on the dryer was excellent and Yankee protection high. Crepe blade wear was less than 0.05 mm/hr, and blade life increased from 6 to 12 hours. A key factor in the increased blade life was the ability to maintain product quality as shown by the NCAT crepe structure results in Figure 6. The average number of crepe structures per inch is shown for new and old creping blades for both the Yankee and air sides of the tissue. The TULIP technology coating provided

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**Figure 5** – Relative softness and average sheet moisture for trial conditions in Case Study 2

**Figure 6** – Average number of crepe structures per inch for tissue produced with new and old creping blades in Case Study 3.
a finer crepe structure and maintained it longer than the PAE coating. For reference the corresponding 20x images of the Yankee sides of the sheets are shown in Figure 7.

**Outcome** – The profitability goals of the producer were achieved. After optimization of the furnish blend to increase the on-site produced slush pulp content by another 10%, nearly a million dollars in savings were recorded. Additionally the overall coating program cost was reduced by 25%.

**CASE STUDY 4**

A tissue producer wanted to improve productivity by decreasing the number of breaks on the machine while at the same time increasing softness.

**Discussion** – The operating window with the incumbent PAE coating was extremely small for this value category bath tissue. Cross direction moisture variability on the machine led to sheet uniformity issues. In turn, converting line speeds were limited due to the paper quality problems. Implementation of the TULIP technology coating in place of the PAE coating improved the coating uniformity in spite of the variable cross direction moisture. Reel build in the cross-direction also became uniform compared to the corrugated appearance with the PAE coating. As is typical with TULIP programs, coating add on was reduced by 40% Production was increased due to fewer sheet breaks and doctor blade changes.

As shown in Figure 8, the crepe structure of the sheet was improved leading to a perceived softness improvement. The crepe structures/inch are shown during the initial trial period for the changeover from PAE coating to TULIP coating. The creping doctor blade was not changed during this 12-hour trial segment. Crepe structures/inch improved once the TULIP coating was established on the Yankee, even though the blade was already six hours old. The improved adhesion provided by the TULIP coating is again apparent in these results.

**Outcome** – Due to the improved sheet quality, converting line efficiency was greatly improved. Line

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![Figure 7](image-url) – Images (20x) of the Yankee sides of tissues produced with TULIP technology and PAE programs for new and old doctor blades
speed in converting was increased by 120 m/min. As expected from the improved crepe structure, an improvement in hand feel softness was also observed.

SUMMARY

A new coating technology, based on proprietary vinyl polymers (TULIP creping technology), was shown to provide superior coating characteristics compared to the conventional PAE chemistries. TULIP technology allows tissue makers to achieve improved sheet properties and/or reduce manufacturing cost.

TULIP technology coating characteristics vs. PAE:
• Greater adhesion
• A wider creping moisture operating window
• Improved coating uniformity and softness
• Superior rewettability without negatively affecting coating durability

Advantage of TULIP technology coating for tissue manufacturing:
• Improved handfeel softness (due to increased adhesion)
• Reduction in the adhesive add-on by up to 50%, while maintaining the same level of adhesion
• Tolerance of moisture variation leading to improved sheet quality and machine productivity
• Ability to substitute lower cost fibers while maintaining quality targets
• Potential to crepe at higher moisture without a loss of adhesion and/or sheet quality, resulting in improved machine productivity and potential energy savings

REFERENCES

1. Outlook for World Tissue Business Mid-Year Update, July 2010, RISI.

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Figure 8 – Crepe structures/inch over the course of one creping blade during the changeover from PAE to TULIP coating (time scale is 12 hours). The high adhesion provided by TULIP improves crepe structure and softness.