Intelligent design of Yankee Coatings

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INTRODUCTION:

All Yankee coatings must perform three critical tasks basic to their performance. They must (1) protect the Yankee surface, (2) provide adequate adhesion to transfer the sheet onto the Yankee and to develop enhanced sheet properties at the creping blade, and (3) be soft enough to allow blade tip penetration into the coating and below the sheet. The tissue machine type and grade being produced greatly influence the ability of the coating to perform these functions. Thus, the coating package and the coating properties which develop must be designed for the machine type and grade conditions in order to run the tissue machine efficiently and produce the desired tissue quality. Nalco Water's Yankee coating offerings including the TULIP™ and NAVIGATOR™ adhesive product lines, when coupled with the appropriate release and modifying agents, perform these tasks over the broad range of conditions employed in the industry today. This review will highlight the coating needs and recommendations for each major machine type – conventional wet press (CWP), (creped) through-air dried (TAD) and hybrid.

Background

Globally, the tissue and towel industry remains in a dynamic phase with good growth, a reaffirmation by consumers of the importance of these products to their personal hygiene, and steady advances in production technology. The FisherSolve® Next database shows a current global capacity for tissue and towel products of over 55 million MT (air dry basis) with the regional breakdown shown in Figure 1.

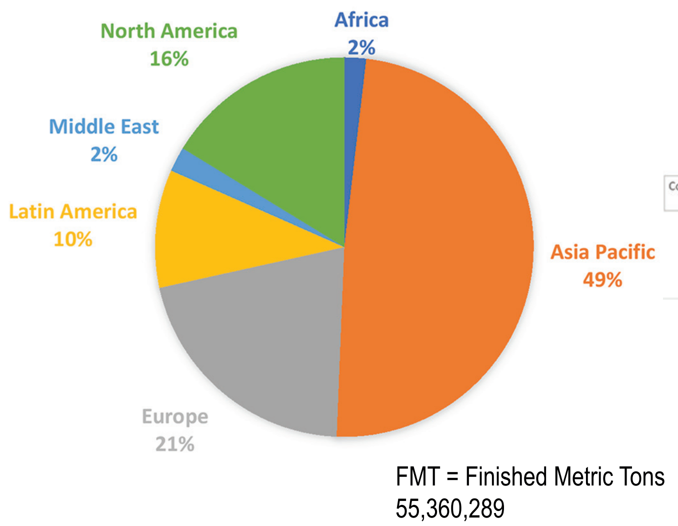


Figure 1: Global capacity for tissue and towel products by region. Total capacity = 55,360,289 finished metric tons (FisherSolve® Next).

Most analysts estimate the underlying growth rate of the industry remains in the 3-4% range per year even though the COVID 19 pandemic has caused some recent fluctuations. Hoarding by consumers in the early days of the pandemic caused a spike in apparent usage (followed by a lull) and emphasized the critical nature of tissue products.

The most important properties to consumer preference remain softness, bulk, absorbency, and cleaning ability. Base paper or parent roll manufacturing of tissue and towel can be categorized into three different technologies: (1) conventional wet press or CWP, (2) through-air dried or TAD and (3) hybrid machines. The hybrid technologies have the capability to produce a structured sheet (prior to creping) like TAD but without utilizing a TAD dryer. Global market share by technology is dominated by CWP (91% of global tons) but the TAD and hybrid machines have steadily increased market share in North America, as shown in Figure 2, now accounting for 41% of the NA tons.

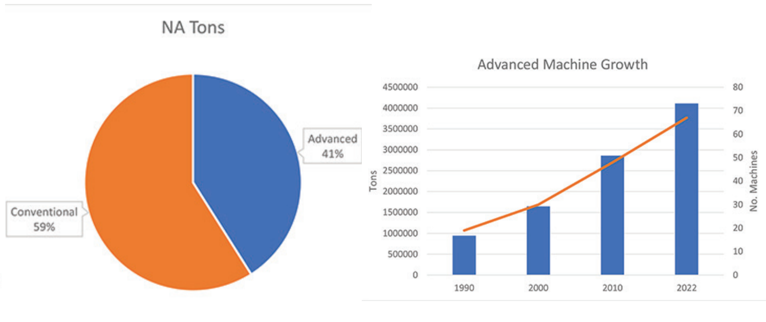


Figure 2a: North America tissue and towel tonnage by machine type. (FisherSolve® Next)
Figure 2b: North America growth of advanced machines.

All current machine technologies emphasize improvements in softness, bulk and absorbency while maintaining necessary product strength in use, however, the TAD and hybrid technologies excel at this, thus resulting in their popularity in N. America. The TAD and hybrid technologies can also be referred to as "advanced" tissue machines that produce "structured" sheets. These technologies are increasingly used by tissue manufacturers to produce premium and ultra-premium products for well-known national brands as well as for the private label market. Reviews of advanced machine technologies capable of producing structured sheets have been presented by both Janda *(reference 1)* and Reisinger *(reference 2).*

Creping remains the key unit operation in the tissue making process having an inordinate influence on machine efficiency, and at least in conventional tissue making technology, largely defining the end-product attributes of the tissue. Creping is governed by the complex interaction between various mechanical, operational, and chemical factors, some of which are depicted in Figure 3. (*overleaf*)

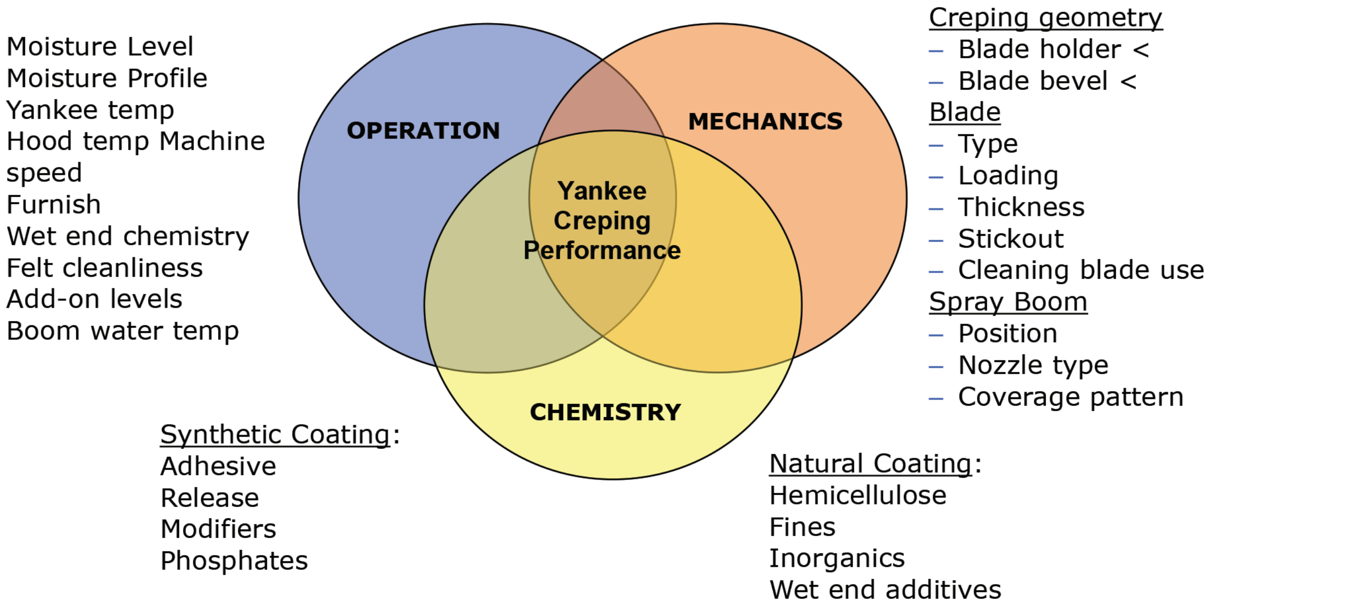


Figure 3: Yankee Creping Performance – Some Key Factors.

Yankee Coating Requirements and Definitions

Given the importance of creping, the chemical component of creping or the Yankee coating is also critical to the overall performance of the tissue machine both from an operational efficiency and finished product quality perspective. The Yankee coating may be described as a thin film which is an agglomerate of (a) materials sprayed directly onto the Yankee surface and (b) "natural" coating components deposited from the furnish and wet end of the tissue machine as depicted in Figure 4 *(reference 3).* To support efficient machine operation and good quality (i.e., good creping) of the tissue, the Yankee coating must perform three critical functions.

1. Protect the Yankee surface against mechanical and chemically induced defects.
2. Provide adequate adhesion to transfer the tissue sheet to the Yankee dryer and then to crepe it effectively to develop the required properties of softness, bulk, and absorbency.
3. Have the correct film softness to allow the tip of the doctor blade to reside within the coating layer and provide good creping and machine operation, yet still be durable enough to protect the Yankee surface.

A practical way to understand the characteristics and behavior of Yankee dryer coatings is to use a model known as "Coating Space" (Figure 5), *(reference 4)*. This model corresponds to the functions listed above where the protection function is now described as durability. It is easily understood by tissue technologists and mill operations personnel.

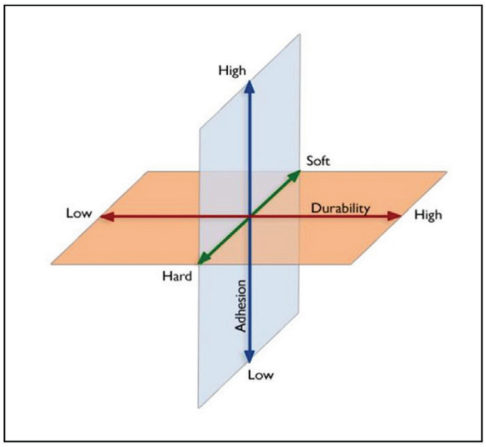


Figure 5: Depiction of the Coating Space Model concept showing the three axes defining film properties (reference 4).

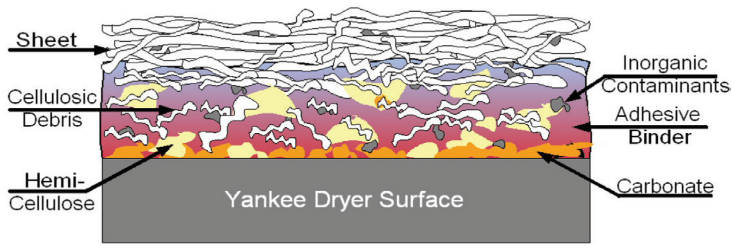


Figure 4: Depiction of Yankee Coating showing various components comprising the film (reference 3).

Before discussing Yankee coating design considerations and to provide a common understanding of the synthetic coating components listed in Figure 3 and depicted in Figure 4, it is helpful to offer the following Yankee coating component definitions.

- **Adhesive** – The adhesive functions to form the main cohesive protective film or coating on the Yankee while providing the necessary adhesion for transfer of the sheet to the Yankee and then to crepe the sheet effectively. More than one adhesive can be used, and these materials are typically film forming polymers.
- **Release** – Release products have traditionally been oil-based with added surfactants for emulsification and application through the spray boom. These products provide release from the Yankee and blade, while controlling excessive coating film build-up.
- **Modifier** – Modifiers are typically surfactant-based and more compatible with adhesives than release oils. They can soften the coating film while increasing its uniformity in terms of appearance and thickness *(see reference 5)*. Modifiers are more commonly used on advanced machines where they provide the necessary release at the blade as well.
- **Humectant** – Humectants can be used to help retain moisture in the coating to keep it flexible and soft while remaining adhesive.
- **Phosphate** – Phosphates are used as inorganic protective agents for the Yankee surface. They can also help anchor the coating thus providing uniformity. Monoammonium phosphate (MAP) is a typical example.

Yankee Coating Design Considerations

Before discussing design of Yankee coatings for specific machine types, it is important to acknowledge other tissue and towel grade factors that will impact coating performance and the choice of components. Primarily these will include furnish, wet end chemistry and end product performance targets like softness and strength. Specifically, a number of these factors contribute to or influence the natural coating components like hemicellulose content, ash, and fines as well as wet end chemistries like strength aids and debonders/softeners *(reference 6)*. Operational considerations, particularly, creping moisture will also play a major role in coating design.

We will now discuss coating design considerations for the major machine types or technologies of CWP, TAD and hybrid. A primary consideration here is the sheet moisture prior to transfer to the Yankee dryer. Figure 6 provides this moisture range for the three machine types.

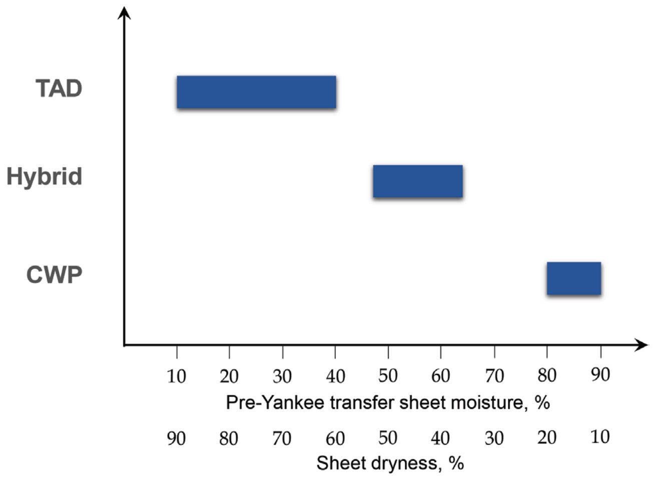


Figure 6: Sheet moisture at Yankee transfer by the three major machine types.

These ranges are approximate but encompass most machines within the machine type classifications. The driest transfer moistures are encountered in TAD with values as low as 10% and the wettest transfer moistures in CWP with values close to 90%. Hybrid machines bring an intermediate moisture content to the Yankee.

CWP – The vast majority of new CWP machines are crescent formers and so we will restrict our discussion to these machines. Crescent formers can run with all furnish types and tissue manufacturers will utilize a wide range of creping moistures (3-7% typical) dependent on softness and energy use targets. When considering an appropriate adhesive for crescent formers, it must be durable enough to withstand the wet transfer conditions (~80-90% sheet moisture) and essentially flooded conditions within the pressure roll nip *(see reference 7)*. Another consideration is the film softness at the creping blade which must be accommodating of the creping moisture. Typical adhesive add-ons can be in the 1-5 mg/m² range. Both release and modifier chemistries may be employed. Oil-based releases are more typical for away from home (AFH) and higher creping moisture grades, whereas modifiers are more common in at home (AH) higher softness grades creped at lower moisture levels. Sometimes humectants can be employed to keep the coating soft at low creping moisture conditions. Phosphate use is common but will be dependent on water chemistry.

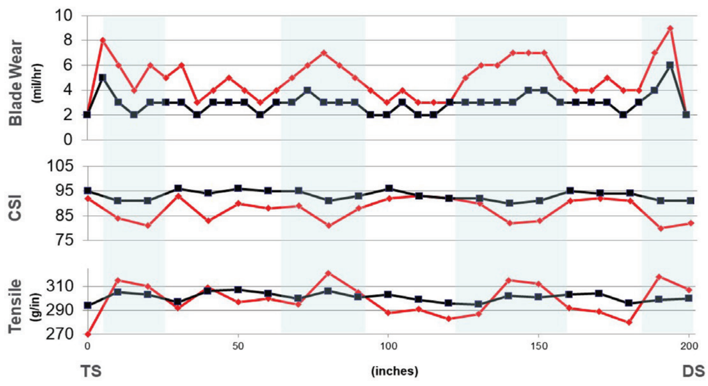


Figure 7: Cross directional profile on a CWP machine showing blade wear (mils/hr), crepe structures per inch (CSI), and tensile strength (g/in) for TULIP™ (in blue) vs. a conventional PAE (in red). The light-blue shaded columns in the CD represent areas of higher sheet moisture coming to the Yankee and hence areas subjected to potential durability issues for the coating. On the x-axis TS and DS represent the tending and drive sides of the machine, respectively.

CWP Case Studies – Nalco Water's TULIP™ adhesive product line, based upon a modified vinyl polymer architecture, offers a unique set of properties including high transfer and creping adhesion, soft film characteristics and good moisture tolerance. It has proven a good fit for CWP machines and *references 8 and 9* may be consulted for further details. A particularly compelling example of Tulip's moisture tolerance is provided in Figure 7. Here a cross directional profile of blade wear and sheet properties is provided for Tulip (in blue) vs. a conventional PAE (in red). Note that the light-blue shaded columns in the CD represent areas of higher sheet moisture coming to the Yankee and hence areas subjected to potential durability issues for the coating. In these high moisture areas, the PAE adhesive has problems with higher blade wear, lower crepe structures per inch, and higher sheet tensile. The Tulip adhesive provides a relatively flat profile for these properties across the CD showing its higher tolerance for moisture variation and thus a wider operating window.

Tissue Results	Before	After
Yankee Speed (m/min)	1900	1950
Reel speed (m/min)	1491	1580
Stretch (%)	15.3	18.0
Crepe ratio (%)	21.5	19.0

Table I: Result summary from a CWP Yankee coating trial utilizing TULIP™ vs. a competitive PAE adhesive on a 16 gsm tissue grade.

On another machine running at 1900 m/min (see Table I), the Tulip adhesive was able to improve tissue stretch values from an average of 15.3% to as high as 22.1% due to the improved creping adhesion. This improved stretch capability was utilized to decrease the crepe ratio while running at higher Yankee and reel speeds. In turn, this resulted in an approximately 2.8% production increase.

TAD - TAD machines can provide a wide range of sheet moistures coming to the Yankee from as low as 10% to upwards of 40%. These machines almost exclusively utilize virgin furnish due to the high softness grades produced, as well as perceived difficulties in efficient use of the TAD dryer with recycle furnish. Creping moistures are typically less than 5%. For TAD machines the adhesive needs to provide the necessary wet tack adhesion to transfer the relatively "dry" sheet to the Yankee. Traditionally this has been accomplished with a two-part adhesive program utilizing polyvinyl alcohol (PVOH) for wet tack and a polyaminoamide-epichlorohydrin (PAE) polymer for dry tack at the creping blade and durability. Recently a simplified single-component advanced adhesive has been introduced for TAD and hybrid machines eliminating the necessity for two-part adhesive programs *(reference 10)*. Required adhesive add-ons are high (30-60 mg/m²) to build a thick enough coating layer to transfer the structured sheet which will only have a contact area of 25% or less with the dryer surface. For TAD coatings modifiers are typically used to soften and control film build as well as to adjust the film durability. Humectants can be used to accommodate the lack of moisture contribution to the coating from the sheet and the low creping moistures. Phosphates are typically beneficial in contributing to uniform films. It should also be recognized that the release chemistry used on the TAD fabric can also impact the Yankee coating properties.

TAD Case Study – Nalco Water's NAVIGATOR™ adhesive products offer customers unique PAE-based adhesives in terms of film softness and durability. Although they can be used on CWP assets, they are particularly effective on advanced machines. Table II provides a snapshot of a recent conversion from a competitive PVOH/PAE adhesive program to a PVOH/Navigator program. Improvements were observed in speed, breaks per day and blade life resulting in a 7% production increase.

Towel Results	Before	After
Yankee Speed (ft/min)	4,250	4,500
Breaks per Day	14	10
Production (relative tons/time)	1	1.07
Creper Life (hr)	24	48
Cleaner Life (hr)	4	8

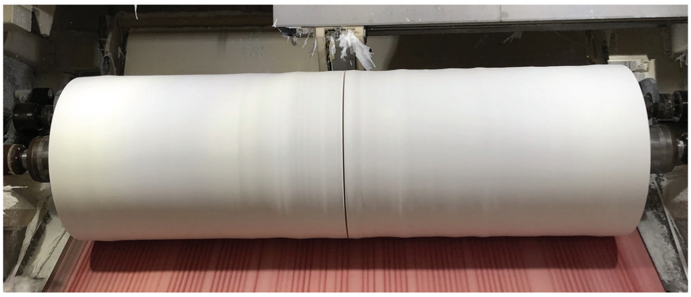
Table II: Result summary of a TAD Yankee coating conversion from a competitive PVOH/PAE adhesive program to a PVOH/Navigator program on a 26 gsm towel grade.

Hybrid – Hybrid machines currently encompass several branded machine types including Advantage™ NTT®, Advantage™ QRT® and Advantage™ eTAD® from Valmet and ATMOS from Voith. The NTT, QRT and ATMOS machines can switch from conventional to structured sheets dependent on the fabric or belt installed. Hybrid machines can present a fairly wide sheet moisture range at transfer to the Yankee (46-64%) and represent an intermediate range between that of CWP and TAD. Hybrid machines are more versatile that TAD's with their ability to handle recycle fiber. Creping moistures tend to be similar to TAD at less than 5%. Hybrid machine technologies are still evolving at a rapid pace, and similarly, components like fabrics/belts and Yankee coatings are also still in a dynamic phase of development. Current Yankee coating technology tends to be a hybrid of TAD and CWP considerations. PVOH is typically used as an adhesive component, similar to TAD, in conjunction with a PAE. Simplified one adhesive programs are also taking hold *(reference 10)*. Depending on machine type, the coating needs to accommodate both "flat" and structured sheets with surface contact areas of essentially 100% (flat) to approximately 25-60% for structured sheets. Adhesive add-on ranges tend to be in the 15-30 mg/m² range, although extremes can be seen as low as 10 mg/m² and as high as 70 mg/m². Both modifiers and releases can be used as well as humectants and phosphates.

Hybrid Case Study – In this example Nalco's NAVIGATOR™ adhesive technology in conjunction with PVOH was utilized to provide dependable transfer to the Yankee, more reliable machine runnability, good adhesion at the creping blade and much more uniform parent reel building. A before and after comparison of reel build with the previous PVOH/PAE program to the PVOH/Navigator program is shown in Figure 8. The combination of good transfer and creping adhesion resulted in a flatter reel profile.

Parameter	CWP	Hybrid	TAD
Transfer Moisture (%)	80-90	46-64	10-30+
Contact Area (%)	~100	~25-60 (structured)	~25
Adhesive Add-on (mg/m^2)	1-5	10-25	30-60
PVOH Use	No	Yes	Yes
Modifier	Sometimes	Mostly	Mostly
Release	Mostly	Sometimes	Sometimes
Humectant	Sometimes	Mostly	Mostly
Phosphate	Varies	Varies	Mostly

Table III: Summary of Yankee coating considerations for the three major machine types.



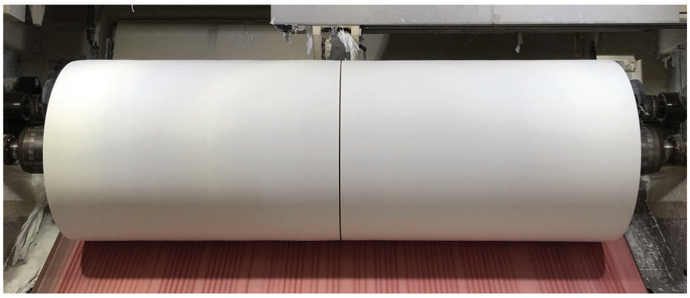


Figure 8: Before and after photographs of parent reel build on an NTT hybrid machine when changing the Yankee coating from a PVOH/competitive PAE program to a PVOH/Navigator PAE program.

CONCLUSION

Yankee coating considerations for the three major machine types discussed in this review are summarized in Table III. The major points discussed in this review include,

- Creping is the key unit operation in the tissue making process and largely defines the end-product attributes of the tissue. It is governed by a complex interaction between mechanical, operational, and chemical factors.
- Yankee coating is critical to the creping process and, therefore, to the overall performance of the tissue machine both in terms of operational efficiency and finished product quality.
- The coating design needs to accommodate the machine type (operating conditions) and grade considerations (fiber and wet end chemistry). Therefore, innovative coating suppliers strive to provide a comprehensive range of adhesive platforms that are tailored to these different conditions.
- Equally important is a full range of other coating components including releases, modifiers, humectants, and phosphates.
- Aligning the correct coating to machine type and operating conditions drives enhanced and more consistent sheet quality and machine efficiency.

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