A statistical study of process variables to optimize a high speed curtain coater — Part I

PEEYUSH TRIPATHI, MARGARET JOYCE, PAUL D. FLEMING, AND MASAHIRO SUGIHARA

ABSTRACT: Using an experimental design approach, researchers altered process parameters and material properties to stabilize the curtain of a pilot curtain coater at high speeds. Part I of this paper identifies the four significant variables that influence curtain stability. The boundary layer air removal system was critical to the stability of the curtain and base sheet roughness was found to be very important. A shear thinning coating rheology and higher curtain heights improved the curtain stability at high speeds. The sizing of the base sheet affected coverage and curtain stability because of its effect on base sheet wettability. The role of surfactant was inconclusive. Part II of this paper will report on further optimization of curtain stability with these four variables using a D-optimal partial-factorial design.

Application: Papermakers may use the findings of this study to optimize the runnability of a curtain coater at high speeds.

High-speed curtain coating is an emerging low-impact coating process [1-11]. The ability to apply a contour-like coating layer with minimal effect on the base sheet can provide better fiber coverage at lower coat weights than conventional coating processes [1, 2]. That might enable mills to reduce costs by using higher filler loading and less expensive fibers in the base sheet. Curtain coating is emerging as the preferred application method for carbonless and thermal paper production [9], where superior coverage is a critical coating attribute. It also can be operated with little or no substrate tension, leading to lower drive power requirements and fewer breaks. Curtain coating is a contour coating method, which is free of film split patterning, resulting in a defect-free coating surface. Curtain coating is a versatile coating process that enables a wide range of coating viscosities and coat weights to be achieved with a single coating head [1-4, 6, 7].

Although curtain coating offers advantages over conventional coating processes, its commercial use has been hampered by the need for advancements in deaeration technology [10] and development of coating formulations with properties suited for this application. The stability of the curtain [1] and air entrainment at the dynamic wetting line at high speeds [1, 2] are two of the major technical problems limiting the commercial acceptance of the curtain coater. To understand the causes for these limitations requires an understanding of the basic operations of a curtain coater.

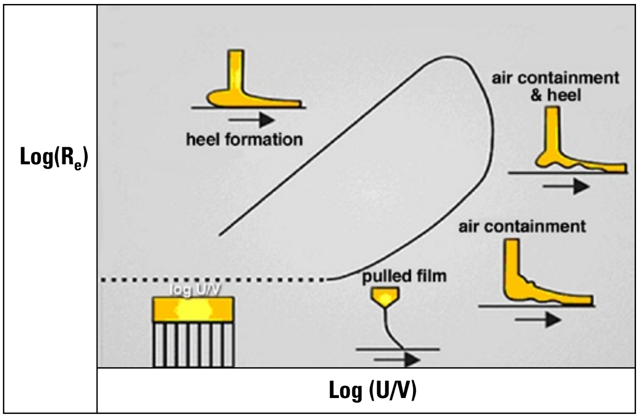
The point of contact between the free-falling curtain, moving substrate, and the adjoining space is termed the impingement zone. Understanding the complex interaction between the substrate and the curtain is a developing science. The presence of boundary layer air, associated with rough substrate movement, further adds to the complexity of these interactions.

In 1961, Brown [12] proposed the principle equations to describe the process. These equations are useful in understanding the fundamental principles governing the influence of the interactions between inertial and surface tension forces on curtain stability. Using these equations, Triantafillopoulos, et al., [1, 2] showed the dependence of curtain stability on Reynolds number, ratio of web speed (U), impingement velocity (V), and Weber number [1, 2]. From these calculations, the operational window for coat weight, Reynolds number and U/V ratios were defined for their given system.

Based on Triantafillopoulos' findings and past studies, the stability of a curtain is related to the Weber number [1]. The Weber number ($\rho v^2 d/\gamma$, where ρ is the density, v is the velocity, d is the curtain thickness, and γ is the surface tension) is a dimensionless flow parameter, which relates the inertial forces to the surface tensional forces of the free-flowing curtain. A Weber number >2 has been considered essential to obtain a stable curtain. However, a more in-depth analysis of the physics of fluid flow [13] suggests that the same criteria can be met at lower inertial forces, or a Weber number >1.5.

Three physical conditions influence the operation of a curtain coater and dynamics of film formation: the heel, strands, and pulled film. **Figure 1** presents a schematic of each physical condition. The heel is formed when the curtain is not completely moved in the direction of the web, but flows slightly in the opposite direction. Strands result from insufficient flow, which causes a well-formed curtain to break up and contract into strands. A pulled film occurs when the coating fails to contact the substrate right below the slot and is pulled forward with the web.

Although much work has been done to understand the



1. Curtain instabilities.

dynamics of curtain coating operation, little has reported on the influence of process and formulation parameters on curtain stability at high speeds. Our objective was to study the effect of various process and coating parameters on high speed curtain stability. Curtain stability was assessed by visual observations and paper coverage.

MATERIALS AND METHODS

In the first phase of this research, we generated a Taguchi [14] experimental design using Stat Ease software to quantify the effect of eight variables on curtain stability. The variables were curtain height, the steam flow rate of a steam substitution system, coating rheology, surfactant dosage, coat weight, web speed, base sheet roughness, and base sheet sizing. The Taguchi method enabled the influence of the main effect variables on response variables to be determined with relatively few coating trials.

The coating studies were performed on a pilot curtain coater at Mitsubishi Heavy Industries (MHI) in Hiroshima, Japan. The offline coater was 600 mm wide and equipped with a high-speed video camera to capture images of the curtain film during operation. These video images were later analyzed to determine the degree of curtain stability for each condition run.

A "generic" offset coating formulation appropriate for lightweight coated (LWC), heat-set web offset commercial publication grade paper was prepared using a high shear Cowles mixer. After preparation, the coating was transferred to a constant temperature tank and maintained at 30°C.

Coating #	Clay Ultra White 90 (Imerys)	Carbonate Carbital (Imerys)	CMC (Cellogen PR)	Latex (JSR 2600)
	pph	pph	pph	pph
I	30	70	0.5	7
II	40	60	0.4	12
III	40	60	0.45	12

I. Coating formulations.

Table I lists the amount and type of each component used. The levels of all other additives were kept the same. The lubricant (Nopcote C-104; Geo Specialty Chemicals, Allentown, Pennsylvania, USA) was added at 0.06 pph, soy protein isolate-based resin at 0.5 pph, and sodium hydroxide at 0.1 pph to keep the coating pH between 9-9.5. A highly soluble anionic surfactant (Niaproof 4; Geo Specialty Chemicals) was added at levels of 0.02, 0.20, and 0.8 pph to obtain different surface tensions (40, 35, and 30 mN/m, respectively). We measured surface tensions of the coatings using a Wilhelmy plate. A stable curtain is especially critical at lower flow rates; the surface tension must be reduced to maintain a proper Weber number. Thus, the understanding of surfactants and the surface tension is fundamental to understanding factors affecting high speed curtain stability.

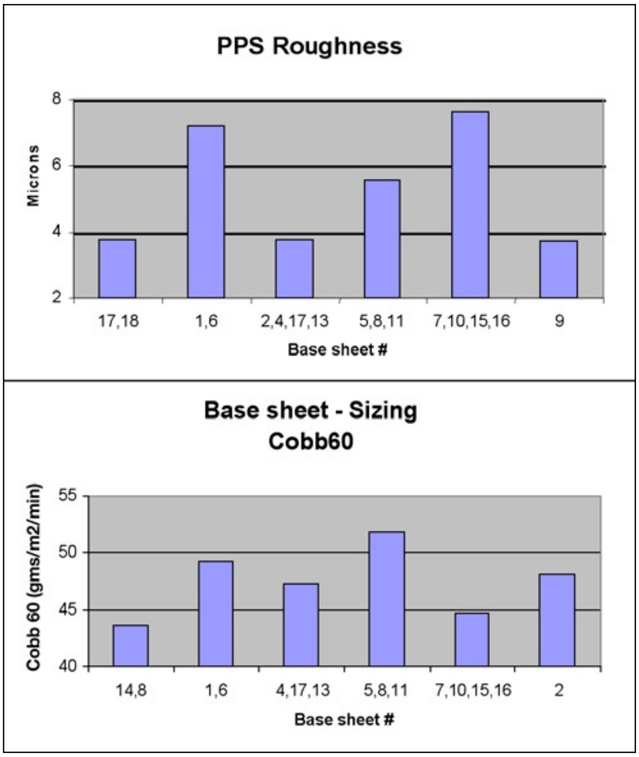
From preliminary studies, we determined the optimum height for the curtain coater to be 100- 400 mm. Based on these findings, the curtain height was maintained at 150-250 mm.

We used a very low molecular weight food grade carboxymethylated cellulose (CMC) as the rheology modifier to alter the shear-thinning properties of the coating. The low shear viscosity was kept in the range of 400-700 cps (Brookfield, #4 spindle, 100 rpm). The high shear rheology was altered from Newtonian to shear thinning by differing the amount of CMC applied and selecting the appropriate coatings from rheograms generated using a Hercules DVT viscometer (E bob, 4800 rpm). All coatings were prepared at approximately 56% solids.

The flow rate of the curtain, at constant speed, determines the achievable coat weight, thus curtain stability is only related to coat weight through the flow rate term in the Weber number. We planned to target coat weights of 12, 8, and 6 g/m^2 by adjusting the flow rate; coatings were applied at web speeds of 800, 1400, and 1800 m/min.

The wetting properties of paper affect the interaction between the curtain and the paper surface. The degree of interaction between the coating and the paper determines the amount of viscous drag on the curtain. Viscous drag influences the curvature of the heel, which directly affects the onset of air entrainment. Because of that, we studied the influence of base sheet absorbency on curtain stability. To control absorbency, the papers were size-press treated with 1 g/m^2 (C1S) of a 10% solution of oxidized starch (Oji Starch, Ichihara, Japan) before being curtain coated.

Base sheet roughness influences the runnability of the curtain coater because it dictates the thickness of the boundary layer air (BLA) dragged along with the web. BLA disrupts the stability of the curtain at high speeds [1, 2] and creates coverage and surface defect issues in the dried coating layer. In this study, we controlled the BLA thickness by altering the level of steam in the steam substitution system (SSS) [3] coming in contact to the sheet, just before application of the coating



2. Differences in base sheet properties.

with the curtain. The SSS was changed by adjusting the steam flow rates per unit width of the coater [3].

The roughness profiles and permeability of the papers were altered by calendering the papers. Calendering was performed on an off-machine supercalender at the Mitsubishi pilot plant facility. The wetting properties of the base sheet were characterized by performing a 60 s Cobb test. The Parker Print Surf (PPS) roughness and porosity of the base paper were measured at 1000 kPa with a soft backing. **Figure 2** shows the properties of the base papers studied. For these trials, we used a commercially produced 54 g/m² LWC base stock.

Table II shows the Taguchi orthogonal array (OA) used in this study. The model contained only the main effects and did not account for parametric interactions. Although the model has large inherent statistical error and low overall R^2 values, it is useful for initial screening of factors. The levels of variables were selected to reduce variations in the response variables. To reduce statistical error, prescreening experiments were performed to determine the appreciated levels of surfactant and CMC to use. Six of the variables that were perceived to be important were assigned three levels. The remaining two variables were assigned two levels (**Table III**).

The coverage of the coated samples was measured using a burnout method [15]. Samples were soaked in a 10% solution of 50% isopropanol and 50% ammonium hydroxide for an hour. The samples were then blotted to remove any excess solution and burned in an oven at 100°F for 1 h. The samples were scanned and analyzed using Adobe Photoshop. Black-and-white area pixels of the scanned pictures were recorded using a gray threshold and the coverage defined as the ratio of white pixels to total black + white pixels.

RESULTS AND DISCUSSIONS

A stable curtain is a prerequisite to good curtain coating, but curtain stability is difficult to describe and measure. Before attempting to measure curtain stability, curtain instabilities must be defined and a method to quantify them established. To accomplish this, videos of the curtain coater during operation were recorded and then analyzed by a group of observers to define the various curtain instabilities. The videos were again observed and the severity of the instabilities quantified on a scale of 1 to 10, with 1 indicating a very unstable curtain and 10 representing a stable curtain. The instabilities identified and quantified were high frequency fluctuations, low frequency fluctuations, back bending, and blowing.

At high speeds, the curtain fluctuated in the cross direction of the paper machine. These fluctuations can be characterized by their sinusoidal frequency and amplitude. At stable operation, these fluctuations can have almost the same amplitude, but very different frequencies. The fluctuations origi-

Study type	Factorial
Initial design	Taguchi OA
Center points	0
Design model	Main effects

Experiments	18
Blocks	No blocks

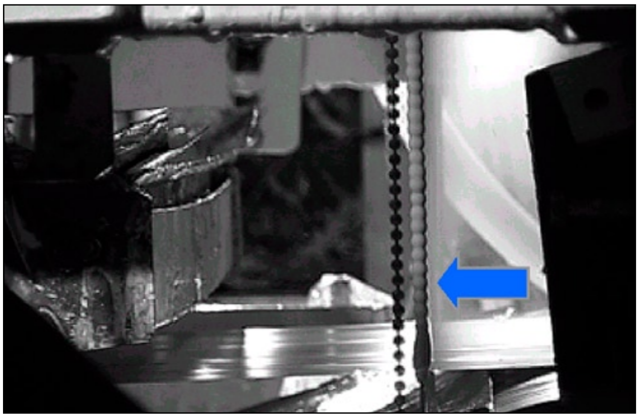
Name	Units	Type	Low Actual	High Actual	Levels
Nozzle height	mm	Categorical	1	2	2
Surface sizing	g/m²	Categorical	1	2	2
Roughness	µm	Categorical	1	3	3
Coating form		Categorical	1	3	3
Surfactant	pph	Categorical	1	3	3
Coat weight	g/m²	Categorical	1	3	3
Web speed	m/min	Categorical	1	3	3
SSS	kg/min	Categorical	1	3	3

II. Statistical layout.

Variable	Level of the variable		
	Low [1]	Medium [2]	High [3]
Roughness	3.5 µm (PPS)	5.5 µm (PPS)	7.7 µm (PPS)
Sizing	1 g/m² [C1S]	—	None
Coat weight	6	8	12
Coating formulation*	I	II	III
Surfactant dosage	0.02 pph	0.20 pph	0.80 pph
Web speed	800 m/min	1400 m/min	1800 m/min
Curtain height	150 mm	—	250 mm
Steam flow rate	0.20 kg/min	0.55 kg/min	1.0 kg/min

*These represent coatings of different rheologies.

III. Variable levels.



3. Straight curtain.

nated from the uneven performance of the BLA removal system in the cross direction of the machine. Upon further study of the problem, an uneven air ejector and steam profile in the SSS was found. The problem was attributed to the way the SSS was machined. Upon remachining and adjustment of the profile, the problem was eliminated.

At higher vacuum levels on the upside of the curtain, the curtain bent backward. The back bending seemed to have a positive effect on the overall stability of the curtain, as it delayed the onset of air entrainment. In severe cases of unoptimized BLA removal, blowing of the curtain occurred. Blowing was characterized by violent downstream movement of the curtain.

Other types of curtain instabilities identified in this study were splashing and "burps." Both effects were induced by viscosity and surface tension effects. If the viscosity of coating was low, splashing occurred. Operating at a low Weber number (low flow rate or high surface tension relative to the flow) resulted in intermittent burps being introduced into the curtain. Splashing and burps led to coating defects in the dried coating layer.

After defining these instabilities, we defined a stable curtain as one that was totally free of any of those effects and one that fell in the same plane as a beaded chain used as a point of reference to the edge of the curtain die (**Fig. 3**).

Having defined the criteria used to quantify the stability of the curtain, the videos could be analyzed and criteria for rating curtain stability established.

Table IV illustrates the influences of coating and process parameters on coating coverage, as determined by analysis of the burned-out samples. **Table V** summarizes the statistical contribution of each formulation and process parameter studied to coverage. The coverage values were very high for the three coat weights applied. Although coverage improved with

Run #	Roughness	Sizing	Formulation*	Surfactant level	Target coating weight	Coating speed	Nozzle height	Steam flow rate	Ejector air flow rate	Actual coat weight	Curtain stability	Coverage
	PPS [µm]	g/m²		Parts	g/m²	m/min	mm	kg/min	m³/min	g/m²	1-10 scale	%
1	7.20	none	I	0.4	6	800	150	0.20	1.0	6.0	8	65
2	3.74	1	I	0.4	12	1400	150	0.60	1.8	8.8	6	75
3	5.57	1	I	0.02	6	1800	150	0.75	2.3	4.3	6	85
4	3.74	1	I	0.2	8	1800	250	0.20	2.3	6.6	9	50
5	5.57	1	I	0.2	12	800	250	0.55	1.0	9.1	7	84
6	7.20	none	I	0.02	8	1400	250	1.00	1.8	6.9	4	91
7	7.61	1	II	0.2	12	1400	150	0.20	1.8	9.0	5	90
8	5.57	1	II	0.02	8	800	150	0.20	1.0	6.7	9	50
9	3.72	none	II	0.02	12	1800	150	1.30	2.3	8.2	9	87
10	5.57	1	II	0.4	6	1400	250	1.00	1.8	4.4	6	92
11	7.61	1	II	0.4	8	1800	250	0.75	2.3	5.2	6	50
12	3.72	none	II	0.2	6	800	250	0.35	1.0	4.1	5	88
13	3.74	1	III	0.4	8	800	150	0.55	1.0	7.8	8	85
14	5.54	none	III	0.2	8	1400	150	2.00	1.8	7.8	7	84
15	7.61	1	III	0.2	6	1800	150	1.30	2.3	5.1	5	95
16	7.61	1	III	0.02	12	800	250	0.35	1.0	9.5	8	85
17	3.74	1	III	0.02	6	1400	250	0.20	1.8	4.9	6	60
18	5.54	none	III	0.4	12	1800	250	0.20	2.3	9.6	7	50

* [I,II,III] are different coating rheologies and formulations.

IV. Summary of results

Variable		Coverage		
		Mean sum of squares	Effect	% Contribution*
Nozzle height	mm	97.72	+	3.11
Surface sizing	g/m²	7.53	+	0.24
Roughness	PPS	123.00	-	3.92
Coating formulation		365.41	+	11.63
Surfactant	pph	498.09	+	15.86
Coat weight	g/m²	19.90	+	0.63
Web speed	m/min	2016.46	-	64.20
Steam flow	kg/min	12.97	+/-	0.41

* Contribution the variable makes in explaining variance in the response variable.

V. Phase I - Overall statistics with respect to coverage.

coat weight, it was only weakly dependant on this parameter. This result was expected, as curtain coating is a true contour coating method. The results support existing theory and demonstrate the potential benefits of curtain coating.

A higher nozzle height resulted in improved curtain stability, and thus favored coverage. No conclusive explanation can be offered at this time, but higher curtain height is known to increase curtain velocity and available surface age. Both phenomena will result in a higher Weber number, increasing curtain stability.

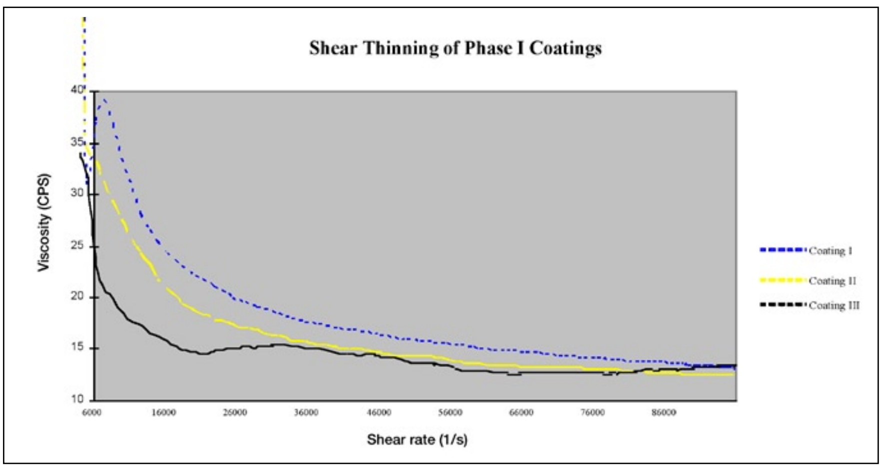
The low shear viscosities of coating formulations were kept in a narrow range, however their high shear response was very different. Haake shear rheograms showed coatings II and III to be slightly more shear thinning than coating I at 4400 rpm (**Fig. 4**). The shear thinning behavior favored better coverage, while the Newtonian rheology resulted in poor coverage. These subtle differences in rheologies resulted in rather large changes in curtain stability, suggesting additional rheological mechanisms may be affecting curtain stability. Extensional rheological measurements are needed to possibly reach a better conclusion.

The results of the burn-out tests, summarized in Table V, show that the smoother base sheet provided better coverage. These results support the concept of a curtain coater being a true contour coater. As roughness levels were varied in this study, coverage continued to improve with base sheet smoothness.

Sizing with hydrophilic starch improved coverage because it improved the wettability of the base sheet, increasing the Cobb value from 44 to 53 g/m² per min. Improving the wettability delayed the onset of air-entrainment, thus improving coverage. The better wettability of the base sheet also resulted in higher viscous drag on the curtain, increasing the radius of curvature of the pulled film on the impingement zone and reducing total pressure. This resulted in delayed and less air entrainment.

Attempts to measure the surface tension using the Wilhemy plate did not produce reproducible results because of the high viscosity and solids of the coating and possible sedimentation effects. Alternatively, Mach angle measurements were performed. Dynamic surface tension measurements [7, 17], obtained by measuring the Mach angle [18] showed surface tensions at 0.20 and 0.80 pph surfactant dosage were the same and much lower than the surface tension at a 0.02 pph dosage (43 and 54 dynes/cm [mN/m], respectively). The low and high surfactant dosages (high and low corresponding surface tensions) resulted in improved coverage. The Mach angle method provides insitu surface tension values in the falling curtain. Unlike the Wilhelmy plate method, this method enables high solids and viscosity coating formulations to be measured. Thus, this result contradicts established concepts of curtain stability, since the Weber number should be increased by lowering the surface tension, although similar results have been presented by Fröhlich [11].

Table V lists the statistical significance of each parameter is given and shows web speed to be the most dominant process variable. The general statistical trend of each factor (positive or negative) also is provided, except for steam flow rate, which has an optimal value. Higher speeds resulted in poorer coverage. Air-entrainment and poor curtain stability were clearly visible at high speeds. At high speeds the curtain was fluttering violently and air-entrainment was severe. An efficient boundary layer air removal system is critical at high speeds. In this study, however, the boundary layer air removal system was fixed at predetermined levels, according to the design of the experiment. A stable curtain could have been realized by manipulating the air ejector pressure and steam flow rate of steam substitution system. The first phase trials did result in a better understanding of the ejec-



4. Rheograms of coatings applied.

Variable		Air-entrainment	
		Mean sum of squares	% Contribution
Nozzle height	mm	0.89	1.75
Surface sizing	gm/m2	15.34	30.24
Roughness	PPS	2.06	4.05
Coating form		8.76	17.28
Surfactant	pph	0.89	1.75
Coat weight	g/m2	3.35	6.60
Web speed	m/min	17.60	34.69
SSS	kg/min	1.85	3.64

VI. Phase I - Overall statistics with respect to air entrainment.

	Nozzle height	Sizing	Roughness	Coating formulation	Surfactant	Coating weight	Web speed	SSS
Straightness	-	↑	↑	↑	↑	↑↓	↓	↑↓
Fluctuation	-	↑	-	↑	↑	↑	↓	↑↓
Back flow	↑	↑	↓	↓	-	↑	↓	↑
Air entrainment	-	-	-	↑	↓	↓	↓	↑
Splash	-	-	↓	↑	↓	↓	↓	↑

VII. Summary of statistical contribution of process and formulation parameters on high speed curtain stability.

tor pressures and steam flow rates required to stabilize the curtain at high speeds.

An apparent optimum rate of steam should be used for each condition. Steam flow rates above or below the optimum level led to unstable and sometimes violent curtain instabilities. The coat weight was controlled by changing the flow rate of the supply pump, which was calibrated for each coating color. Some conditions were run for longer periods than others causing the flow rates to change as the coating temperature changed over time. This is the reason for differences between actual and target coat weights (Table IV).

Curtain stability was analyzed studying videos of the trials and assigning a number between 1-10, the higher the better. The videos were analyzed by assessing the straightness of the curtain, amount of backflow and fluctuations, and the amount of air entrainment and splashing that occurred just around the dynamic wetting line. Three observers were used and the scores averaged to rate the contribution of the input variables to curtain stability. The results are summarized in **Tables VI** and **VII**. The shaded boxes depict the most important variables. These are the variables that were found to have the strongest effect on air entrainment and curtain stability.

This study improved our understanding of how to use the boundary layer air removal system (ejector pressure and steam flow rate) to improve the stability of the curtain, but stabilizing the curtain at high speeds remained a concern. To address this concern, we decided to keep the web speed (higher side) as a variable in the next set of pilot plant trials. Shear thinning coating rheologies were found to favor curtain coating runnability. This is consistent with previous findings [8]. Therefore, we decided that all rheologies would be shear thinning in the next study, but each would have a different degree of shear thinning.

Because web speed was found to be the single most important factor, we decided to more closely examine the effect of web speed. The curtain is very stable at low speeds, so we decided that only high speeds would be studied in the next phase of pilot trials. We also determined that the boundary layer air removal system must be fine-tuned to the web speed, and decided that steam flow rates would be further studied.

Although base sheet smoothness had a positive effect on coverage, high coverage was achieved even for the base sheet of highest roughness. As a result, we decided not to further explore base sheet roughness effects as part of this study. Because curtain coating coverage was almost insensitive to the coat weight, this parameter also would not be considered further. In addition, we decided that the curtain height would be fixed, as would the level of surfactant added.

CONCLUSIONS

The first phase of a curtain coater statistical optimization experiment used a Taguchi model to identify four important variables from a broad array of eight. In an unoptimized curtain operation, web speed is the single most important variable affecting curtain stability and air entrainment at the dynamic wetting line and overall coating coverage. Curtain stability is only one of the factors affecting coating coverage in curtain coating. Control of boundary layer air, which is governed by web speed, is critical to realize a stable curtain at high speeds. Coating rheology was found to be the next important variable affecting coating coverage and curtain stability. These variables, along with paper roughness, will be used to further stabilize the pilot curtain coater in next phase of this study.

ACKNOWLEDGEMENTS

We are indebted to the pilot operators Ikeda-san, Nakashima-san, Izumi-san, and research engineer Horie-san. This study would not have been possible without their hard work and active participation. We also thank Imerys Inc., Engelhard Inc., and DKS, Japan, for their generous support in supplying the materials for these trials.

Received: October 19, 2006
Revised: September 26, 2007
Accepted: March 23, 2008

LITERATURE CITED

1. Triantafillopoulos, N., Grön, J., Luostarinen, I., et al., *TAPPI J.* 3(11): 6(2004).
2. Triantafillopoulos, N., Grön, J., Luostarinen, I., et al., *TAPPI J.* 3(12): 11(2004).
3. Sugihara, M., Miura, H., Yamada, K., et al., *2002 Coating Conference Proceedings*, TAPPI Press, Atlanta, Georgia, USA, pp. 173-200.
4. Mendez, B., Tietz, M., and Morita, H., *PTS-Streicherei Symposium* 129, pp. 1492-1497 2001.
5. Miyamoto K. and Katagiri Y., "Curtain coating", *Liquid film Coating: Scientific Principles and their Technological Implications*, 1997, pp. 463-494.
6. Tripathi, P., Joyce, M., Lee, D.I., et al., *Proceedings of the 2006 TAPPI Coating & Graphic Arts Conference*, TAPPI PRESS, Atlanta.
7. Tripathi, P., "A study for the statistical optimization of a curtain coater," Ph.D. dissertation, Western Michigan University, Kalamazoo, Michigan, USA, 2005.
8. Voss, M. and Tadjbach, S., Extensional Rheology of Coating Colors for Curtain Application, *TAPPI 2004 Coating and Graphic Arts Conference*, Baltimore, MD, USA, 16-19 May 2004, p. 15
9. Urscheler, R., Roper, J., Nurmiainen, T., et al., "Key Attributes and Opportunities of Multilayer Curtain Coating for Paper," *TAPPI Coating and Graphic Arts Conference and Exhibit*, Atlanta, GA, 17-20, in Toronto, ON, Canada, (2005)
10. Urscheler, R., *Proceedings of the 1999 TAPPI Coating and Graphic Arts Conference and Trade Fair*, TAPPI PRESS, Atlanta, pp. 351-356.
11. Fröhlich, U. and Tietz, M., "Influence of Surfactants on Curtain Coater Runability", *Proceedings of the 2006 TAPPI Coating & Graphic Arts Conference*, April 24-27, Atlanta.
12. Brown, D., "A study of the behavior of a thin sheet of moving liquid" *J. Fluid Mechanics*, vol. 10, 1961, pp 297-305.
13. Kistler, S.F., "The fluid mechanics of the curtain coating and related viscous free surface flows with contact lines," Ph.D. thesis, University of Minnesota, Minneapolis, 1984.
14. Taguchi, G., *Taguchi Methods, Design of Experiments, Quality Engineering Series, Vol. 4*, ASI Press, Dearborn, Michigan, USA, 1993.
15. Dobson, R.L., *Proceeding of the 1975 TAPPI Coating Conference*, TAPPI PRESS, Atlanta, pp. 123-131.
16. Smoothness reference [Author: Add reference!!!]
17. Tripathi, P., Joyce, M., Lee, D.I., et al., "Understanding the Role of Surfactants in the Stabilization of a Coating Curtain", submitted to J. Coll. Int. Sci.
18. Schweizer P.M., *Paper Tech.* 45(2): 28(2004).

INSIGHTS FROM THE AUTHORS

Curtain coating is one of the emerging coating technologies that has potential to displace blade coating as the dominant coating technology. Curtain coating has inherent advantages over other coating technologies and can lead to improved products and process robustness. As this technology is still is in its infancy, it is a good topic for research to further our collective understanding of fundamentals.

Before this research, the information on variables in curtain coating and their impact on the process were fragmented. There was no large study in which all variables were considered and their effect quantified. This research is unique in that we took almost all know variables in curtain coating and, in two steps, statistically quantified their impact on curtain coating.

The unique and conflicting role of surfactants in the curtain coater is least understood technical area. The same surfactant that improves curtain stability via lowering surface tension also leads to increased foaming, one of the biggest hurdles in curtain coating. Very little is known about the effect of different surfactant types on the curtain stability and coating deaerability, and that is only empirical. We partly addressed this by conducting a large study on the dynamics of different surfactant types in curtain coating. Hopefully, others will research the effect of surfactants on coating deaerability.

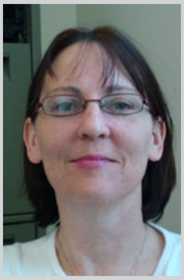
Confirmation of some of the fundamental physics of free-standing thin films was the most exciting results of this research. The observations on role of Weber number in curtain stability, boundary layer air management, and behavior of interfacial surfactants in continually stretching surface was in line with our collective understanding.

This research helps broaden general understanding of curtain coating. Quantification of effect of various variables will help mills connect a specific operational issue to a specific process, paper, and formulation variable.

The focus now is to build value from this understanding for curtain coating. There are still many process and quality issues that remain unsolved. We will be furthering private research to address those technical issues and prepare this technology for industry-wide adoption in the near future.

Tripathi is with Sappi Fine Paper, Westbrook, Maine, USA; Joyce and Flemming are with Western Michigan University, Kalamazoo, Michigan; and Sugihara is with Mitsubishi Heavy Industries, Hiroshima, Japan; email Tripathi at peeyush.tripathi@sappi.com.

Tripathi



Joyce

Flemming

Sugihara