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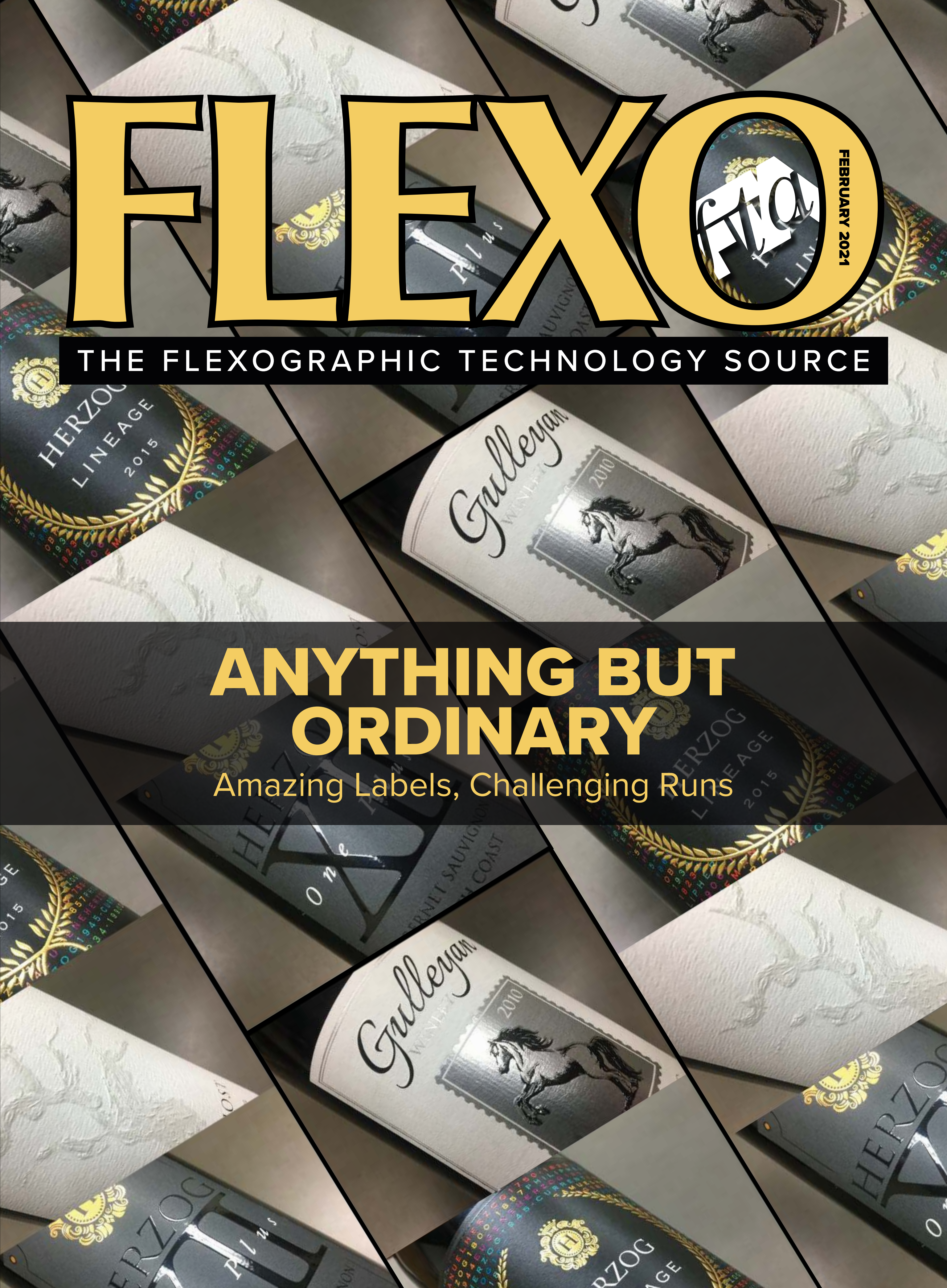

ANYTHING BUT ORDINARY

Amazing Labels, Challenging Runs

Viscosity Standardization

ONE PRINTER'S APPROACH TO CONTROLLING A CRITICAL VARIABLE IN LABEL & FLEXIBLE PACKAGE PRODUCTION

> *"Tight control with an accurate sensor, combined with a responsive control system, has enabled us to streamline our printing process while improving color quality and reducing waste."*

Bert Verweel

Despite the highly sophisticated quality control and automation systems available on the current generation of printing machines, one of the most crucial variables in the printing process—ink viscosity—is still frequently measured with inexact and cumbersome methods, such as efflux cups and falling ball viscometers.

Besides the negative effects these methods have on printing quality, they perpetuate an attitude toward ink viscosity measurement that is reflected in the conventional unit of "cup seconds"—the time required for ink to flow out of a measurement funnel as documented with a stopwatch!

Viscosity is a very important parameter in the final quality of the printed matter. It requires close attention, given:

- If the viscosity is not correct, the flow behavior and ink layer thickness will vary, leading to deterioration of print quality
- Poorly adjusted ink viscosity may cause excessive ink consumption and unnecessarily high costs
- Viscosity automation and predictive tracking control results in waste reduction and efficiency improvements

Although a wide range of more modern technologies is now available for inline and continuous monitoring of ink viscosity, sensitivity to contamination, installation variables and baseline shifts have led to some suspicion of these methods as long-term solutions to ink viscosity measurement and standardization. This article addresses some of the advantages and shortcomings of available technologies, and the benefits from using stable, easily cleanable and repeatable viscosity sensors.

Using sensors that measure up to the accuracy operators expect from their color control and press adjustment systems enables online, automatic, dynamic control of viscosity within previously unattainable narrow limits, affording start-to-finish maintenance of print quality in even the longest printruns.

CONTROL = EFFICIENCY

Above all, print quality matters!

In a highly competitive industry with often tight margins, each job rejected by a customer for unacceptable print quality can be a major blow to both the reputation and the profit of the operator. "Reject" here can mean a truck returning with several tons of wasted material!

Maasmond Paperindustrie bv Oostvoorne in The Netherlands houses a W&H Primaflex CS press, equipped with viscosity sensors and other automated print quality control systems.
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The main purpose of viscosity control is to maintain print quality from start to finish of a job, no matter how long or complex.

A second goal is improvement of operating efficiency. Efficiency starts with setting up a job. Being able to nail the proper viscosity for all stations without cut-and-dry tinkering means rapid job turnover, keeping the machines printing instead of idling.

Achieving these goals requires a system: on the one hand, an accurate and repeatable sensor is needed that can provide the viscosity resolution necessary for producing accurate and consistent color. Equally important is an automatic control system that continually and smoothly adjusts the ink viscosity, considering variables like temperature and rate of evaporation of solvents.

ACCURACY

Every operator is used to working with some sort of viscosity measuring cup. Cup measurements have never been totally standardized and are only "reliable" over a relatively narrow measuring range with a large margin (5 percent to 10 percent) of error. Some of these errors are caused by the cup itself, others are a function of operator skill:

» Measurements are not repeatable

» Temperature, which has a strong influence on viscosity, is difficult to control

» Contamination of the cup and different densities of inks influence the run-out speed

» All add up to poor repeatability and accuracy of viscosity cup measurements

In practice, error margins can be as high as 10 percent, which is a big bandwidth of viscosity. For example, for an ink that has a viscosity of 20 seconds, an error margin between 5 percent and 10 percent means a bandwidth between 1 second and 2 seconds!

Having years of experience using a great variety of viscosity sensors in a flexographic plant, I'm familiar with several that are based on electromechanical resonators—elements that vibrate in various ways, and whose vibration is damped by the viscosity of the ink. Electronics units connected to these sensors evaluate the damping of the vibrations and translate it into a viscosity measurement.

Sensors utilize various forms of resonators, including quartz crystals, surface acoustic wave resonators, vibrating metal rods, and torsional resonators that execute microscopic, high-speed twisting vibrations. The latter are particularly robust, and are relatively insensitive to both contamination by ink residues and to the influence of mechanical vibrations from the printing machine, two influences that have been particular challenges for vibrational viscometers.

One particularly compact, robust and accurate sensor is based on a so-called "symmetric torsional resonator" (US patents 10,502,670 and 9,267,872) SRV. It offers high accuracy—better than 5 percent of the actual reading—and reproducibility better than 1 percent of its reading, making it particularly suitable for high-accuracy, reproducible job-to-job color matching. Because its resonator is completely balanced, its accuracy is immune to its mechanical environment. It is also extremely robust, meaning it can be cleaned, when necessary, by wiping it with a solvent-soaked rag.

What do its broad measuring range and high accuracy mean in practice? We tested its accuracy by adding 20-g. of solvent to 25-kg. of ink. The sensor (installed in the press ink line) registered a viscosity change of 0.1-mPa.s, which is the equivalent of a cup measurement difference of 0.02 seconds! This is a previously unknown accuracy of the measurement of viscosity in this industry. And because the SRV incorporates an accurate temperature measurement into the sensing element, it is possible to accurately compensate for the effects of temperature.

We have found that working with the cup is not only outdated, but actually counterproductive. After a few months, we stopped converting to cup seconds altogether, finally elevating viscosity measurement, the last crucial variable in printing, to the same technological level as the rest of the process. We finally brought our printing press fully to the 21st century.

Due to the accuracy and repeatability of the sensor, we have gained a lot of insight into the behavior of inks—sometimes more than we expected. Ink is a rheologically complex medium, and the sensor gives us some insight into that complexity that is not observable with the DIN cup.

NON-NEWTONIAN BEHAVIOR

Solvent-based inks exhibit non-Newtonian behavior. Under the influence of shearing force, their viscosity changes. Ink is also thixotropic, a stationary ink having an appreciably different viscosity than an ink that is in motion. The viscosity of a stationary ink can differ from that of a moving ink by as much as 20 percent!

In addition, ink viscosity is strongly temperature dependent. On printing presses on which the temperature of the inks is not conditioned, ink temperature—and therefore viscosity—can vary greatly due to changes in the ambient temperature, but also due to the heat generation in the press itself. One of the first things that we have explored with the sensor is the temperature dependency of ink viscosity.

We built a test setup consisting of a closed flow loop in which the ink is continuously pumped in a circuit, at a speed comparable to that of the ink circuit in our press, and slowly heated up. Every second the temperature and viscosity are measured, giving more than a thousand measurement points in a typical test run.

The graph in *Figure 1* shows the temperature dependence of the viscosity of a number of different inks (modified nitrocellulose ink yellow, magenta, silver and a polyurethane white) over a temperature range of 20 degrees Celsius. Over this range, the viscosity can differ by up to 60 percent.

One of the most important uses of viscosity measurement is to determine when and by how much ink must be diluted in order to compensate for loss of solvent during the printing process. Solvent evaporation increases the pigment loading of the ink, resulting in poor print quality and excess ink consumption. This loss of solvent also increases the viscosity of the ink. However, since viscosity is also a strong function of temperature, it is necessary to distinguish between the effects of temperature and evaporation in order to determine the amount and timing of solvent addition.

Without temperature compensation, an ink at a low temperature would give a high viscosity reading, suggesting that dilution is necessary. However, diluting the ink would give a lower color

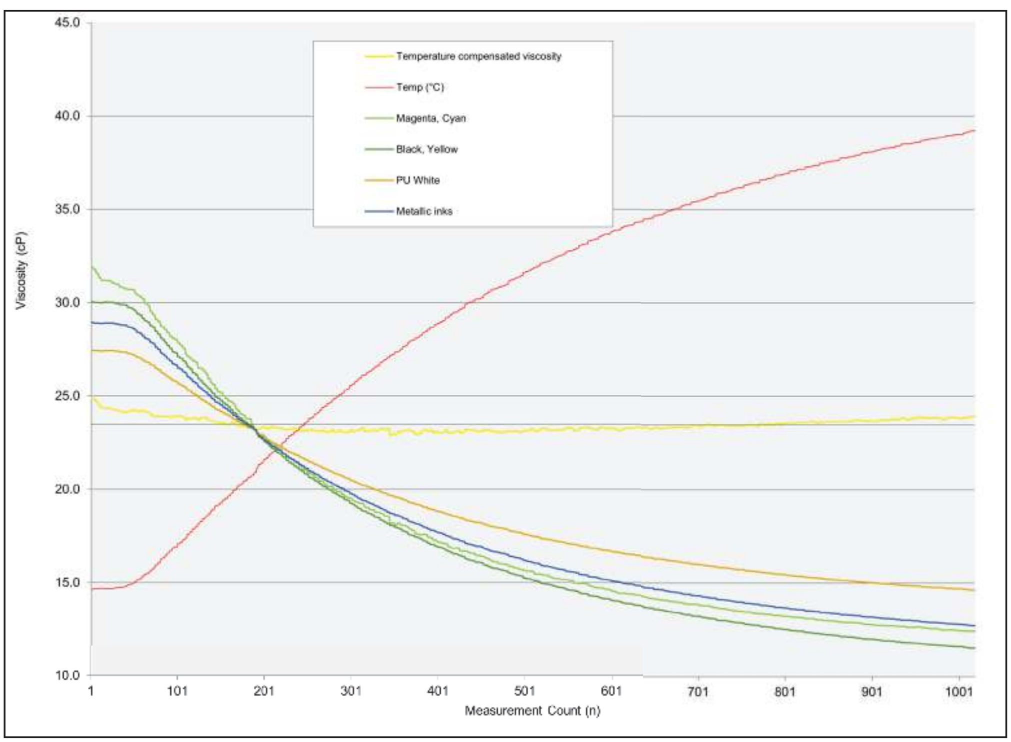

Figure 1: Temperature dependence of ink viscosity

density, since the higher viscosity was due to lower temperature, not due to higher pigment loading.

Using graphs such as those in *Figure 1*, we developed an algorithm that allows us to compensate for the effect of temperature on the viscosity, resulting in a "temperature-compensated viscosity" that is a true measure of the pigment loading. Therefore, it can be used directly to control solvent addition to make up for evaporation, because it removes temperature as a variable affecting the measurement.

Using our compensation algorithm, we reduce the error deviation to 1 percent over the entire temperature range. In the automatic viscosity control, the temperature compensation can be selected for each type of ink. We have determined this curve for almost every ink we use, and have determined the temperature-compensation parameters using our special algorithm, enabling us to finally achieve tighter control over pigment loading and its effect on printing quality.

Figure 2: Sensor installed in ink line

INSTALLATION

The sensor is mounted in a connector with an inlet and outlet opening and installed in the supply line between the ink pump and the doctor chamber (seen in *Figure 2*). Influences such as machine vibrations or pressure pulsations from the diaphragm pump have no effect on sensor operation or measurement accuracy.

The sensor is maintenance-free—each cleaning cycle of the lines and doctor chamber ensures that the sensor is clean again, since it is automatically washed in solvent. As shown in *Figure 3*, only a very thin haze of color may remain on the sensor, which has no influence on its accuracy or repeatability. And because of the sensor's robust construction, any necessary cleaning can be done with a solvent-soaked rag, with no danger of damaging the sensor or changing its calibration.

Figure 3: The sensor after measurement in cyan ink

All sensors are separately connected via industrial grade cables (*Figure 4*) to their electronics units, and these communicate with an industrial grade computer. The computer controls a valve island, which in turn controls the pneumatically-actuated valves for dosing solvent. The system (*Image 1*) includes a touchscreen, next to the operator control panel, which operates the intuitive user interface of the viscosity control software. In the creation of the user interface it was obvious that it had to be clear, intuitive, effective and quick to operate.

Figure 4: Four symmetric resonator viscometers installed on a press, using simple pipe tees as adapters

"The main purpose of viscosity control is to maintain print quality from start to finish of a job, no matter how long or complex."

The interface displays a dashboard, on which the operator can monitor the viscosity of all stations. Touch-sensitive controls enable the operator to switch individual stations on or off, enable automatic control and to set the viscosity limits. A separate station hub switches to a display that monitors the viscosity over time and allows adjustment of specific sensors and valves. Furthermore, the software notifies the operator when the viscosity changes are too large and helps by making the right correction to solve the problem.

PREDICTIVE TRACKING CONTROL

During printing, there is continuous evaporation of solvents. Evaporation increases with faster printing speed and rising ink temperature. Sensors measure the actual value of the viscosity

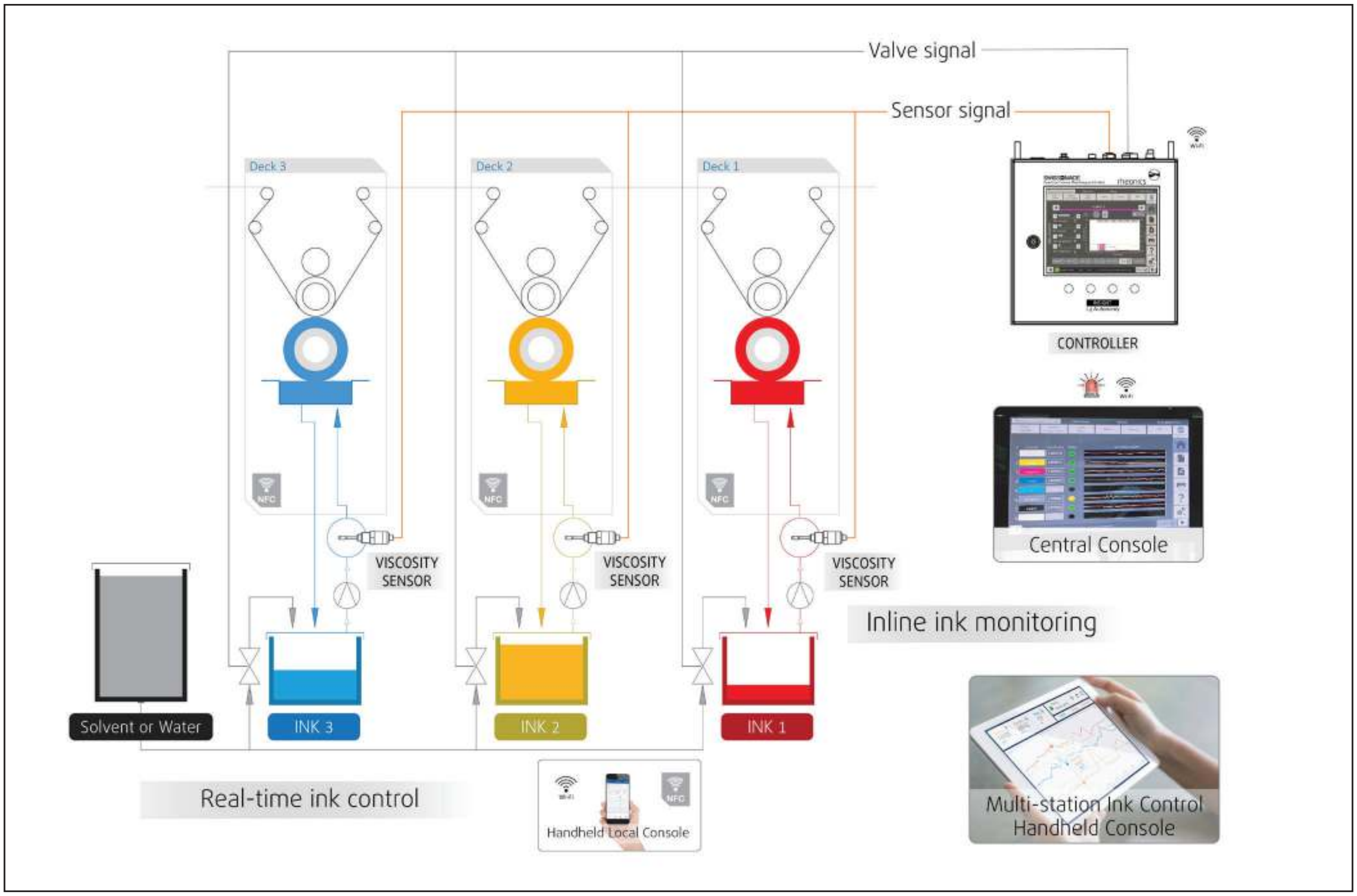

Image 1: Real-time ink control is achieved through inline ink monitoring facilitated by placement of viscosity sensors at each print deck. They connect and transmit data to central, multi-station and single-station handheld consoles.

Figure 5a: Temperature-compensated viscosity (black, 25cP) and temperature (green, ~18 degrees Celsius) vs. time, coarse vertical scale

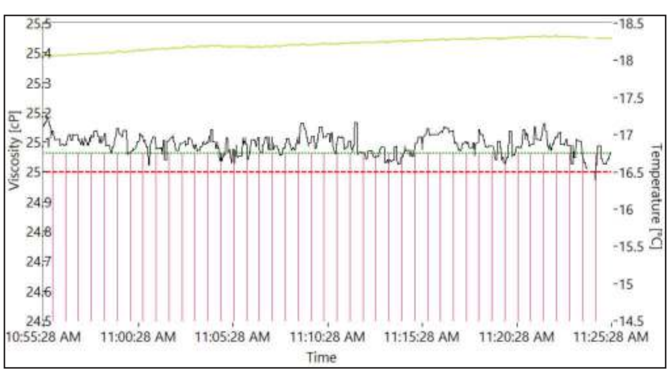

Figure 5b: Same plot as above, with expanded vertical scale. Temperature-compensated viscosity variation is less than 0.2 mPa.s.

and ink temperature once per second, enabling the software to calculate the temperature-compensated viscosity. This, in turn, enables the controller to determine whether the temperature-compensated viscosity falls within the desired tolerance. The controller will add a quantity of solvent that depends on the size of the deviation from the setpoint. During printing, it is possible to maintain a deviation of only 0.5 percent from the setpoint. Dosing valves used can add very small amounts of solvent

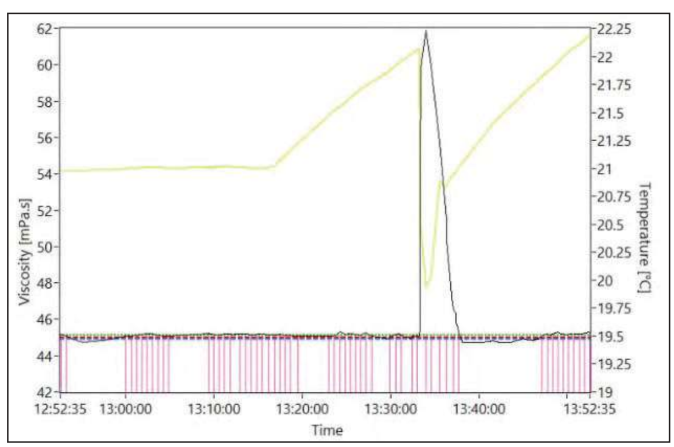

Figure 6: Response of the system to adding a large volume of cool ink to a system running at 21 degrees Celsius. Note the rapid recovery time of the temperature-compensated viscosity.

that are necessary to achieve such fine control. *Figure 5a* and *Figure 5b* are of the same color with different scales, with vertical magenta lines indicating automatic solvent dosing.

The control system is extremely accurate because it can compensate rapidly for the evaporation that is occurring constantly during the printing process. To achieve such very small deviations from the setpoint, the system will sometimes dose as little as 10-g. of solvent every 30 seconds.

If an ink with too high a viscosity is added to the ink bucket, the control responds immediately by measuring the response to each solvent dose, with the subsequent dosing of solvent being adjusted accordingly, as in *Figure 6*. In the end, the setpoint is reached very gradually with very little overshoot. Besides the extremely accurate control, it's possible to keep the viscosity stable when the level in the ink bucket is very low, just enough to pump the ink through the system.

QA & STANDARDIZATION

An experienced operator knows what viscosity must be maintained for which types of ink in the particular process being used. This depends on the kind of ink—the Pantone color as well as special challenges, such as those presented by metallic and white inks, which have a somewhat different behavior with temperature than "normal" inks. Desired viscosity also depends on the type of substrate on which the printing is done.

To better understand the problem and its solution, we performed a series of experiments on the effects of ink dilution on print quality and measured ink viscosity. With these results, we know which viscosities have to be maintained for the type of substrate (paper, polyester, polyethylene, polypropylene).

In a first experiment, 10-kg. ink was 10 percent diluted, press running at 656.17 fpm, the polyester film was marked, and the press was stopped. The ink was diluted with a further 3 percent of solvent, the ink was circulated until the viscosity stabilized and the process was repeated a total of 15 times. The film was

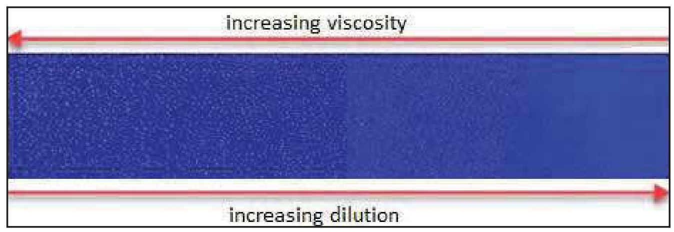

Figure 7: Color density variation with ink dilution and viscosity

removed, all 15 segments were measured with a spectrophotometer, and photographs of the film segments were made for subjective visual evaluation.

Figure 7 shows the visual appearance of the printing quality at a series of dilutions. It depicts color density variation with ink dilution and viscosity.

At the lowest dilution (highest viscosity), too much ink is deposited and does not flow properly. Pinholes develop and overall quality is poor. Although the color between the pinoles is quite dense, the measured density is low, due to the high reflectivity of the pinholes. As dilution increases, viscosity decreases and the flow improves, but pigment loading decreases and the color becomes lighter. Each sample was measured with the spectrophotometer and compared with the digital PMS reference. *Figure 8* and *Table 1* show the Delta E 2000 and color density as functions of dilution and viscosity. Viscosity difference values are referred to sample 6, which is the target density.

Table 1: Numerical Values of Delta E 2000 and Color Strength vs. Dilution
(Viscosity Difference is relative to sample 6)

Sample	Viscosity	Dilution	Viscosity Difference	dE	Color Strength
1	69	10%	5.3	1.07	94.2%
2	63	13%	3.9	0.79	97.8%
3	57	16%	2.5	0.55	96.4%
4	52	19%	1.4	0.41	98.8%
5	49	22%	0.7	0.19	98.8%
6	46	25%	0.0	0.00	100.0%
7	42	28%	-0.9	0.20	98.9%
8	38	31%	-1.9	0.50	98.0%
9	36	34%	-2.3	0.64	98.0%
10	33	37%	-3.0	0.83	97.2%
11	30	40%	-3.7	1.26	96.8%
12	28	43%	-4.2	1.69	95.0%
13	26	46%	-4.6	1.73	95.0%
14	24	49%	-5.1	2.49	92.3%
15	22	52%	-5.5	2.70	91.6%

This experiment shows that with this system, very accurate viscosity control can be achieved, with a viscosity bandwidth of 0.5 percent. By dosing very small quantities of solvent about every 30 seconds, the system enables very small variations in Delta E values to be achieved.

At the time these experiments were done, the customary viscosity bandwidth was ±0.5 cup seconds (about ± 2.2-mPa.s) with the viscosity being checked manually every 15 minutes to 20 minutes. The amount of solvent that was then dosed was between 0.2-kg. and 0.5-kg. (depending on the ink coverage, type of solvent, anilox volume, machine speed and temperature).

We now have changed the process of printing a Pantone color, because we not only know which viscosities have to be maintained for the type of substrate, but can hold tight tolerances on this viscosity. Certain substrates require a higher viscosity due to the fact that the ink "sinks" too far and so the structure becomes visible, resulting in a decrease in color strength, while other substrates need a lower viscosity due to their smooth surface and good ink acceptance.

With the experience gained with this system, we know exactly which viscosity should be maintained for the type of substrate (polyethylene, polypropylene, polyamide, polyester, paper and biodegradable), and have actually determined a standardization for ourselves.

With the very first print, the color density of the Pantone color is measured and then the operator checks whether the ink has the correct viscosity for the relevant substrate. (The ink is usually not brought to the correct value in advance because the substrate may vary slightly in terms of surface quality, so we have some room to play with the viscosity for optimum results.)

In the older method, if a color had too high color density, we reduced it with varnish and/or with a different anilox roll. If in doubt, the viscosity was checked with a cup, which usually necessitated re-calibration of the relevant sensor.

Because we now have a more reliable measure for the initial temperature-compensated viscosity of the ink, its viscosity can immediately be adjusted automatically by diluting an ink to the correct value. Because the correct viscosity values are maintained, this leads to better ink transfer from anilox roll to printing plate and finally to the substrate. Contamination of the anilox roll can also be noticed earlier because we know which color strength should be reached with a certain viscosity.

Too high viscosity leads to poor transfer resulting in visual characteristics like opacity and "ghosting." Due to a more accurate viscosity, the cell of the anilox roll is better emptied and the ink usually flows better, giving in a smoother ink layer and increased color strength. With increasing speed, the ink transfer decreases, but because the ink has the correct viscosity and performs optimally, these variations are smaller compared to our earlier method using cup-calibrated sensors.

In the last six months, we have improved color quality and are able to maintain much smaller deviations of Delta E 2000 values, especially during long runs. A result of tighter viscosity control is that the print inspection system sees far fewer errors in color strength deviations. Machine operators show high confidence in the accurate and repeatable values of the sensors and control system. This trust has led to our press achieving excellent print quality for jobs small and large.

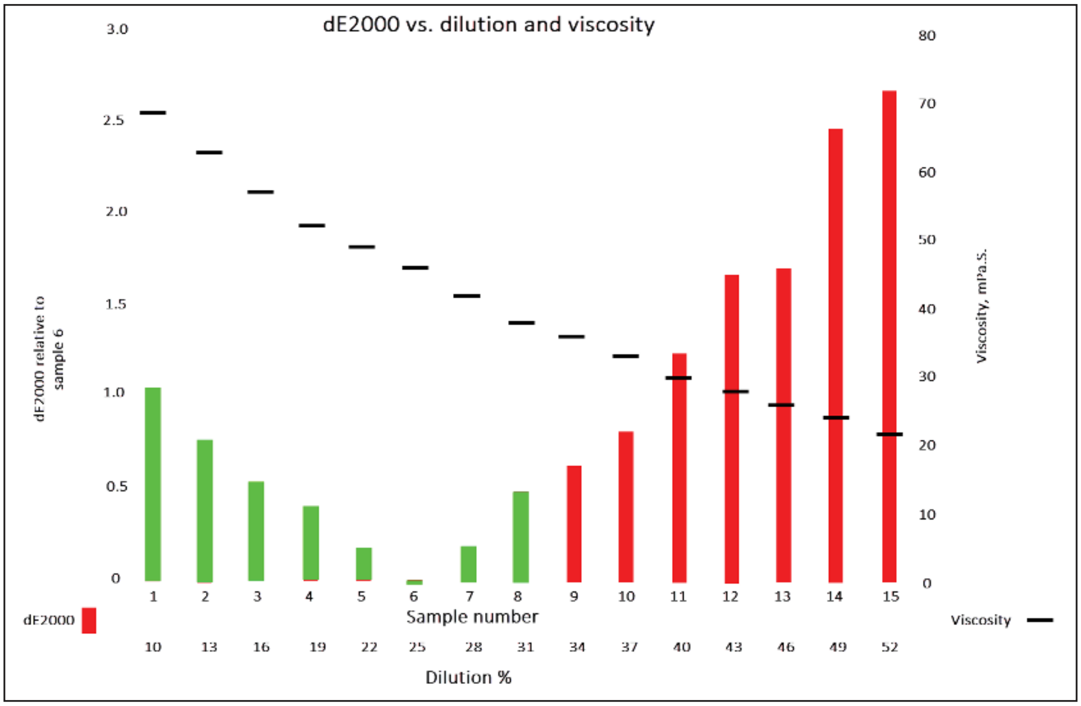

Figure 8: Color density as a function of ink dilution and density. Delta E 2000 values are referred to sample 6.

In addition, we have performed neither maintenance nor calibration of the sensors and beyond our initial temperature-compensated viscosity parameter measurements for each ink, no further standardization of the viscosity values needs to be done. We now know what viscosities should be maintained for specific substrates. After printing each new order, we store the viscosity set values and use these for repeat orders of the same job.

MPA.S TO CUP SECONDS?

Although formulas exist to convert viscosity values from mPa.s to DIN cup seconds, we have found that abandoning cup seconds has several advantages.

Above all, it has changed the way we think about viscosity. As long as we thought in terms of cup seconds, keeping a tight control on viscosity seemed like an impossible task. Our expectations were limited by our previous experiences, so we set the bar lower than was necessary to achieve the kind of print quality we knew was attainable.

Furthermore, thinking in terms of cup seconds made us want to grab a cup and check the accuracy of these new sensors, with which we were unfamiliar at the time. But checking the accuracy of the sensors with a much-less-repeatable method can give the false impression that the sensors themselves are not repeatable!

It is only when we compared actual printing results using the new sensor system to what we were accustomed to that we saw the real value in thinking in the new, unfamiliar units. It enabled us to "think small," to be able to see small variations in viscosity that were otherwise invisible. Furthermore, it let us get our viscosity under tighter control, which had direct positive impact on the quality of our final product, which is, after all, our main goal.

As printing speeds increase, and profit margins get tighter, "getting it right the first time" becomes much more important. An error in initial viscosity setting can result in producing several thousand meters of waste in no time at all. Tight control with an accurate sensor, combined with a responsive control system, has enabled us to streamline our printing process while improving color quality and reducing waste. ■

ABOUT THE AUTHOR: *Bert Verweel is the owner of Maasmond Papierindustrie bv Oostvoorne in the Netherlands. He did his bachelor's degree in mechanical engineering from TU Delft, and has 25 years' experience in flexographic printing, laminating, engineering, biological treatment of air emissions. Over the years, he has tested multiple types of inline sensors for ink viscosity monitoring and control.*

Maasmond is a family owned company (founded in 1969) with 50 years of experience in converting of paper and plastics. For the converting of food and non-food packaging and labels, it houses a broad range of modern narrow and wide web flexographic printing presses (UV- and solvent-based inks), laminating (water- and solvent-based adhesives), and slitting, diecutting and perforating machines. Maasmond produces a wide range of high-quality labels and flexible packaging which adhere to the highest food packaging standards. Learn more at www.maasmond.com.