Experimental and theoretical study of the manifold flow in a curtain coater

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ABSTRACT: Curtain coating is a contactless process with the potential for increased quality and productivity for coaters. Nevertheless, this demanding process requires a perfectly stable curtain to obtain good coverage. Problems can originate from the internal flow when the fluid goes through cavities and slots before reaching the inclined plane. Three-dimensional computational fluid dynamics simulations were performed in the manifold of a laboratory curtain coater to analyze the phenomena taking place in the first cavity, determine the causes of defects, and propose potential solutions. Reynolds number is a relevant parameter for Newtonian and non-Newtonian fluids and increasing it leads to disturbances in the manifold. The power law index also significantly affects flow uniformity, because its decrease leads to perturbations. Finally, yield shear stress has no effect on vortex formation for coating colors. To maintain vortex-free operation, the Reynolds number at the inlet must remain below a critical value (equal to 20 with the studied geometry), whatever the fluid. Geometrical changes were simulated with a higher radius of the inlet pipe or an end-fed manifold, resulting in improved flow uniformity. Simulation results were validated using flow visualization experiments with tracers using a transparent replica of the coater.

Application: This study helps establish the missing link between physico-chemical/rheological properties of the coating color and a flow in the manifold without any disturbance.

The objective of coating is to modify surface properties to improve the aspects and printability of the paper or obtain barrier properties. The curtain coating process has been used for years in food and photographic industries. In papermaking, it is used for specialty papers such as thermal and inkjet papers and has been commercially used for relatively wide web manufacturing of carbonless papers and paperboard [1]. This contactless technology has many potential advantages compared to traditional methods of coating such as blade coating or metering size press coating [2]. Indeed, this premetered technology is expected to enable increases in productivity, and give the best uniformity in coating thickness and the best coating coverage [3]. Moreover, it allows multilayer coating, meaning that several layers with different properties can be deposited onto the surface all at once, whereas with other systems, several successive coating and drying iterations must be performed.

Nevertheless, this process is demanding and its requirements differ from conventional processes as to the composition and preparation of coating colors. Different types of fluids are used depending on the objectives; for example, to improve printability, pigment-based colors are used. To obtain barrier properties against grease, moisture, oxygen, etc., polymer-based colors such as polyvinyl alcohol (PVOH) or starch are applied. These fluids have different rheological behavior, which is important for flow study.

Weinstein and Ruschak studied the flow elements of self- and pre-metered coating processes with physical insights [4]. In curtain coating, a perfectly stable curtain is required, which is hardly achieved over a large range of operating conditions [5,6]. The difficulty of obtaining a fixed geometry, which must be versatile enough for such a wide range of fluids, must be solved before wide adoption of the curtain coater is seen. Many published reports deal with problems linked to the dynamic contact line and ways to obtain a uniform and stable film on paper [7,8]. Other authors have studied the stability of the curtain itself and identified variables to optimize a high speed curtain coater [5-9]. The subject of this paper is to explore whether uniformity problems come from upstream, and more particularly, from the internal flow. Indeed, problems could originate from the internal flow when the fluid goes through the inlet manifold (first cavity), slots, and a possible second cavity. Leonard [10] showed that the usefulness of a secondary cavity depends on the fluid. For a circular geometry, he determined the break-even point for power law fluids as a function of power law index for different additional cavity areas. These results showed that for a Newtonian fluid, a second cavity is useful, whereas it is useless for a shear thinning/pseudoplastic fluid.

The internal cavities of coating dies distribute the coating liquid to produce a liquid film with uniform dimensions and properties. The distribution chambers of most coating dies consist of a cavity, substantially oriented in the cross-web direction and connected to a slot. The combination of the cavity and slot is referred to as the distribution manifold. The resistance to flow in the cavity is minimized by choosing a relatively large cross-sectional area, and the slot is designed to have high resistance to flow. In this way, the fluid entering the distribution chamber tends to distribute widthwise before entering the slot, where the flow is oriented primarily toward the slot exit. Two types of distribution manifold are the T-manifold and the coat-hanger manifold. The T-manifold has a uniform cross-section across the width of the die, so flow resistance is equal through the die manifold. The coat-hanger manifold features decreasing slot length and cavity size with cross-web distance from the feed location to reduce the liquid residence time.

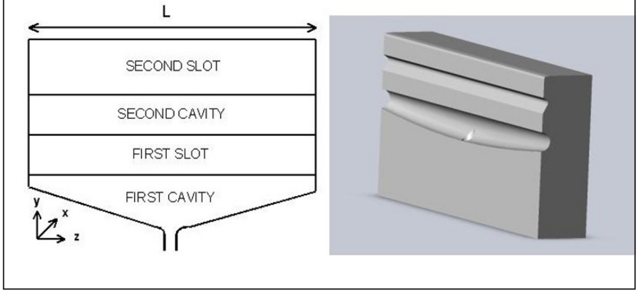
Typically, flow analyses of die manifolds use a combination of a one-dimensional flow model of viscous effects in the cavity and the slot to determine flow uniformity [11-13]. A number of papers specifically address the problem of using one-dimensional cavity flow models for the often-encountered noncircular shapes [14,15]. Other authors modeled the second cavity in two dimensions to find conditions of vortex formation for several fluids and geometrical conditions [16,17]. These authors used simpler shapes of manifold because of industrial interests or computation possibilities. In practical terms, know-how still outperforms physical knowledge.

The internal flow in curtain coating is a three-dimensional (3D) problem, but little published information is available on the topic. Some authors studied the flow uniformity for extrusion dies on 3D simulations, but neglected the inertial force because polymeric fluids are very viscous liquids [18,19], contrary to Wen and Liu, who also made a comparison with experimental observations [20,21]. We performed 3D computational fluid dynamics (CFD) simulations of the internal flow in a laboratory curtain coater to analyze the phenomena taking place in the manifold, find parameters that cause defects, and propose potential solutions to reduce the nonuniformity of the flow. An experimental study was performed to validate results using a flow visualization technique with tracers in a laboratory model with transparent parts.

MATERIALS AND METHODS

Coating die cavities

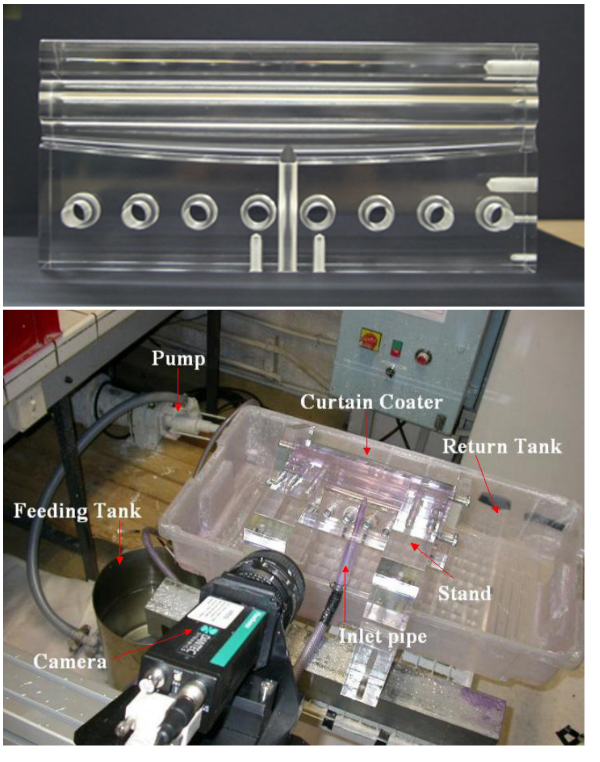
This study used a laboratory curtain coater and focused on the inlet manifold where the radius of the cavity increases along the section, but the length of the slot is constant (**Fig. 1**). Coat-hanger and T-manifolds have been more generally described [22], but the literature contains no mention of this new shape. This slide die coater has a variable semicircular cross-section for its first cavity and a triangular shape with round ends for the second cavity. The inlet pipe is tangent to the manifold cross-section. **Table I** shows the geometric parameters of this laboratory coater. This study focused on vortex formation in the first cavity only, because for the studied geometry, the possible instabilities created in the manifold are stronger than in the second cavity. A commercial computational fluid dynamics program was used to solve equations of the flow, considering a steady state with isothermal and incompressible fluid and laminar flow. The internal volume was meshed with preprocessing software. Because of the particular geometry of the manifold, unstructured mesh was used.



1. Design of the internal cavities of the laboratory coater.

Parameters	Dimensions
Manifold width L	260 mm
First slot thickness	254 µm
Second slot thickness	500 µm
Manifold diameter (side)	14 mm
Manifold diameter (center)	22 mm
Inlet pipe diameter	9.4 mm

I. Geometric parameters of the laboratory curtain coater.



2. Plexiglas laboratory coater (top) and experimental assembly (bottom).

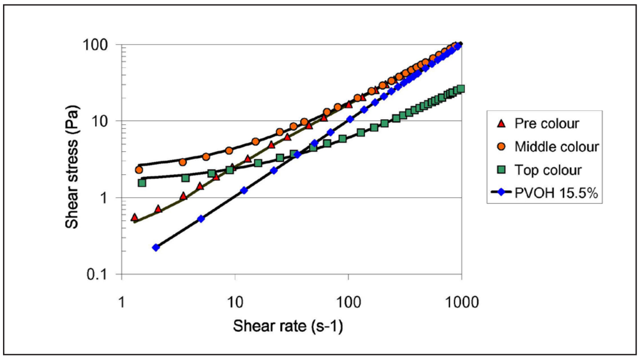
To increase accuracy and minimize computing time, half of the flow in the manifold was simulated. The first cavity was meshed with about 1.2 million elements, with an average volume of 1.54×10^{-2} mm^3, the maximum being 6.19×10^{-2} mm^3. The flow in the slot also was simulated. To validate simulation results, an exact replica of the pilot curtain coater was manufactured with polymethyl methacrylate (PMMA) (**Fig. 2,** top). Two PMMA stands were designed to have the same angle with respect to the horizontal plane as on the pilot curtain coater. The system was fed with a pigtail pump and all tests were run in a closed loop. A digital video camera was installed behind the coater to enable flow observation in the manifold (Fig. 2, bottom). Tracers with the same density as the cavity fluid were used for the flow visualization. To introduce the tracers into the fluid, the pipe between the pump and the curtain coater was punctured with two syringes and the needles were kept close to the inner wall so that the streamlines would be close to the wall at the junction between the inlet pipe and the manifold. Dyes were injected into the flow under isokinetic conditions.

Fluids

Several fluids were selected, some were Newtonian and some were non-Newtonian. In addition to the real fluids, model shear-thinning fluids were used in the simulation. A PVOH solution, adjusted to different concentrations, was used as the Newtonian liquid for the experiments and simulations. PVOH, a synthetic binder used in papermaking, has a wide range of viscosity that is adjustable with the concentration. Three coating colors classically used in multilayer coating for wood-free coated paper (precoat, middle-coat, and top-coat colors) were simulated. **Table II** shows their formulations and solid contents. All are shear-thinning and exhibit a yield stress. Their rheological behavior follows the Herschel-Bulkley model in Eq. (1):

$$\tau = \tau_0 + K\dot{\gamma}^n \qquad (1)$$

All "real fluids" were characterized in the laboratory at constant temperature with a cone-plate controlled stress rheometer. **Figure 3** presents the results; dots represent the experimental points and lines represent the best fitting models. We also simulated power-law and Herschel-Bulkley fluids to analyze the influence of the rheological parameters. The value of the power law index was between 1 and 0.7 for the Newtonian case and cases close to those of coating colors. All rheological parameters of these fluids are gathered in **Table III**. The pre- and middle colors have nearly identical rheological properties because they have almost the same composition; the only difference is a slightly higher yield shear stress for the middle color.



3. Rheological characterization of fluids with a cone-plate controlled stress rheometer.

Reference	Precoat	Middle Coat	Top Coat
SB Latex 1 (pph)	6	8	
Coarse GCC (pph)	100	100	
SB Latex 2 (pph)			11
Fine GCC (pph)			100
PVOH (pph)			0.6
OBA (pph)			0.6
Native starch (pph)	10	6	
Surfactant (%/water)	0.6	-	0.8
Solids (%)	62	66	64

II. Color compositions and solid contents for trials and simulations.

Fluids	Density kg/m³	Rheological Properties		
		τ_0 (Pa)	K (Pa·s^n)	n
Pre color	1600	0.27	0.38	0.82
Middle color	1600	2.22	0.32	0.84
Top color	1600	1.6	0.14	0.75
PVOH (15%-20%)	1200	0	0.1–0.8	1
Power law	1200	0	0.1	0.7–0.9
Herschel-Bulkley	1600	0.1–1.5	0. 1–0.6	0.7–0.9

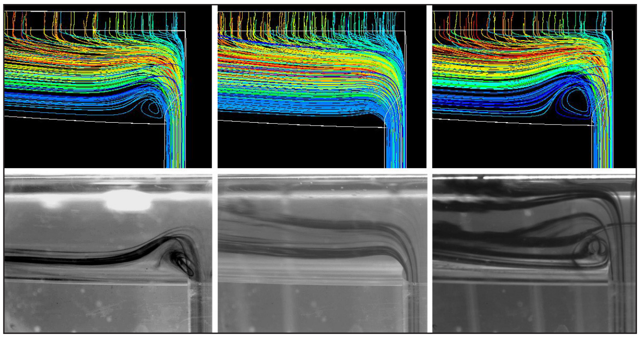
III. Physical properties of fluids.

SIMULATION RESULTS AND EXPERIMENTAL VALIDATIONS

In the pilot study, nonuniform flow during the coating process caused some streaks on the final paper. Because the pilot coater is made of steel, we could not see the flow or measure parameters inside the internal cavities. Differences of concentration were observed only in the center zone of the curtain. Thus, CFD simulation was the best solution to determine the process limitations and find the origin of the nonuniformity. Then, we could manufacture a replica of the curtain coater with PMMA to use in validating the results. Several flow rates ranging between 1.9 and 11.6 L/min·m (coat weight between 5 g/m² and 25 g/m²) were tested with Newtonian and non-Newtonian fluids. We could use streamlines to visualize our results with CFD and experiments.

Influence of flow rate, viscosity, and power law index on the flow

We first studied the influence of flow rate and viscosity on the



4. Influence of flow rate and viscosity on vortex formation for a Newtonian fluid with, from left to right: μ = 100 mPa·s, Q = 5.8 L/m·min; μ = 300 mPa·s, Q = 5.8 L/m·min; μ = 300 mPa·s, Q = 11.6L/m·min.

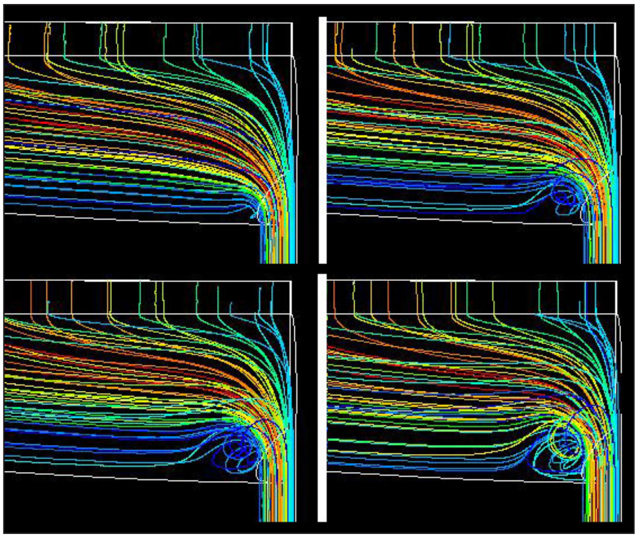
flow for fluids without yield. The flow was uniform with high viscosity fluids or at low flow rates. The flow with higher flow rates and lower viscosities for Newtonian fluids was simulated next. Results for PVOH solutions, depicted with streamlines on **Fig. 4**, clearly showed that increasing the flow rate or decreasing the viscosity leads to significant disturbances, which may generate instability later in the curtain. The streamlines from the simulations and experiments were very similar. Experiments validated, as expected, that the flow was symmetrically distributed into the first cavity, as demonstrated by streamlines that were symmetrical compared to the centerline of the inlet pipe.

Concerning non-Newtonian fluids, other parameters might be considered for vortex formation: the power law index and the yield shear stress. To study the influence of the yield shear stress with coating colors, simulations can be done, but flow visualization with dyes is not possible since coating colors are opaque. Triantafillopoulos and Farrington used X-ray radiography to visualize coating flows [23]. Simulations showed that the yield shear stress has no influence on vortex creation for the range tested (0.27-2.22 Pa). The eddies are located close to the wall, therefore the wall shear stress for Herschel-Bulkley fluids was calculated and compared to the yield shear stress, knowing that, as in Eq. (2) [24]:

$$\frac{Q}{\pi R^3} = \frac{n}{3n+1}\left(\frac{\tau_w - \tau_0}{K}\right)^{\frac{1}{n}} \times \left[1 - \frac{1}{2n+1}\frac{\tau_0}{\tau_w} - \frac{2n}{(2n+1)(n+1)}\left(\frac{\tau_0}{\tau_w}\right)^2 - \frac{2n^2}{(2n+1)(n+1)}\left(\frac{\tau_0}{\tau_w}\right)^3\right] \quad (2)$$

Whatever the other rheological parameters, the yield shear stress has no influence on vortex formation at the manifold inlet for this geometry because its value is less than 5% of the wall shear stress in all studied cases.

To study the influence of power law index, simulations for power law fluids with values of the power law index close to those of coating colors were conducted. The flow rate and consistency index were kept constant and gave vortex-free condition for a Newtonian fluid. **Figure 5** shows that power law index significantly affects vortex formation. With real fluids, it is not possible to master this parameter contrary to flow rate or viscosity; from a practical view, therefore, it is better to conclude that using fluids with decreasing power law index might lead to higher instabilities.



5. Influence of power law index on vortex formation for a power law fluid with K = 600 mPa·sn at Q = 15.4 L/m·min, and from left to right: n=1, n=0.9 (top); n=0.8, n=0.7 (bottom).

q (L/m·min)	Q (m³/s)	n = 1	n = 0.9	n = 0.8
1.9	8.33E-06	613	390	254
3.9	1.67E-05	607	359	214
5.8	2.50E-05	605	343	194
7.7	3.33E-05	604	331	182
11.6	5.00E-05	602	317	167

IV. Apparent viscosity at wall, in mPa·s, for fluids with τ_0=1.5 Pa and K = 600 mPa·s^n.

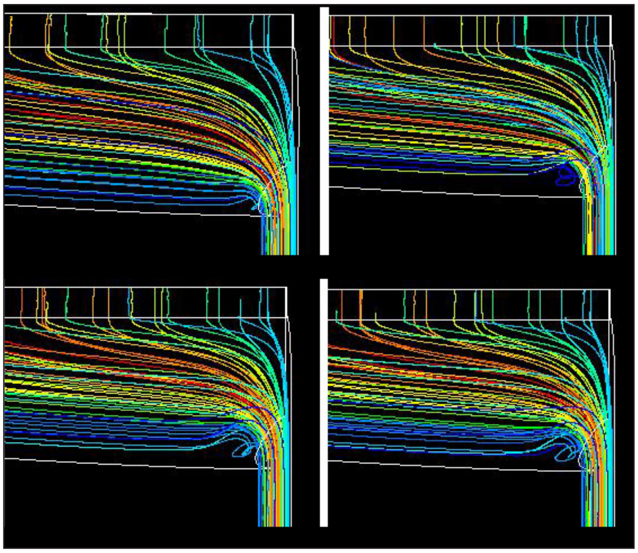
To understand the role of this parameter, the apparent viscosity at the wall of the inlet pipe was calculated for Herschel-Bulkley fluids after the wall shear rate is known using Eqs. (3) and (4):

$$\tau_w = \tau_0 + K\dot{\gamma}_w^n \quad (3)$$

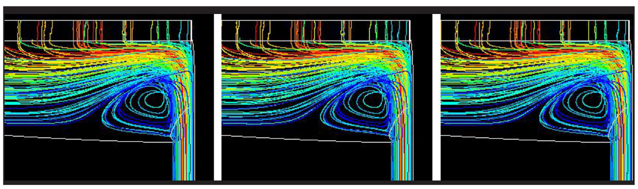
$$\mu_{app} = \frac{\tau_w}{\dot{\gamma}_w} = \frac{\tau_w}{\left(\frac{\tau_w - \tau_0}{K}\right)^{\frac{1}{n}}} \quad (4)$$

Table IV shows typical results.

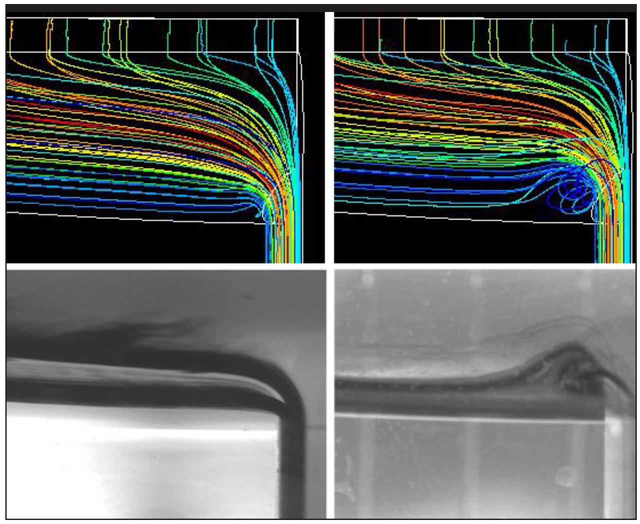
Results indicate that for a given flow rate, fluids with a lower power law index have a lower apparent viscosity close



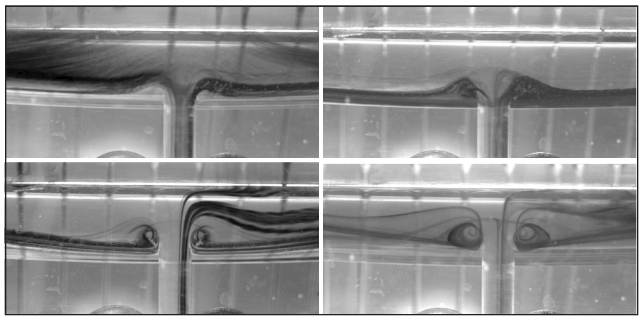
6. Influence of n and flow rate on vortex formation for a power law fluid at K = 600 mPa·s^n at Re = 20, with from left to right: n=1, n=0.9 (top); n=0.8, n=0.7 (bottom).



7. Influence of flow rate and viscosity on flow uniformity at Re = 114, with from left to right: μ = 100 mPa·s, Q = 15.4 L/m·min; μ = 600 mPa·s, Q=93.1 L/m·min; μ = 1500 mPa·s, Q = 232.3 L/m·min.



8. Illustration of the existence of a critical Reynolds number (Re) on vortex formation (PVOH at μ = 110 mPa·s), with Re = 18 <Re_c (left) and Re = 24 >Re_c (right).



9. Evolution of vortex size with Re= 19 (upper left), Re=24 (upper right), Re=37 (lower left) and Re=74 (lower right).

to the wall. This viscosity is nearly divided by three when the power law index varies from 1 to 0.8. As described above, decreasing the viscosity leads to instability, and the use of fluids with lower power law index involves having a lower apparent viscosity at the junction between the inlet pipe and the manifold in the area where vortex could appear.

Influence of Reynolds number on the flow

Taking into account other research [15], we assumed that the Reynolds number is a determinant of flow. Increasing the Reynolds number will lead to flow perturbations. A Reynolds number cannot be defined in the manifold, so we referred to the one for the inlet pipe. For Newtonian and power law fluids, it is defined as:

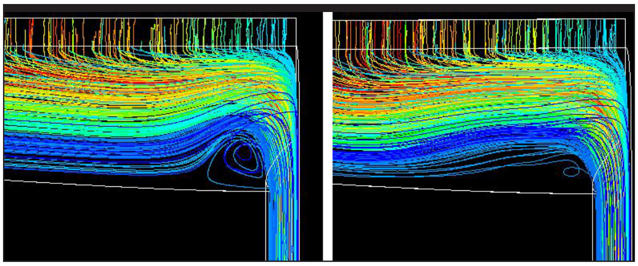
$$\mathrm{Re} = \frac{8\rho V^{2-n} R^{n}}{\left(3+\frac{1}{n}\right)^{n} K} \qquad (5)$$

For Herschel-Bulkley fluids, the Reynolds number is given by an implicit equation.

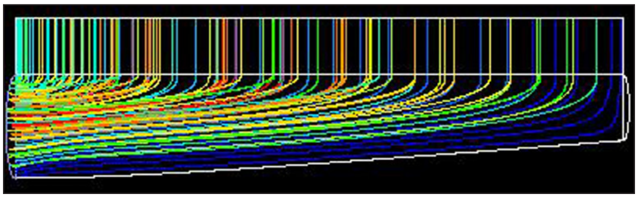
The aim of this study was to determine whether or not the Reynolds number predominates. A study was conducted that used the previous power law fluids at a constant Reynolds which were identical. Taking into account these two results, we can conclude that the inlet Reynolds number prevails over other parameters in flow perturbations for Newtonian and non-Newtonian fluids. Because the study used a fixed geometry, no conclusion can be made regarding the influence of other parameters, such as the angle of deviation.

CFD simulations suggest that the Reynolds number is a relevant parameter for the flow in the manifold, whatever the fluid. Because the geometry is similar to the inlet in a T die, the angle of deviation (90° here) also is taken into account. Whether the fluid is Newtonian or not, the critical Reynolds number is equal to 20 in this study (**Fig. 8**). This value is specific to this special geometry; it means that if the geometry is different, the critical Reynolds number will not be the same.

Finally, simulations enable us to validate an obvious result, which is that vortex could have different sizes and is bigger when increasing the flow rate or decreasing the viscosity. It means that increasing the Reynolds number when being already over the critical Reynolds number leads to a bigger vortex, which is highlighted by experiments with PVOH (**Fig. 9**).



10. Influence of inlet pipe size on vortex creation (middle colors, Q = 5.8 L/m·min), with R_{inlet}= 4.7 mm (left) and R_{inlet}= 5.4 mm (right).



11. Streamlines in an end-fed curtain coater with extreme operating conditions at Re = 280.

Solutions to avoid vortex creation

The aim here is to reduce the Reynolds number in the inlet tube. The radius of the inlet pipe was increased by about 15% to reduce velocity, keeping the same flow rate.

Figure 10 compares results for the two geometries and, as expected, fewer perturbations occur in the cavity when the inlet diameter is bigger. Thus, a solution to reduce vortex creation is to increase the diameter of the inlet pipe. The problem of vortex creation comes from the junction between the inlet pipe and the manifold and is similar to a problem of flow in a T die. As a result, we decided to study the behavior of colors flowing into an end-fed cavity to evaluate whether this internal geometry could lead to better results.

To do so, half of the initial geometry was used and the inlet was located at the wider cross-section, i.e., the centerline of the laboratory coater. A new meshing was created and several simulations were run at the same flow rates used with the previous geometry. For a Newtonian fluid, the Reynolds number at inlet for the end-fed system will be twice as low as the one with the pilot configuration at the same flow rate. Thus, less flow disturbance is expected. The streamlines were plotted in the manifold for all cases, and results of simulation showed that a vortex-free flow was obtained, whatever the operating conditions.

An important point is the absence of deviation of the flow in the end-fed system compared to the center-fed system. To study the influence of flow deviation on vortex creation, an extreme operating condition was simulated and the flow is still vortex-free (**Fig. 11**).

To reduce vortex creation, we suggest two solutions:

1. An increased diameter for the inlet pipe to reduce the Reynolds number
2. A new internal geometry (end-fed geometry) that will not create instabilities in this area, given that for a specific flow rate, the Reynolds number is twice as low and the flow does not deviate

The main parameters in the manifold are the inlet Reynolds number for a given geometry and the angle of deviation. That is why a manifold with an inlet pipe in the shape of a trumpet should be efficient to avoid instabilities.

CONCLUSIONS

A 3D flow simulation with experimental validations of the flow in the manifold in a curtain coater is presented. Relevant parameters for Newtonian and non-Newtonian fluids on flow uniformity — the inlet Reynolds number and the angle of deviation between the inlet pipe and the manifold — are highlighted.

Increasing the Reynolds number led to flow perturbations. The power law index also affects flow uniformity, because its decrease leads to a lower apparent viscosity in the area of vortex formation. In the operating conditions of this study, the apparent viscosity is divided by three when the power law index varies from 1 to 0.8. To maintain vortex-free operation, the Reynolds number at the inlet must not exceed a critical value (20 on the pilot geometry). Moreover, the yield shear stress of coating colors does not affect the behavior of the flow in the manifold.

Flow visualization tests in the manifold of a PMMA-made replica of the laboratory coater were performed to validate the simulation results. Results of the simulations and experiments were in accordance: the same value of the critical Reynolds number and identical vortex sizes were observed.

Finally, some solutions to improve flow uniformity exist, such as increasing the radius of the inlet pipe or changing to end-fed internal geometry. Indeed, at a constant flow rate, the Reynolds number varies as the reciprocal of the diameter size; therefore, increasing the radius of the inlet pipe improves the uniformity of the flow by reducing the Reynolds number. The second solution proposed is to change the geometry of the curtain coater to an end-fed curtain coater. This geometry makes it possible to eliminate the angle of deviation between the inlet pipe and the manifold, which deeply affects vortex creation. **TJ**

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LITERATURE CITED

1. Helmer, K., Karppinen, T., and Lindqvist, B., *Pap. Technol.* 46(6): 37(2005).
2. Salminen, P., Yang, A., and Kritzinger, J., et al., *PaperCon, Proc.*, TAPPI PRESS, Atlanta, Georgia, USA, 2010, Conf. CD.
3. Endres, I. and Tietz, M., *Tappi J.* 6(11): 24(2007).

4. Weinstein, S.J. and Ruschak, K.J., *Annu. Rev. Fluid Mech.* 36(1): 29(2004).
5. Tripathi, P., Joyce, M., Fleming, P.D., et al., *TAPPI J.* 8(1): 20(2009).
6. Triantafillopoulos, N.G., Grön, J., and Luostarinen, I., et al., *TAPPI J.* 3(12): 11(2004).
7. Black, T.D., Clarke, A., and Ruschak K.J., *AIChE J.* 40(2): 229(1994).
8. Shikhmurzaev, Y.D., *AIChE J.* 42(3): 601(1996).
9. Tripathi, P., Joyce, M., and Fleming, P.D., et al., *TAPPI J.* 8(1): 29(2009).
10. Leonard, W.K., *Annu. Tech. Conf. - Soc. Plast. Eng.* 31: 144(1985).
11. Weinstein, S.J. and Ruschak, K.J., *AIChE J.* 42(9): 2401(1996).
12. Winter, H.H. and Fritz, H.G., *Polym. Eng. Sci.* 26(8): 543(1986).
13. Kamisli, F., *Int. J. Eng. Sci.* 41(10): 1059(2003).
14. Miller, C., *Ind. Eng. Chem. Fundam.* 11(4): 524(1972).
15. Liu, T. and Hong, C., Polym. Eng. Sci. 28(23): 1559(1988).
16. Lee, K. and Liu, T., *Polym. Eng. Sci.* 29(15): 1066(1989).
17. Lee, K., Wen, S., and Liu, T., *Polym. Eng. Sci.* 30(19): 1220(1990).
18. Dooley, J., *TAPPI Polym., Laminations Coat. Conf.*, TAPPI PRESS, Atlanta, 1990, p. 957.
19. Wang, Y., *Polym. Eng. Sci.* 31(3): 204(1991).
20. Wen, S.H. and Liu, T., *Polym. Eng. Sci.* 34(10): 827(1994).
21. Chang, Y.H., Wen, S.H., and Liu, T., *Polym. Eng. Sci.* 36(21): 2663(1996).
22. Secor, R.B., in *Liquid Film Coating* (S.F. Kistler and P.M. Schweizer, Eds.), Chapman and Hall, London, UK, 1997, pp. 369-398.
23. Triantafillopoulos, N.G. and Farrington Jr., T.E., "Flash X-ray radiography techniques for visualizing coating flows," IPC Technical Papers Series 274, 1988. Available [Online] http://smartech.gatech.edu/jspui/bitstream/1853/2623/1/tps-274.pdf
24. Chhabra, R.P. and Richardson, J.F., *Non-Newtonian Flow in the Process Industries*, Chapman and Hall, Oxford, UK, 1999.

NOMENCLATURE

K: consistency index
n: power law index
Q : flow rate
R : pipe radius
V : bulk velocity
ρ : density
μ : viscosity or apparent viscosity
τ : shear stress
τ_0 : yield shear stress
τ_ω: wall shear stress
$\dot{\gamma}$: shear rate

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This work forms part of a doctoral degree project on flow modeling in curtain coating undertaken by Philippe Martinez. Curtain coating has prominent advantages over conventional techniques, such as blade coating or size-press, but for the moment, know-how outperforms physical knowledge. This paper provides part of the missing link between physical-chemical / rheologic properties of the coating colors and efficient curtain coating, thanks to 3D simulations and experimental validations of the flow in the manifold.

There is a wealth of literature about the dynamic contact line, but we wondered if problems also come from upstream, and, more particularly, in the internal flow when fluids pass through the inlet manifold and, eventually, the second cavity and slots. The internal flow in curtain coating is a 3D problem, but little information is available on that in literature. Some authors studied the flow uniformity for extrusion dies on 3D simulations, but they neglected the inertial force since polymeric fluids are very viscous.

One of the biggest challenges we faced was to carry out both CFD simulations and laboratory work, which required building a transparent coater and using several experimental techniques.

A particularly rewarding finding was that CFD simulations and experimental tests were in totally accordance. We first carried out simulations to analyze phenomena taking place inside the manifold because it was not possible to observe the flow in our pilot coater and then validated the presence of vortices under specific operating conditions, thanks to a transparent replica of the coater. Future work will consider the flow downstream of the manifold.

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