

Optimization of coating with water-based barriers

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ABSTRACT: For reasons of personal health and the environment, consumers are searching for “green” products. Packaging producers and consumers are seeing increased regulations set by authorities for packaging material and waste. Thus, interest in the development of renewable, sustainable fiber-based packaging products is growing. In recent years the paper industry has focused on finding substrates and the chemical suppliers have focused on developing different coating media to enhance properties. Sustainable paper and board barrier products are needed to create an alternative to the use of conventional packaging solutions containing plastics, perfluorocarbon, and wax. Typically, products with a water-based barrier coating are more expensive than conventional packaging solutions. Therefore, to make the new products with water-based barrier coatings cost competitive, the best achievable performance with the lowest coat weight is important so that production costs can be kept as low as possible. Results from pilot trials are presented that consider base stock (pretreated and non-pretreated), application methods by long- and short- (zero) dwell, and metering by rod and resilient tip. Laboratory evaluations of the coverage and barrier performance indicate the proper direction for obtaining a barrier.

Application: Mills can benefit from a new means to apply and meter barrier coatings. Optimization of base stock, coating application, and metering will result in a barrier-coated stock that combines performance and economics.

Sustainable paper and board barrier products are needed to create an alternative to the use of conventional packaging solutions containing plastics, perfluorocarbon, and wax. Typically, products with a water-based barrier coating (WBBC) are more expensive than the conventional packaging solutions. Therefore, achieving the best performance with the lowest coat weight is important to make the new products with WBBCs cost competitive by keeping the production costs as low as possible.

It is well known that a precondition to enable barrier properties is to get full coverage of the surface. For a continuous film to be achieved, the barrier layer should have no defects. Examples of defects are pinholes caused by protruding fibers, differential coat weight across the sheet, foam holes, excess penetration of the coating into a rough, porous sheet [1], or pinholes related to drying [2]. The coverage is dependent on different application and metering methods, as well as the base substrate [2].

A key area of development is food wraps with low basis weight for carryout foodservice applications. This is expected to be one of the major grades as the demand for carryout food increases. Market reports have concluded that this grade of product is significantly increasing because of global megatrends and growth of the “food-on-the-go” industry [2]. Furthermore, food wraps that are oil and grease resistant (OGR) are an optimal product for WBBCs in an initial stage. The OGR barrier is in contact with the media it is intended to protect for a significantly shorter time (approximately one hour) than products that are in contact with the media during the entire shelf life, which can be up to several months.

Lightweight food wraps require achieving OGR barrier at very low coat weights. Minimization of coat weight is particularly necessary in this application because cost is crucial, the final sheet basis weight must remain the same, running a very lightweight sheet through a paper machine with too high a substitution of fiber with coating is difficult, and too much coating interferes with repulpability and recyclability.

The base paper used in the study was a machine-glazed paper with a basis weight of 27 lb/3300 ft² (40 g/m²), which is a commonly used base for flexible packaging such as food wrap. The normal treatment to enhance the grease resistance is by means of fluorochemicals, wax, or both. This treatment is not optimal for the recyclability, and there are also questions regarding sustainability in terms of safety for users [3].

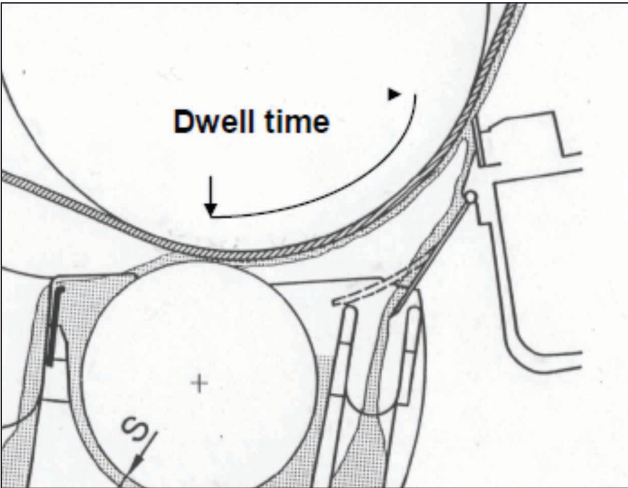
The media used for the trials was a WBBC that is available in the market. Because the media is both recyclable and repulpable, the results from the trials with the WBBCs will give guidance about the possibilities of an alternative treatment that enables the end product to be recyclable and repulpable, in comparison with conventional products.

METHOD

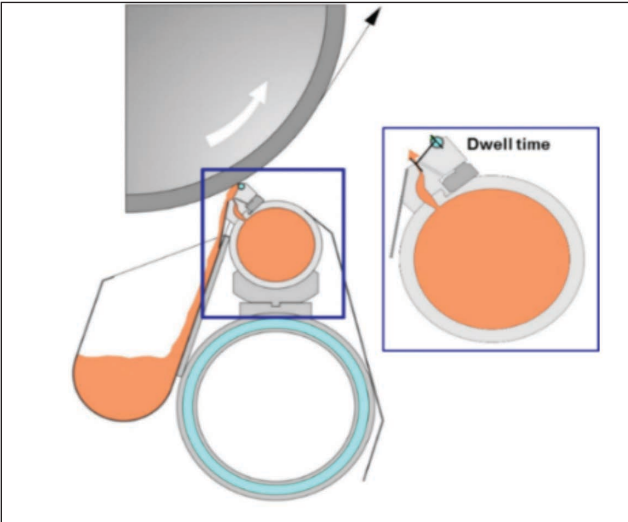
Barrier properties related to the coverage

A condition to achieve sufficient barrier properties with WBBCs is to get good coverage with the barrier. The coverage relates to different factors such as type of media applied, coat weight, absorbency of the media into the base, and coating technology [4]. Different barrier media have different properties and working areas (amount of media required for properties). However, the common factor is that the media held out

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1. Dwell time in a conventional rod/blade coater with roll applicator.



2. Dwell time in a zero-dwell time coater.

onto the surface of the substrate gives the barrier properties, whereas material absorbed contributes little to the barrier.

To achieve barrier and a sustainable production economy, absorption of the media into the base needs to be minimized. This can be optimized in two ways: either by having a more

closed structure of the base [1], or by adapting the coating technology dwell time (time between application and metering).

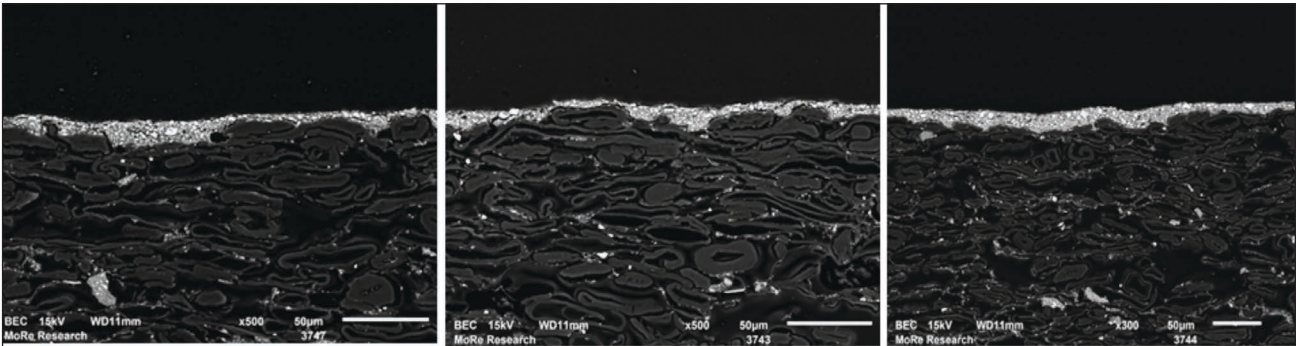
In the trials, two different base papers were used. One was an untreated base with a more open and porous structure and the other was a surface-sized base with a more closed and less porous structure. To analyze the effect of the absorption of the media into the base, two different applications were used. The first was long dwell time application by means of a roll applicator and the second was short dwell time by means of a zero-dwell applicator.

Figures 1 and 2 show the two different coating technologies evaluated: long (Fig. 1) and short (Fig. 2) dwell time (time between application of the media and the metering element). The dwell time relates to the position of the roll applicator, blade beam, and backing roll diameter. For the conventional long-dwell coater shown in Fig. 1, if the backing roll has a diameter of 31.5 in. and an operating speed of 984 ft/min, then the dwell time is 0.125 s. The coater shown in Fig. 2 has a design that enables a very short dwell time (also called zero-dwell time coater). The dwell time at 984 ft/min is 0.006 s.

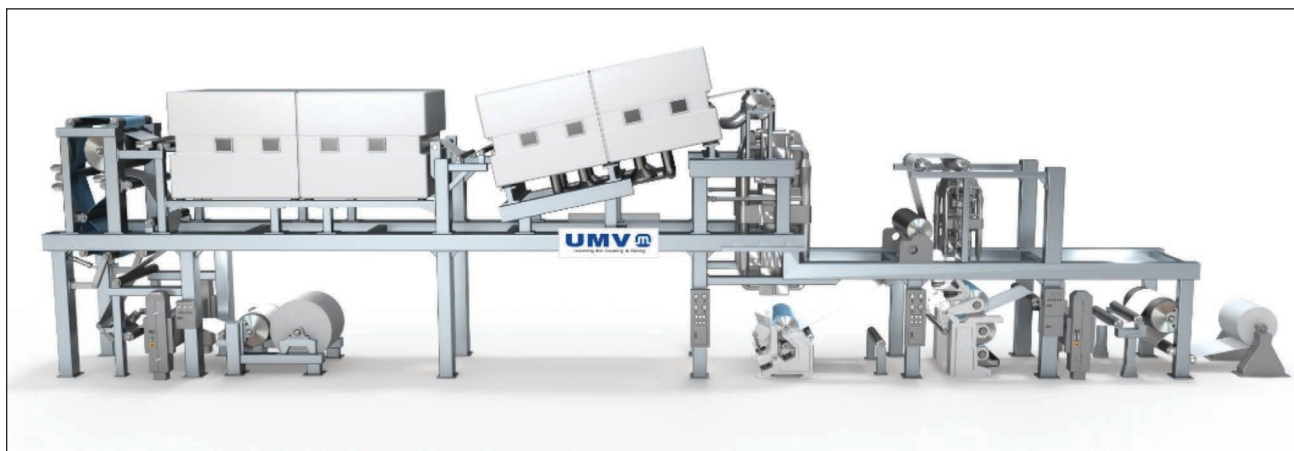
In addition to the dwell time, a barrier is most vulnerable to areas of failure where the coat weight is lowest. Therefore, the target is the same coat weight all across the web. A contour coating of uniform thickness is preferable to the smooth coating that is achieved with blade doctoring [5]. The images in **Fig. 3** show the distribution of coating media related to different metering elements. The magnitude of the difference between the coat weight in the peaks and valleys depends on which metering element is used [6]. Bent-blade doctoring tends to give the highest coat weight, rod doctoring shows some contours, and resilient metering devices show the most

Variables	Constants
Base paper	Speed
Metering element	Media
Application technology (dwell time and layers)	Drying strategy

1. Variables and constants for pilot trials at UMV pilot coater.



3. Scanning electron microscope (SEM) image showing distribution with blade, rod (smooth), and resilient metering.



4. UMV Coating Systems pilot coater.

			Coating Station Setup					Comment
TP	Base	Speed (ft/min)	Media	Solids	Coater concept	Coatweight lbs/1000ft ² (g/m ²)	Metering element	
Pre-trial	Untreated	984	Starch	15%	Surface sizing	0.185 (0,9)	Rod	
1	Untreated	984	WBBC	47%	Zero dwell coater	0.51 (2,5)	Rod	
2	TP1	984	WBBC	47%	Zero dwell coater	0.33 (1,6)	Rod	2nd layer on TP1 total cw: 0.88 lbs/1000ft ²
3	Untreated	984	WBBC	47%	Zero dwell coater	0.51 (2,5)	Resilient metering	
4	TP1	984	WBBC	47%	Zero dwell coater	0.33 (1,6)	Resilient metering	2nd layer on TP3 total cw: 0.88 lbs/1000ft ²
5	Surface sized	984	WBBC	47%	Zero dwell coater	0.51 (2,5)	Rod	
6	Surface sized	984	WBBC	47%	Zero dwell coater	0.51 (2,5)	Resilient metering	
7	Untreated	984	WBBC	47%	Blade coater roll metering	0.51 (2,5)	Rod	
8	Untreated	984	WBBC	47%	Blade coater roll metering	0.88 (4,3)	Rod	
9	Untreated	984	WBBC	47%	Blade coater roll metering	0.51 (2,5)	Resilient metering	
10	Untreated	984	WBBC	47%	Blade coater roll metering	0.88 (4,3)	Resilient metering	
11	Surface sized	984	WBBC	47%	Blade coater roll metering	0.51 (2,5)	Rod	
12	Surface sized	984	WBBC	47%	Blade coater roll metering	0.51 (2,5)	Resilient metering	

5. Trial plan with the different variables implemented (WBBC = water-based barrier coating).

complete and uniform coverage. For the trials, metering by means of a smooth rod and a resilient metering element (INVO Tip, UMV Coating Systems; Säfte, Sweden) was used.

Pilot trials to investigate the impact of different variables

Pilot trials at UMV's pilot coater in Säfte, Sweden (**Fig. 4**), were performed to investigate the impact of the different variables and constants presented in **Table I**. The base paper was either untreated or surface sized, with a basis weight of 27 lb/3300 ft² (40 g/m²). The coating was on the rougher (not machine glazed) side. Metering was either with a smooth rod or resilient metering. Application technology was either with a conventional roll applicator (i.e., long dwell) or a zero-dwell

applicator. The machine speed was 984 ft/min (300 m/min).

The media used for application was CHP-30 (CH Polymers; Espoo, Finland). CHP-30 is a water-based dispersion of polymers with renewable ingredients and mineral pigments. The media is biodegradable, recyclable, and repulpable and complies with U.S. Food and Drug Administration §176.170 and 176.180 and German BfR XXXVI requirements. The media has a solids content of 48%, viscosity of 300 mPa, and pH 7–8.

The drying strategy was single-sided infrared drying to achieve the same moisture on the winder as on the unwinder. The maximum temperature during drying was 200°F (93°C). Drying was followed by a cooling cylinder at 39.2°F (4°C). The preliminary trial plan is shown in **Fig. 5**.

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Trial Point	Metering Element	Coat Weight lb/1000 ft ² , g/m ²	Total Coat Weight lb/1000 ft ² , g/m ²	Comment
1	Rod (14 mm)	0.61 (3)	0.61 (3)	Single coat
2	Rod (14 mm)	0.35 (1.7)	0.96 (4.7)	2nd layer on TP1
3	Resilient tip	0.57 (2.8)	0.57 (2.8)	Single coat
4	Resilient tip	0.33 (2.8)	0.90 (4.4)	2nd layer on TP3

II. Trials with zero-dwell application on untreated base.

Trial Point	Metering Element	Coat Weight lb/1000 ft ² , g/m ²	Total Coat Weight lb/1000 ft ² , g/m ²	Kit Test	Olive Oil Grease Test
1	Rod (14 mm)	0.61 (3)	0.61 (3)	4	Fail
2	Rod (14 mm)	0.35 (1.7)	0.96 (4.7)	12	Pass
3	Resilient tip	0.57 (2.8)	0.57 (2.8)	8	Pass
4	Resilient tip	0.33 (2.8)	0.90 (4.4)	12	Pass

III. Properties of zero-dwell application on untreated base.

Trial Point	Metering Element	Coat Weight lb/1000 ft ² , g/m ²	Total Coat Weight lb/1000 ft ² , g/m ²	Comment
5	Rod (14 mm)	0.41 (2)	0.45 (3)	—
6	Resilient tip	0.45 (2.2)	0.41 (2.2)	—

IV. Trials with zero-dwell application on surface-sized base

Trial Point	Metering Element	Coat Weight lb/1000 ft ² , g/m ²	Total Coat Weight lb/1000 ft ² , g/m ²	Kit Test	Olive Oil Grease Test
5	Rod (14 mm)	0.41 (2)	0.45 (3)	4	Fail
6	Resilient tip	0.45 (2.2)	0.41 (2.2)	7	Pass

V. Properties of zero-dwell application on surface-sized base.

Methods for analyzing and evaluating the samples from the trials

TAPPI T559 cm-02 “Grease resistance test for paper and paper-board,” commonly known as the Kit test, was used to evaluate the barrier properties. The Kit test was developed to determine grease resistance of papers treated with fluorochemicals and is still a well-known and widely used way to evaluate grease barriers for film-based barrier solutions.

For the olive oil test, olive oil at room temperature was applied on the base and left for 1 min. If no pinholes developed, the sample passed.

RESULTS

Trials with zero-dwell application on untreated base

Before the trials, air permeability was measured with a Bendtsen measurement device to determine the porosity/openness of the base. The results showed an air permeability of 90 mL/min Bendtsen.

The base was single- and double-coated with a zero-dwell application with the metering element as a variable. **Table II** shows the trial points performed. The samples from the trials were measured to analyze the final properties (**Table III**).

Trial Point	Metering Element	Coat Weight lb/1000 ft ² , g/m ²	Total Coat Weight lb/1000 ft ² , g/m ²	Comment
7	Rod (14 mm)	0.45 (2.2)	0.41 (2.2)	Single coat
8	Rod (14 mm)	0.88 (4.0)	0.88 (4.0)	Single coat
9	Resilient tip	0.51 (2.5)	0.51 (2.5)	Single coat
10	Resilient tip	0.88 (4.3)	0.88 (4.3)	Single coat

VI. Trials with long-dwell application on untreated base.

Trial Point	Metering Element	Coat Weight lb/1000 ft ² , g/m ²	Total Coat Weight lb/1000 ft ² , g/m ²	Kit Test	Olive Oil Grease Test
7	Rod (14 mm)	0.45 (2.2)	0.41 (2.2)	2	Fail
8	Rod (24 mm)	0.82 (4.0)	0.82 (4.0)	4	Fail
9	Resilient tip	0.51 (2.5)	0.51 (2.5)	6	Pass
10	Resilient tip	0.88 (4.3)	0.88 (4.3)	8	Pass

VII. Properties of long-dwell application on untreated base.

Trial Point	Metering Element	Coat Weight lb/1000 ft ² , g/m ²	Total Coat Weight lb/1000 ft ² , g/m ²	Comment
11	Rod (14 mm)	0.57 (2.8)	0.57 (2.8)	4
12	Resilient tip	0.57 (2.8)	0.57 (2.8)	7

VIII. Trials with long-dwell application on surface-sized base.

Trial Point	Metering Element	Coat Weight lb/1000 ft ² , g/m ²	Total Coat Weight lb/1000 ft ² , g/m ²	Kit Test	Olive Oil Grease Test
11	Rod (14 mm)	0.57 (2.8)	0.57 (2.8)	3	Fail
12	Resilient tip	0.57 (2.8)	0.41 (2.8)	7	Pass

IX. Properties of long-dwell application on surface-sized base.

Trials with zero-dwell application on surface-sized base

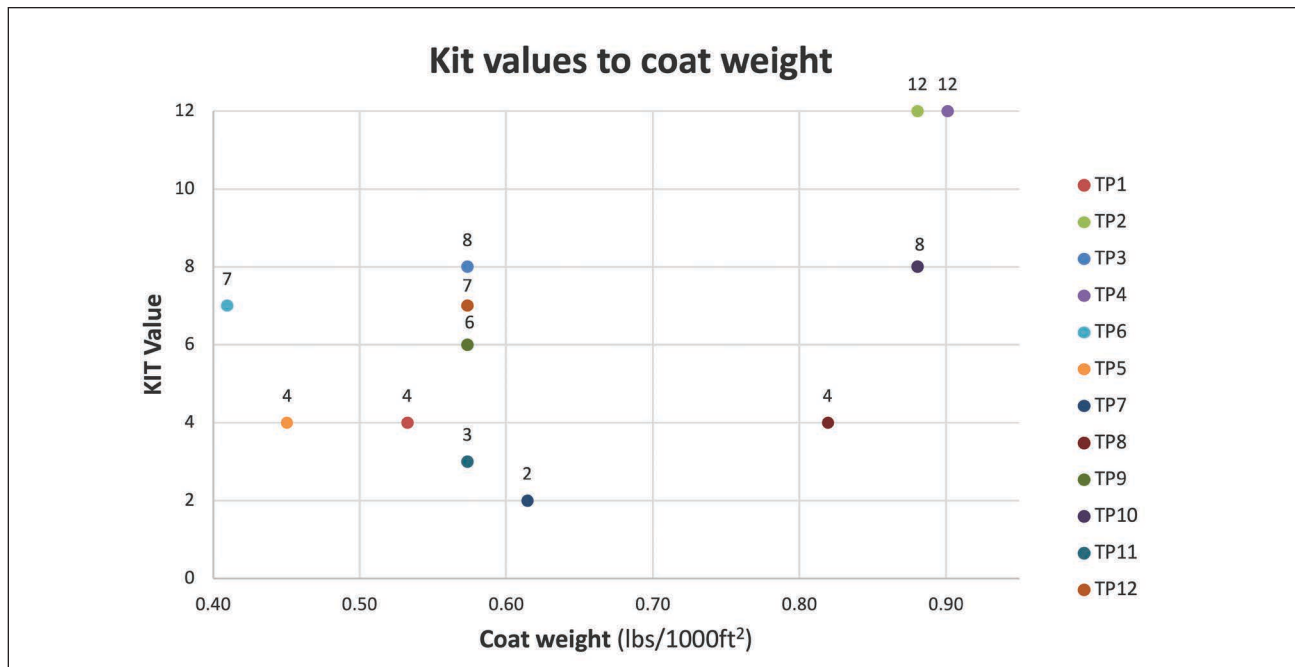
Before the barrier coating trials, the base paper was surface sized with starch with solids of 15% and a coat weight of 0.18 lb/1000 ft² to decrease the porosity/openness. The air permeability was controlled with a Bendtsen measurement device. The results showed air permeability of 39 mL/min Bendtsen.

The base was then single coated with a zero-dwell application with the metering element as a variable.

Table IV shows the trial points (TPs) performed. The samples from the trials were measured to analyze the final properties (**Table V**).

Trials with long-dwell application on untreated base

The base was single coated with a long-dwell application with the metering element as a variable. **Table VI** shows the trial points performed. The samples from the trials were measured to analyze the final properties (**Table VII**).



6. Graph showing relation between coat weight with Kit values for each trial point.

Trials with long-dwell application on surface-sized base

The surface-sized base (same as for the trials with zero-dwell application) was coated with a long-dwell application with the metering element as a variable. **Table VIII** shows the trial points performed. The samples from the trials were measured to analyze the final properties (**Table IX**). **Figure 6** shows the relation between coat weight and Kit values.

DISCUSSION

The conventional reverse-side coater in paper and board machines has a long-dwell application and smooth rod metering. The control for the study is shown in trial points (TP) 7 and 8. By changing different variables, the target was to optimize the barrier properties with approximately the same coat weight. The results varied depending on the different parameters.

The first thesis explored was that better holdout of the coating onto the paper surface would result in better barrier properties. Holdout was controlled either by having a more closed surface (surface sizing) or by minimizing the dwell time.

The impact of surface sizing is shown by comparing TP1 (smooth rod zero-dwell coater), TP7 (smooth rod long-dwell coater), and TP11 (smooth rod long-dwell coater). The trial points had a similar coat weight (approximately 0.60 lb/1000 ft²). However, the end Kit values varied from Kit 4 (TP1), Kit 3 (TP11), and Kit 2 (TP7).

Another interesting point is that when using a zero-dwell coater on a surface-sized base (TP5 and TP6), the properties did not improve compared with the similar trial points when an untreated base was used (TP1 and TP3). Thus, when operating with a coater with minimum dwell time, the structure

of the base is less important than with a long-dwell coater.

The trials with surface-sized base seemed to confirm the first thesis. Greater surface WBBCs will give better barrier properties. The use of a surface-sized base gives more room to optimize the barrier.

The second thesis is that the barrier is further enhanced by optimizing coating distribution on the surface. A better contour coat improves film continuity and coverage, thus optimizing barrier properties. Conclusions can be drawn by comparing TP1 (smooth rod zero-dwell) and TP3 (resilient metering zero-dwell), TP7 (smooth rod long-dwell), and TP9 (resilient metering long-dwell), and TP8 (smooth rod long-dwell) and TP10 (resilient metering long-dwell). All are comparable trial points with similar coat weights. However, the difference in barrier properties is significant between trial points when using a smooth rod, which is more levelling, and resilient metering, which follows the structure of the base (contour coating). For all these trial points, the Kit values increase by four units with resilient metering compared with smooth rod metering (TP1 and TP3 Kit 4–8, TP7 and TP9 Kit 2–6, and TP8 to TP10 Kit 4–8).

Barrier performance related to coat weight is also highlighted when comparing two thinner coating layers with one thicker layer. Double-coated trial points TP2 and TP4 can be compared with single-coated TP8 and TP10, for example. The trial points have approximately the same total coat weight (0.88–0.90 lb/1000 ft²). However, the Kit values are 12 for both double-coated trial points (TP2 and TP4) versus 4 (TP8) and 8 (TP10) for the single-coated points. By splitting the application into two layers, the second layer eliminates the defects from the first layer. OGR is increased dramatically by

applying a second layer, which is shown again in the TP1 and TP2 comparison. Adding an additional 0.35 lb/1000 ft² to the TP1 coating in the TP2 condition (smooth rod zero-dwell metering) raised Kit performance from 4 to 12.

From the previously described comparison, a conclusion may be drawn that to achieve the maximum barrier properties, two layers is beneficial. However, in many paper and board machines, having two coating stations for the reverse side is not possible because of space limitations. Typically, there is only one reverse-side coater; therefore, to enable best achievable performance with lowest coat weight possible, an optimization of the existing reverse-side coater is beneficial.

The study shows that there are ways to optimize the barrier layer that are applied in one step. Going from the starting point of TP7 (long-dwell application and smooth rod metering) with a Kit value of 2 to TP3 (zero-dwell and resilient metering) results in an increase in Kit value from 2 to 8. This means that there is great potential to optimize the performance of water-based barrier coatings. This optimization could be a step toward alternative products that could challenge the conventional packaging solutions.

CONCLUSIONS

The water-based barrier coating used in the trials was a constant, and at trial points with similar coat weights the result

varied because of different application and metering. This means if the application and metering of the WBBC is optimized, then the OGR properties will be increased.

With a long-dwell application, the use of a surface-sized base gives more room to optimize the barrier. However, when operating with a zero-dwell time application, the improvements are shown to be marginal.

Decreasing the dwell time or using surface-sized base is also interesting from a runnability point of view. Operating with lower basis weights because of less absorption of the water in the WBBC causes fiber swelling, which may lead to wrinkles [7].

In addition to the dwell time, a barrier is most vulnerable to areas of failure where the coat weight is lowest. Therefore, the target is the same coat weight all across the web, achieving equal coat weight in the peaks and valleys of the substrate surface structure.

To achieve high-performance barrier products, an application in two layers is needed. By splitting the application into two layers, the second layer eliminates the defects from the first layer.

The results indicate there are ways to optimize the performance of the water-based barrier layer. The application and metering can enable a transition to OGR products that are biodegradable, recyclable, and repulpable, in comparison with the conventional products. **TJ**

ABOUT THE AUTHORS

New barrier products are needed to create an alternative to the conventional solutions containing plastics, perfluorocarbon, and wax. A lot of research has been done on what to apply in barrier coating. In this study we wanted to research from another angle; that is, how to apply barriers.

Previously, we have studied application of barrier in multiple applications, which was presented at PaperCon 2015 under the topic "New coating concept gives improved barrier properties at reduced coat weight." The result from that study was reconfirmed in this research at application with two layers compared to one. What differs is that in this research, more variables are considered to find what differences are made to end properties. In addition, most research considers single-layer application.

Our research involved pilot trials at our pilot coater, which considered a lot of variables while trying to keep good runnability. We would like to thank our operators for good teamwork, and all the trials were done according to the plan.

From our previous work, we knew that minimizing the dwell time and having more contours would enhance the barrier properties. However, the magnitude each adaptation gave was something new to us. A surprising finding was the difference in grease

barrier properties with the conventional coater settings compared with the properties with an optimized coating application.

This work shows how water-based barrier coatings can be applied for achieving cost-competitive alternatives to the conventional products containing plastics, perfluorocarbon, and wax. For mills that have already made the transition, the research provides a way to minimize the usage of barrier media while keeping the properties at the same level.

We are now looking at alternative water-based barrier coatings that can have much higher viscosity than during the trials.

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