Journal of Korea TAPPI
Vol. 32. No. 5, 2000
Printed in Korea

Coating Immobilization Using Soy Protein Polymers: Technical Concepts and Importance to Quality

Donald F. Hiscock and Thomas B. Merrifield

ABSTRACT

Coating immobilization is the process by which the wet coating applied to paper or paperboard reaches the final form. A coating immobilization point is defined as the solids content reached during drying where no further redistribution of coating materials occurs. Good control of coating immobilization is important in producing coated paper and paperboard with consistent high quality. This paper discusses the technical concepts of how coatings immobilize, and describes the importance of good immobilization control on coating holdout and coating structure. The use of soy protein polymers to modify the coating immobilization point is discussed. Soy proteins, because of their interaction with coating pigments, make a significant contribution to the immobilization characteristics of coatings. This technology gives the formulator options for changing the immobilization point to improve the performance of the coating. The importance of immobilization on coating uniformity, microporosity and sheet qualities is discussed, including binder migration, mottle, gluing, and print quality.

1. Introduction

The three main steps in the process of coating paper or paperboard are (1) Application, (2) Metering, and (3) Drying. Coating immobilization occurs at some point after the coating is metered onto the sheet, but before the coating is completely dry. The immobilization characteristics of the coating are important in determining the final structure of the coating layer, and are important for obtaining consistent high quality. Numerous researchers have discussed the importance of coating immobilization to quality, including Coco[1-2], Coco and Whalen-Shaw[3], and Baumeister.[4]

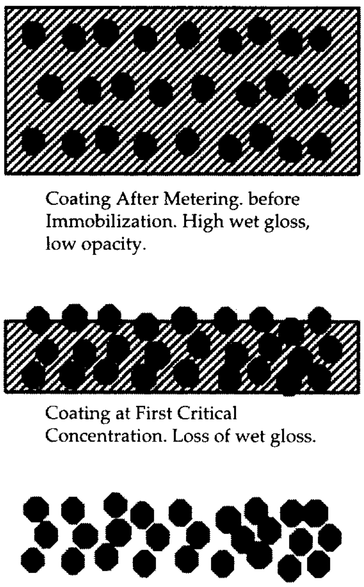
The immobilization properties of the coating are determined by the formulation, the interaction of the coating with the basepaper, and the drying conditions. This paper discusses how soy protein polymers can be used to modify the immobilization point of paper and paperboard coatings, and how these concepts can improve sheet quality.

2. Impacts of Coating Immobilization

Immediately after metering, the wet coating applied to the paper surface has maximum bulk and coverage. The wet coating on the paper surface remains fluid for a period of time, and during this time the pigment particles will pack closer together, the water phase of the coating will penetrate into the base sheet. The coating loses water through dehy-

• Protein Technologies International, a DuPont Company, USA.

dration into the base sheet, and increases in solids content. Small pigment particles can penetrate into the base sheet. Consolidation and packing of the pigment can lead to nonuniformity in the distribution of coating components. There may remain on the paper surface a film of surfactants or other aqueous phase components. The coating particles pack closer together as the continuous phase of water retreats, causing a loss in coverage and bulk. The coating loses pore volume as the coating density increases. Small scale variations in the immobilization rate of the coating can lead to mottle in the final product or in the printed image on the final product. Processes that require good coating microporosity, such as offset printing or gluing of packaging board, can be lower quality if the coating immobilization process is not controlled.



Coating After Metering. before Immobilization. High wet gloss, low opacity.

Coating at First Critical Concentration. Loss of wet gloss.

Coating at Second Critical Concentration. Increase in opacity.

Fig. 1. First critical and second critical concentrations.

3. Theoretical Background

LePoutre[5] described coating immobilization using two important concepts, which are easily understood and easily observed, although not easily measured. The First Critical Concentration (FCC) is defined as that solids content reached during drying where the surface gloss of the coating layer decreases. This happens when the water in the coating no longer forms a smooth film on the surface and the roughness of the pigment particles scatter light on the coating surface. The Second Critical Concentration (SCC) is defined as that solids content where the opacity of the coating layer increases. This happens when the coating becomes dry enough by water loss between the pigment particles in the coating, leading to light scattering. The FCC and SCC are illustrated in Fig. 1.

Measurement of the FCC and SCC is difficult because they are transient phenomena occurring during a dynamic process. Simple laboratory techniques have been developed to simulate the immobilization process and aid formulation development. One of these techniques, called Viscosity Immobilization Solids (VIMS), is based on bench top viscosity measurements. VIMS normally measures coating immobilization at a solids content lower than the FCC, although the same mechanisms relate the two. The following steps explain the VIMS concept and how measurements are made:

1. The coating is applied at a certain viscosity/ solids level (the running conditions on the coater).

2. The coating immediately begins to consolidate, drying initially through water loss into the base sheet.

3. At some point long before the coating is completely dry, the coating becomes immobilized. The immobilization point

is defined as the point where there is no further redistribution of coating components. This happens when the viscosity becomes too high for the components to redistribute.

Since the viscosity/solids relationship can be modeled using an exponential function, the VIMS point occurs when the curve becomes asymptotic. This is the viscosity immobilization solids.

4. For consistency, VIMS is defined as the solids level where the Brookfield 10 rev/min viscosity reaches 20000 mPa · s. Low shear rates are used because this mimics the static conditions of the coating after metering. The 20000 mPa · s is somewhat arbitrary. It really doesn't make much difference what level is used beause the viscosity is increasing exponentially at this point. It is possible to make these measurements at elevated temperature, if the temperature coefficient of viscosity of the coating is significant. In the laboratory, the coating is prepared at high solids and 3 to 7 viscosity measurements are made as it is diluted over a range of 10-20%.

5. The results are graphed, using extrapolation if needed to estimate the VIMS point. Most graphics software allows exponential trend lines to be fitted to the data, and calculates statistical estimates of fit. As an alternative to make analysis of the data more convenient, the viscosity vs. solids data can be graphed using a semi-log scale. In this case the exponential curve becomes a straight line. This makes extrapolation and comparison easier, and does not require software.

Fig. 2 illustrates that the slope of the line predicts the immobilization rate of a coating. The exponential relationship between coating solids and viscosity can be expressed using the following relationship:

$$y = ae^{bx}$$

The logarithmic form makes this a linear equation, as follows:

$$\log(y) = \log(a) + bx \cdot \log(e)$$

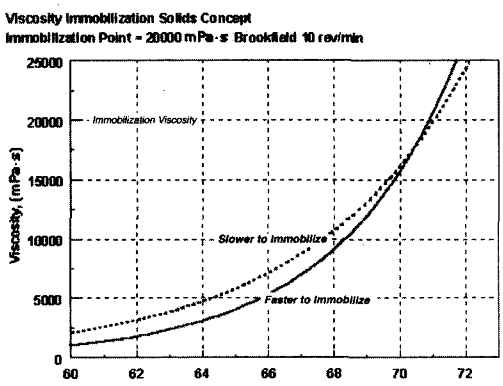


Fig. 2. Linear axis VIMS graph showing coating solids content vs. viscosity for faster and slower immobilizing coatings.

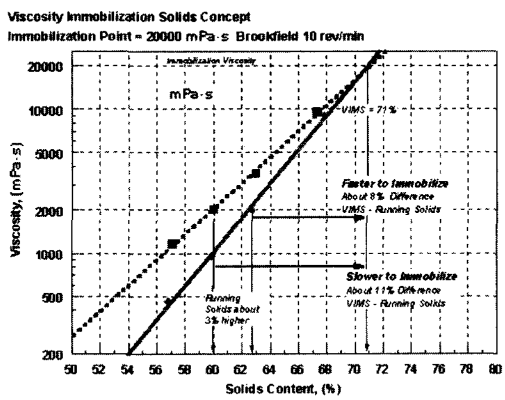


Fig. 3. Semi-log axis VIMS graph showing coating solids content vs. viscosity for faster and slower immobilizing coatings.

In this case b, the exponent in the original exponential equation, becomes the slope of the linear equation. This means that steeper slopes for the VIMS line result in faster coating immobilization.

Rapid coating immobilization is key to producing coating bulk and coverage, as shown in Fig. 4. It is important to minimize the difference between running solids and immobilization solids. This can be achieved by using the highest possible running solids, which is one reason why high-solids coatings are a popular and sound technical strategy. In some cases, however, there are practical limitations to increasing the running solids. Too high coating solids can lead to high-shear instability of the coating, and problems with coat weight profile, coat weight control, and blade runnability (streaks and scratches) in some systems. Coating application systems usually have an optimum low-shear viscosity range for operation, and this can limit the solids content of the coating on machine. In situations where the operating window of the coating or coater dictates running solids, it is not always possible to run the highest solids needed for quality. Regardless of the running solids of the coating, and decreasing the immobilization point can enhance coating properties. Water holding must be controlled to provide a balance of good runnability and good immobilization. Runnability requires the coating to have sufficient water holding, yet immobilization requires rapid water removal. Air knife coatings often use soy protein polymers to improve immobilization control because the low solids used for air knife coatings can result in a poor quality due to mottle, binder migration, and poor coverage if immobilization is not controlled.

Soy protein polymers control immobilization through pigment interaction. These interactions are a result of electrostatic and steric effects. The extent of pigment interaction is dependent on formulation (pigment type, binder level), operating conditions (coating solids, pH), and the soy protein polymer chemistry (molecular weight,

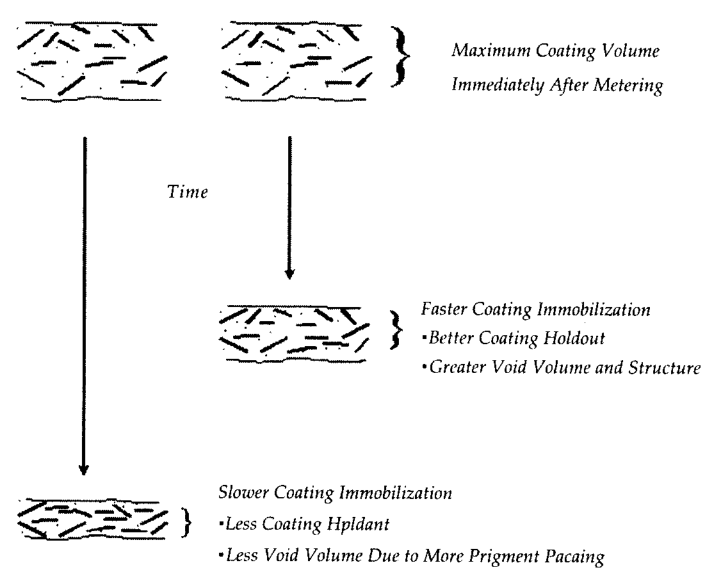


Fig. 4. Rapid coating immobilization gives better coating properties.

charge characterisitics). Details about soy protein polymer chemistry have been discussed by Coco.[1)]

4. Practical Applications of Immobilization Control

A trial was run in order to demonstrate the effect of changing the difference from running solids to immobilization solids on finished paperboard properties. The objective of the trial was to improve the print quality of the double coated board, specifically reducing the tendency to mottle. Print mottle takes several forms, all of which are related to non-uniformity in the distribution of coating components. The precoat formulation was adjusted to result in acceptable application properties, coat weight control, and rapid immobilization to result in increased void volume to reduce the print mottle.

The trial replaced the sodium carboxymethyl cellulose thickener and part of the latex binder with soy protein polymer. The final paperboard was 210 g/m^2 with target coat weights of 12 g/m^2 precoat and 10 g/m^2 topcoat. The coating configuration was blade precoat followed by blade topcoat, and the coatings were applied at 280 m/min. Table 1 shows the formulations used for this precoat trial.

IMS graph of the reference and trial precoats is shown in Fig. 5.

The reference and trial pre-coat samples were top-coated using the formulation shown in Table 2.

Sheet properties were measured for the

Table 1. Precoat formulations for precoat immobilization machine trial in blade-blade coated ivory paperboard

	Ingredient	CMC Precoat	Soy Polymer Precoat
1.	$CaCO_3$, 60%<2 μm	100	100
2.	Latex	14.0	12.0
3.	CMC	1.0	-
4.	Soy Protein Polymer	-	2.5
	Solids Content	65.7	67.9
	Viscosity (mPa · s, 100 rpm)	1500	900

Table 2. Topcoat formulation for precoat immobilization machine trial in blade-blade coated ivory paperboard

	Ingredient	CMC Topcoat
1.	$CaCO_3$, 97%<2μm	65
2.	US Number 1 Clay	35
3.	Latex	15.0
4.	CMC	0.6
	Solids Content	62.0
	Viscosity (mPa · s, 100 rpm)	1500

Table 3. Precoat board test results for precoat immobilization machine trial in blade-blade coated ivory paperboard

Property	(units)	CMC Precoat	Soy Polymer Precoat
1. Basis Weight	g/m^2	215	215
2. Target Coat Weight	g/m^2	12	12
3. Brightness, ISO	points	84	84
4. Smoothness, PPS S-10	μm	3.5	3.4
5. Croda Red Ink Receptivity, 30 sec	point drop	48	50
6. IGT Dry Pick Printability, using: Ink Tack: 7, Speed: M, Pressure: 50	cm/sec	No Pick	No Pick

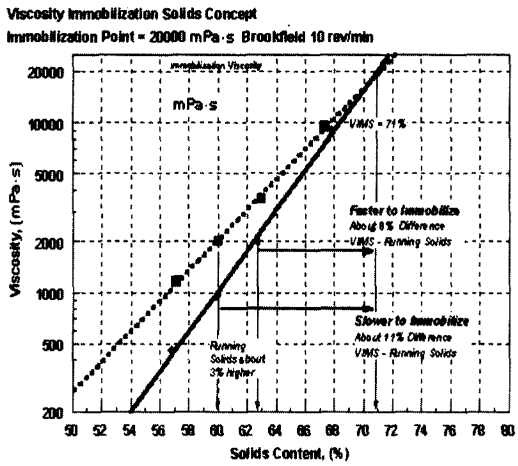


Fig. 5. VIMS chart for reference and trial precoats, showing improved difference from running solids to immobilization for soy protein polymer formulation.

precoat only samples and for the double-coated finished samples. Commercial print trials were conducted to measure print quality. Precoat results are shown in Table 3. The smoothness of the soy polymer precoat is better, and ink receptivity tests show greater porosity. This will improve, in turn, the immobilization and uniformity of the topcoat. These results demonstrate the effects of improved coating immobilization.

Properties of the double-coated paperboard are shown in Table 4. Higher ink gloss and significantly reduced print mottle were achieved with the improved precoat. Smoothness and sheet gloss were also improved. This trial shows that the precoat has a significant effect on the final board quality. The improved precoat, achieved through coating immobilization control, results in more uniform structure and print quality in the final coated board.

Table 4. Double-coated board test results for precoat immobilization machine trial in blade-blade coated ivory paperboard

Property	(units)	CMC Topcoat	CMC Topcoat
		CMC Precoat	Soy Polymer Precoa
1. Grammage	g/m^2	215	215
2. Target Coat Weight, Total	g/m^2	22	22
3. Oxygen Ash	%	9.2	9.2
4. Brightness, ISO	points	89	88
5. Color, CIE	L	93.7	93.6
	a	0.4	0.5
	b	-2.4	-2.0
6. Sheet Gloss , 75°	%	47	49
7. Smoothness, PPS S-10	µm	1.2	0.8
8. Croda Red Ink Receptivity , 30 sec	point drop	37	40
9. IGT Dry Pick Printability, using: Ink Tack: 7, Speed: M, Pressure: 50	cm/sec	No Pick	No Pick
10. Prüfbau Printability			
Wet Pick	1-5,5=best	3.5	3.5
Ink Refusual	1-5,5=best	4.0	4.0
Ink Gloss	%	92	98
11. Print Mottle, Commercial Offset Printing	visual rating	More	Much Less

5. Conclusions

Good control of coating immobilization is important in producing coated paper and paperboard with consistent high quality. Soy protein polymers can be used to modify the coating immobilization point through interaction with coating pigments, and can help the coating reach its immobilization point more rapidly during drying. This technology gives the formulator options for changing the immobilization point to improve the performance of the coating, with resulting improvements in sheet properties that are affected by coating void volume and coating uniformity, such as binder migration, print quality and print mottle, and gluing.

Literature Cited

1. C. E. Coco, Modified Soy Protein-Tools for Controlled Coating Properties, 1983 TAPPI Coating Conference Proceedings, p. 109.
2. C. E. Coco, The Effect of Protein-Latex Ratio on Binder Migration, Runnability and Resultant Coated Board Properties., 1984 TAPPI Coating Conference.
3. M. Whalen-Shaw and C. E. Coco, "The Effect of Controlled Coating Structure on Offset Printability", 1985 TAPPI Coating Conference Proceedings, p. 97.
4. M. Baumeister, "Significance and Implications of the Concept of Immobilization Solids in Relation with Coating Structure", 1987 TAPPI Coating Conference Proceedings, p. 84.
5. J. Watanabe and P. LePoutre, "An Investigation of the Development of the Structure of Clay-Latex Coatings", TAPPI Coating Conference Proceedings, p. 181.