Flexo Quality Consortium
Research Committee of the Foundation of FTA

FINAL REPORT

FQC Ink Temperature Study

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Submitted August 1, 2021

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Introduction

The flexographic industry has, over the past few decades, enjoyed a period of rapid growth. This growth has been accompanied by profound changes in printing technology, both in flexo and other segments of the printing industry. In order to help the industry cope with these technological changes, the Flexo Quality Consortium (FQC) was formed in 1990 to investigate the flexo printing process and gain a better understanding of the factors controlling the quality of the printed image. The FQC's mission statement:

The Flexo Quality Consortium (FQC), acting as a select standing committee of the Foundation of Flexographic Technical Association, Inc. (FFTA), will provide the industry with a better understanding of the factors controlling the quality of a flexographic image. FQC projects investigate selected printing variables in flexographic printing technology.

Currently the Consortium is directed by an Executive Committee that develops and evaluates proposed research projects. Open participation is encouraged by qualified technical representatives from companies in the printing industry on a non-discriminatory basis. A simple philosophy guides all FQC projects in the experimental design and execution:

- The Consortium will use only commercially available materials – no proprietary products or products under development. The goal of the Consortium is to provide process research for the members of the flexographic community, not to do R&D work for the members of the Consortium.
- The Consortium will use industry standard practices throughout – no special procedures to make any component (plate, anilox, ink, etc.) perform better. This avoids biasing the results and further ensures that each company will be able to duplicate and/or apply the results of the experiment to his own equipment.
- The Consortium will use a statistically designed experiment to assure a total systems approach. This type of experimentation yields the highest quality data with the smallest outlay of time and materials.

Projects follow a well defined sequence of steps; they are ***designed experiments***. Broadly speaking, the experiments are performed under controlled conditions, holding all input variables constant and changing selected input variables according to a statistically designed plan. A process model was developed. (See Figure 1.) Specified output parameters are measured and analyzed, again using statistical techniques.

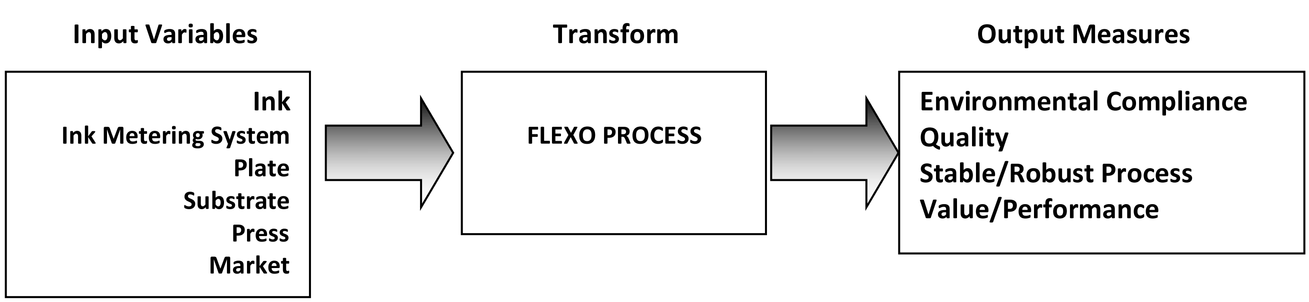

Figure 1 – Process Model

In recent years, another type of experiment has been carried out called a process capability study. These studies still adhere to the process model shown in Figure 1. These types of projects represent an expansion of the original concept of the types of projects undertaken by the FQC and seek to answer specific questions regarding some aspect of flexo printing. These projects are categorized as a capability study.

Each project begins with a proposed charter that follows the approved project charter template and includes:

- Project Title
- Team Members
- Objective
- Scope
- Business Impact
- Duration of Project
- Resource Requirements
- Project Milestones

The Executive Committee reviews the proposed charter and advises the project team on content and technical relevance. Once approved the project team begins to execute the project and brings it to completion. The results are presented to the Executive Committee for final review. Once the Executive Committee supports the results based on the documented data a final report is prepared for the industry. The following report has met the criteria of an FQC project and is considered valid research that examines various factors affecting flexography and can be used by member companies and standards bodies to further the understanding and technology that is flexography.

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Letter of Thanks

Mark and Ann would like to personally thank everyone who was involved with the Ink Temperature Study. Without the contribution of all of the team members, suppliers, FTA Staff and FQC members, this project would not have been possible.

A special thank you to the team members who were able to be onsite for our trials during unprecedented times.

Also a special thank you to our hosts; Sonoco Institute at Clemson University, for the donation of press time and the support in advance to ensure that our trials went smoothly. Their assistance in carrying out the trial plan is greatly appreciated!

Equipment and Material Donations

A HUGE thank you goes out to the following companies for their donations to the project:

- Substrate supplier, Green Bay Packaging
- Plate and imaging supplier, Miraclon Corporation
- Ink pumping systems, Graymills
- Ink Suppliers, FlintGroup; Actega; Siegwerk EIC, LLC
- Viscometer, Inkspec Viscosity Controls
- Heat exchanger, XDS
- Temperature control system, Saint Clair Systems | Norcross
- Flexo press, Sonoco Institute at Clemson University

Project Participants

- Mark Portelli, Saint Clair Systems | Norcross
- Ann Warzecha, AWT Labels & Packaging
- Paulo Vieira & Paul Bowden, FlintGroup
- Shawn Scheel & Corey Snyder, Actega
- John Kilbo, Siegwerk EIC, LLC
- Keegan Odell, Sealed Air
- Greg Ginnow, XDS
- Craig Shields, Graymills
- Ray McMillen & Catherine Green, Miraclon Corporation
- James Dulong, PAD, Inkspec Viscosity Controls
- Catherine Haynes, All Printing Resources
- Jean Engelke, FQC
- Jean Jackson, FQC
- Duane Woolbright, FTA

- Kenny Tucker, Press Assistant/Project Coordinator
- Bobby Congdon, Data Checker/Institute Assistant Director
- Shane Hutchings, Press Operator/Pressroom Manager
- Maggie Dailey (PKSC), Coleman Pope (PKSC), Zack Dotson (GC), Undergraduate student help
- Dovie Jeffcoat (GC), Cat Bromels (GC), Graduate student help

Project Scope

1. Identify the impact that Temperature has on the printability of inks.
2. Run tests to determine effects temperature on quality using a controlled methodology.
3. Provide industry an understanding of effects on ink characteristics and parameters that impact print and press performance to support pressroom practices and provide documentation for *FIRST* recommendations and updates.

Statistical Design

Fixed Parameters

Spot Color

Ink Color: Green PMS 334

Anilox: 800 LPI / 2.8 BCM/in^2

Plate: 0.067" Solvent Plate

Stickyback: 0.020" Medium Soft

Press Speed: 250 fpm

<u>Process Color</u>

Ink Color: Cyan

Anilox: 1200 LPI / 1.8 BCM/in^2

Plate: 0.067" Solvent Plate

Stickyback: 0.020" Medium Soft

Press Speed: 250 fpm

Variable Parameters

<u>Spot Color</u>

Ink Type 1: Water-Based

Ink Temp: 70° to 120° F

Ink Type 2: UV

Ink Temp: 70° to 140° F

Substrate 1: 3mil Unsup. Wh BOPP

Substrate 2: 3mil C1S paper

Plate Screen: 120 - 200 LPI

<u>Process Color</u>

Ink Type 1: Water-Based

Ink Temp: 70° to 120° F

Ink Type 2: UV

Ink Temp: 70° to 140° F

Substrate 1: 3mil Unsup. Wh BOPP

Substrate 2: 3mil C1S paper

Plate Screen: 120 - 200 LPI

Temperature Control Process

The goal was to apply inks at certain temperatures to see the impact that temperature has on the quality of the print. To accomplish this, we needed to deliver temperature controlled ink into the ink pan, which is the closest point to the application of ink to the substrate.

We accomplished this by pumping and recirculating ink out of a 5 gallon bucket and through a heat exchanger; which was controlled by a temperature control unit that is capable of maintaining a constant temperature setpoint.

The temperature control unit maintained temperatures for the different set points as it was pumped through a heat exchanger coil. We cycled at 4 minute intervals, at each temperature, to allow the ink temperatures to adjust to the desired set point. Then the temperature was verified with a submerged probe in the ink pan and the viscosity with an inline viscometer or Zahn cup. Once the temperature was stable in the ink pan, we ran a 3 minute print run.

- Ink at required process temperature as close as possible to point of application
    - Pan feed application
    - Temperature Control Unit (TCU) setpoint
    - Ink flow/turnover through heat exchanger
- 3-minute run interval at each temperature.
    - Consistent ink temperature applied to pan
    - Process calibrator in pan to verify actual process temp
- No viscosity management system
    - Only influence on viscosity was temperature
    - Runtime too short to have any other effect on viscosity

Challenges

In a controlled experiment we wanted to be consistent with our protocol for testing; this included the equipment used from run to run. However, based on the increase in viscosity of the UV inks, we were forced to pause testing. We encountered some issues with the type/rating of hose being used. With higher viscosity, more pressure was created and flow was lost and hoses failed. Once the correct hose was installed on the ink circulation system, we were able to restart testing.

Measurements

- Ink Maintenance
- pH and Viscosity
- Viscosity unit of measure: Seconds and centipoise (cP)
- Ink Adhesion
- Rub (water or alcohol and swab) and Tape tests
- Color
- L*a*b*C*h° via spectrodensitometer
- Print Quality
- Density and Tone Value via spectrodensitometer

Execution of Experiments

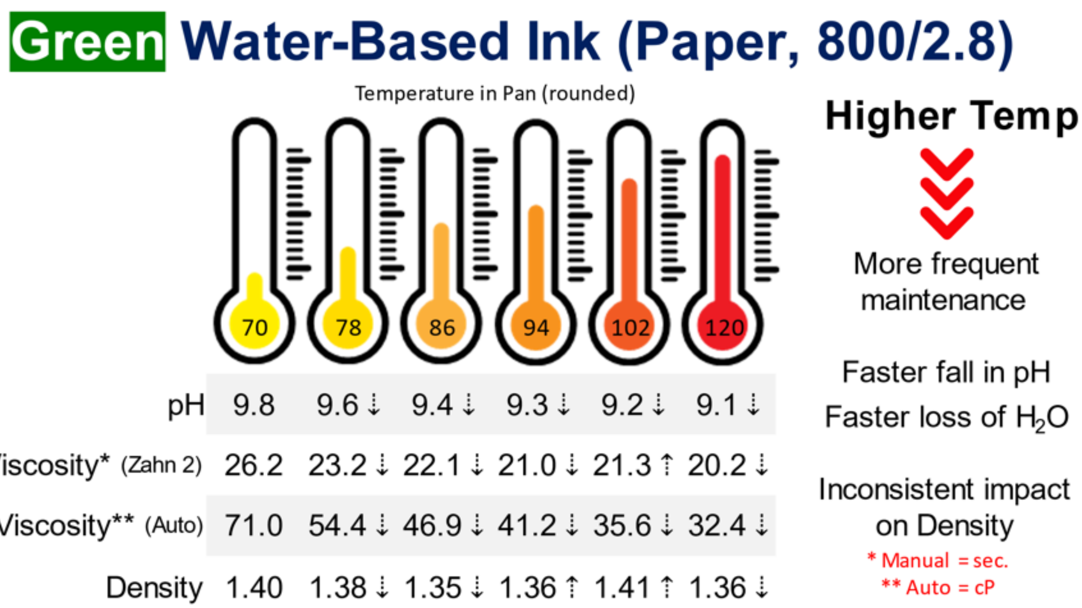
- **Press Operator(s)** – took and recorded ink maintenance specs
- **Ink Techs** – took and recorded ink adhesion specs
- **On-site Team Support** – measured and recorded color and print quality and managed data entry
- **Other Support** – support lines piped in remotely during trials due to COVID-19 restrictions

Data Analysis - Water-Based Inks

It can be observed on the results shown in Figure 1 for Green Water-Based ink on paper, that basically when we increased temperatures at our intervals, we saw pH decrease as a function of evaporation. We determined that increasing the temperature would require more maintenance of the ink. We also noticed that there was an inconsistent impact on the ink density.

The results shown in Figure 2 also show higher temperatures decreased viscosity resulting in thinner, faster flowing ink. Also there was a general increase in dot gain.

The print sample in Figure 3 shows the visual difference of the increase in dot gain from the 70 degree sample to the 120 degree sample.



	70	78	86	94	102	120
pH	9.8	9.6 ↓	9.4 ↓	9.3 ↓	9.2 ↓	9.1 ↓
Viscosity* (Zahn 2)	26.2	23.2 ↓	22.1 ↓	21.0 ↓	21.3 ↑	20.2 ↓
Viscosity** (Auto)	71.0	54.4 ↓	46.9 ↓	41.2 ↓	35.6 ↓	32.4 ↓
Density	1.40	1.38 ↓	1.35 ↓	1.36 ↑	1.41 ↑	1.36 ↓

Figure 1. Results Summary - Green water-based on paper

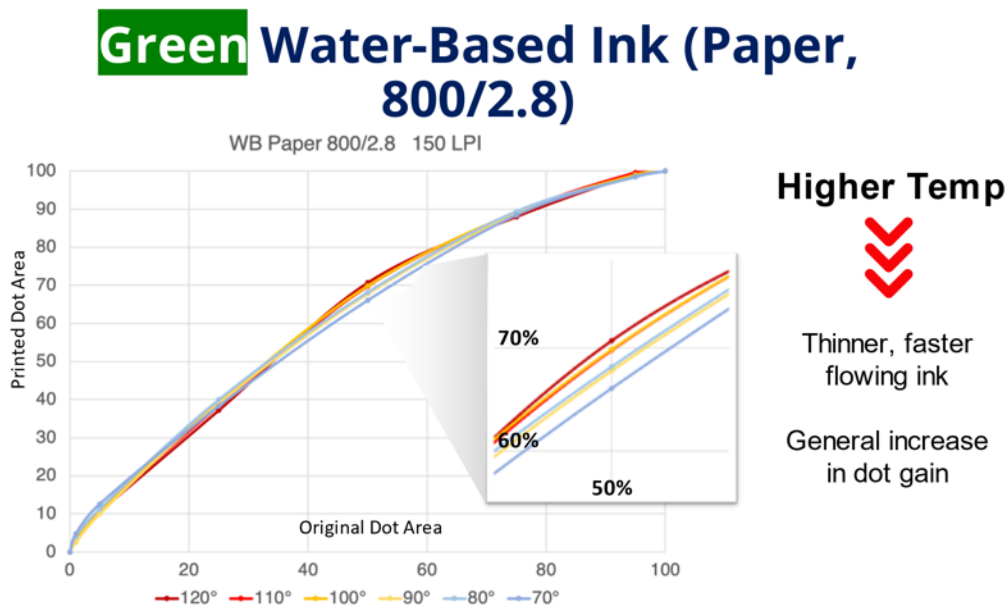


Figure 2. Results Graph - Green water-based on paper

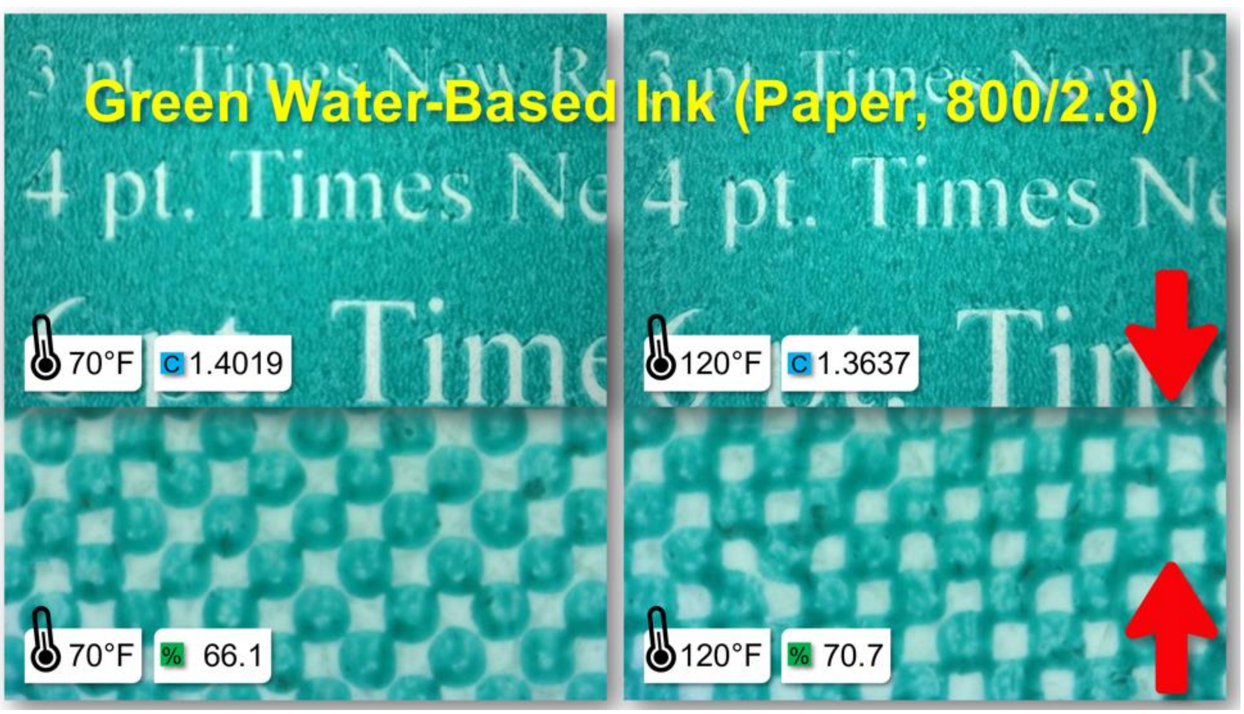


Figure 3. Print Sample - Green water-based on paper

The cyan water-based ink (Figure 4) also showed the relationship between pH decreasing as ink temperature increases. Also similar inconsistencies for the impact on ink density. Similar to the green water-based ink, we saw the viscosity decreasing and thinning of the ink (Figure 5). However, we measured a general decrease in dot gain (Figure 6).

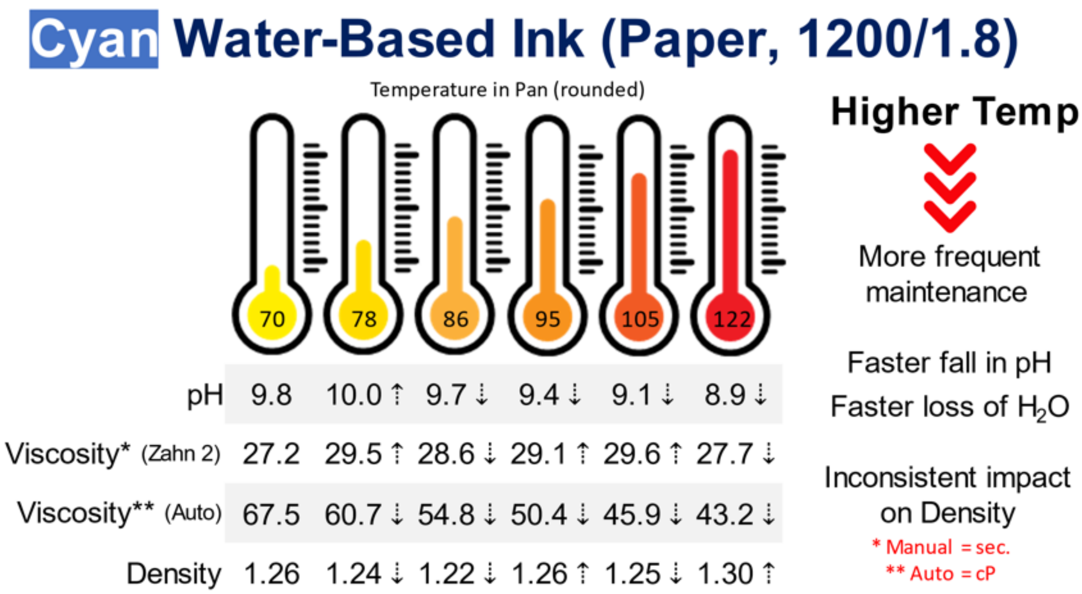


Figure 4. Results Summary – Cyan water-based on paper

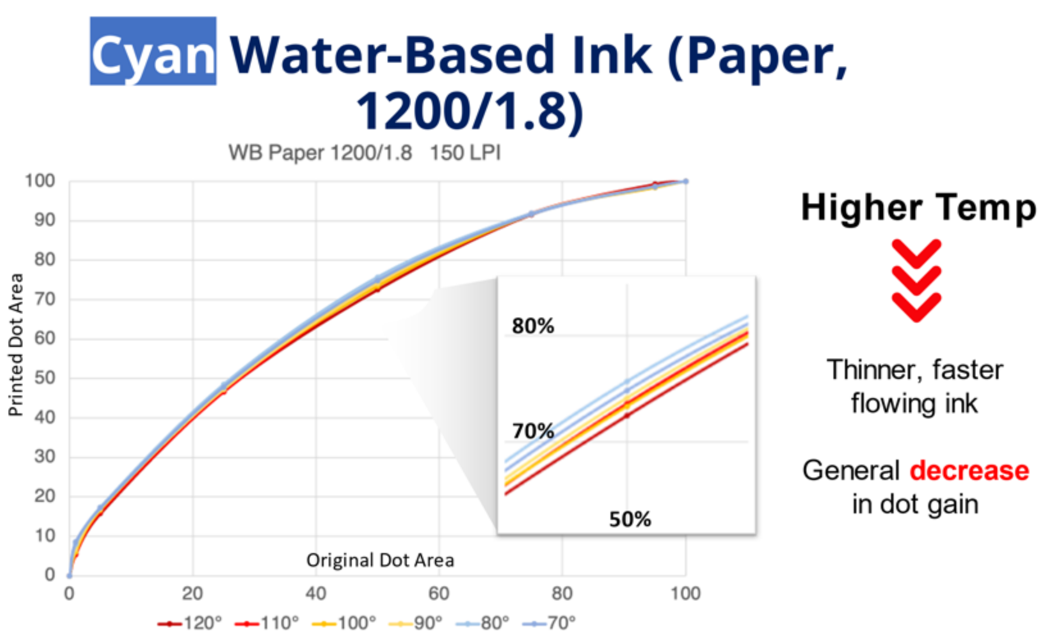


Figure 5. Results Graph – Cyan water-based on paper

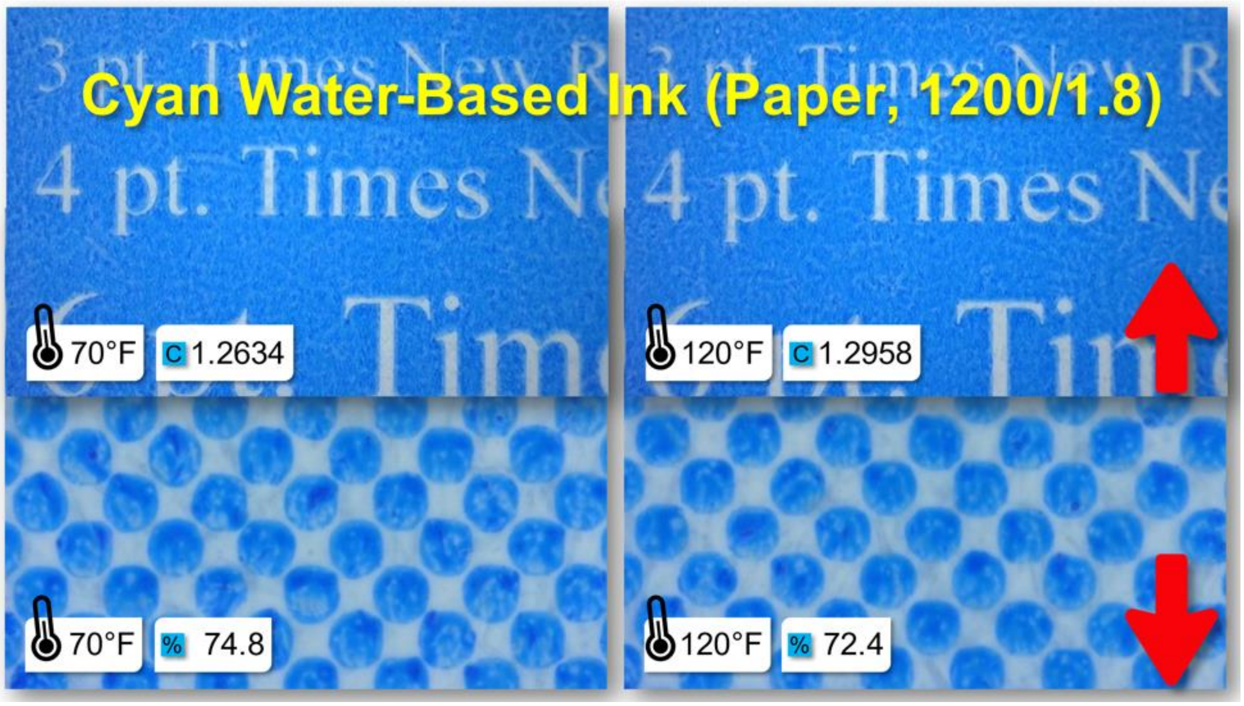


Figure 6. Print Sample – Cyan water-based on paper

In the results for green water-based ink on film (Figure 7), at higher temperatures we noticed a decrease in pH due to more evaporation. Also there was an inconsistent impact on density. The results graph (Figure 8) shows that as the ink viscosity decreased with temperature increasing, we saw a general increase in dot gain (Figure 9).

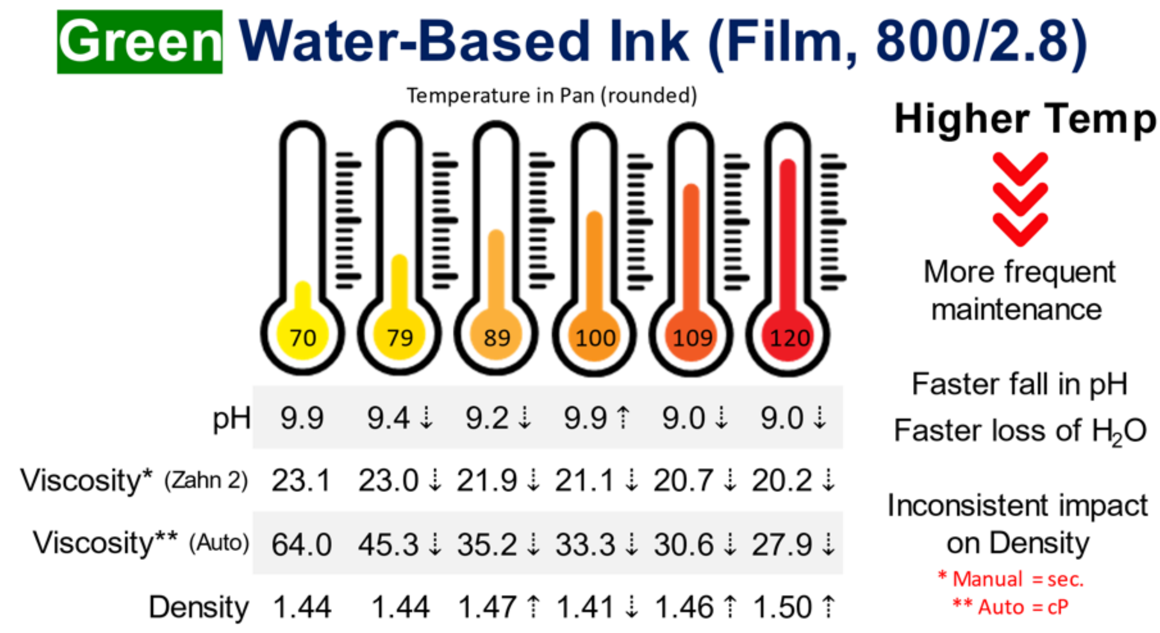


Figure 7. Results Summary – Green water-based on film

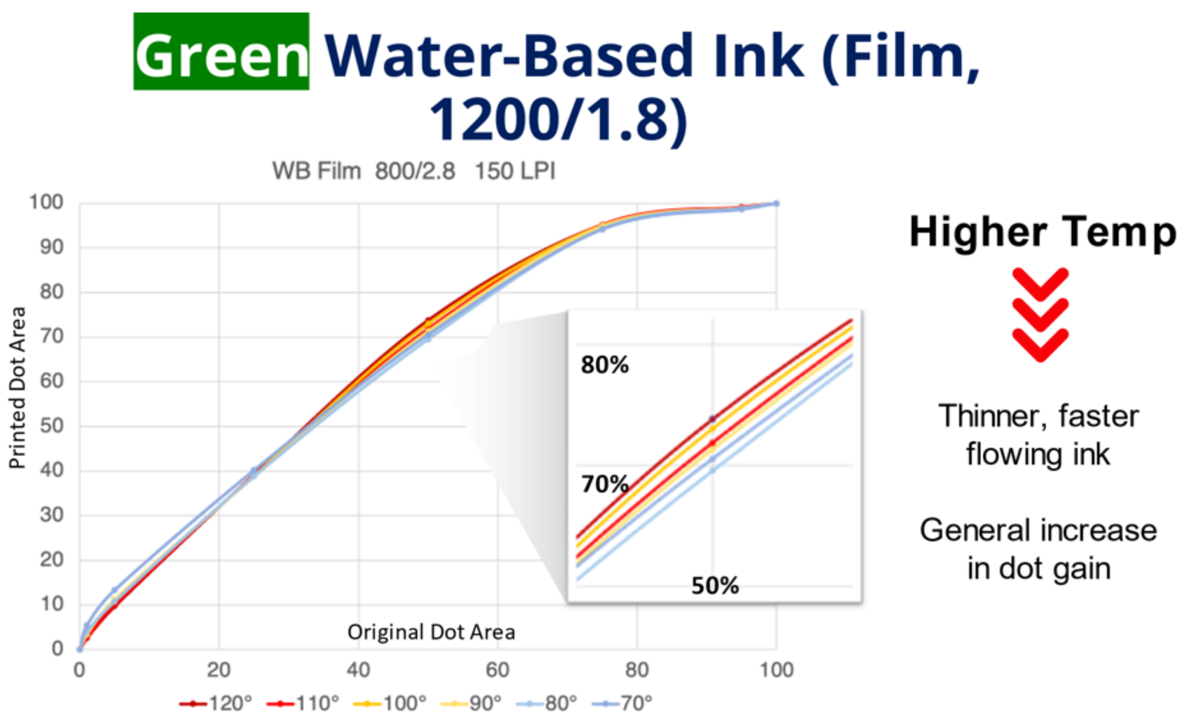


Figure 8. Results Graph – Green water-based on film

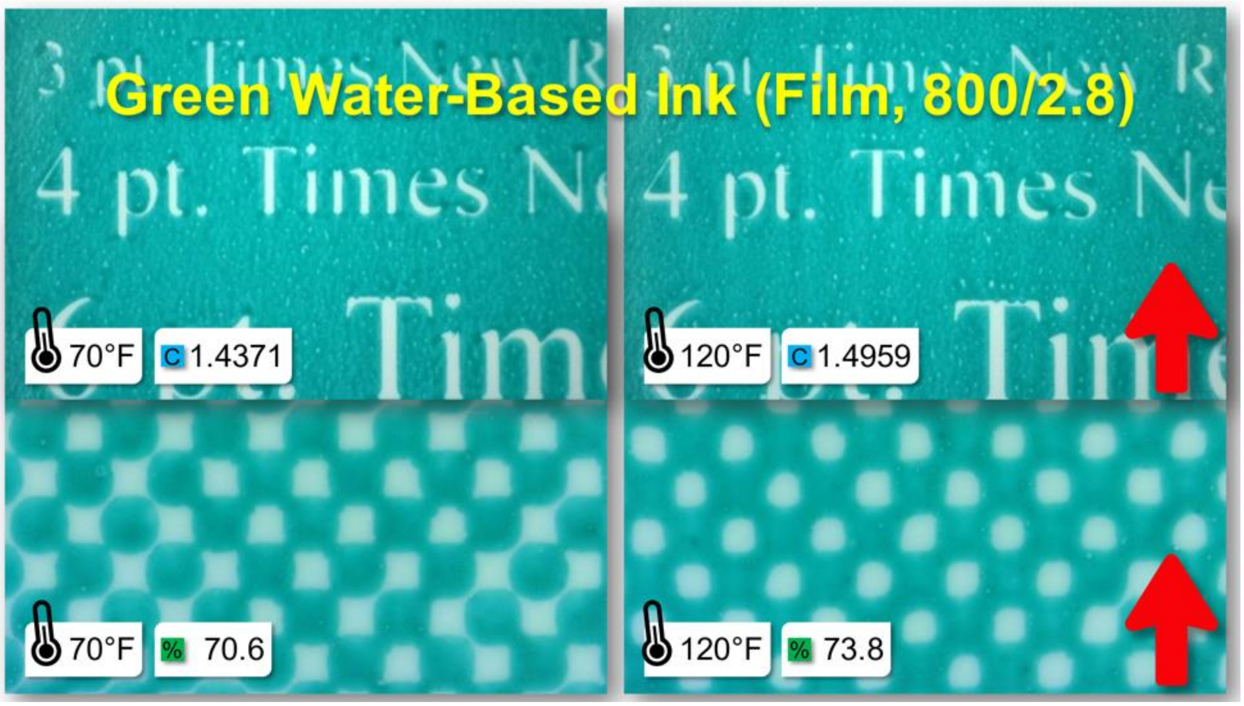


Figure 9. Print Sample – Green water-based on film

For the Cyan water-based ink on film (Figure 10), similar results were observed to the green ink. As temperature increases, we noticed a decrease in pH due to more evaporation. Also there was an inconsistent impact on density. As we increased the temperature we measured a decrease in viscosity (Figure 11), which created thinner/faster flowing inks. Also, a general decrease in dot gain for this sample as well (Figure 12).

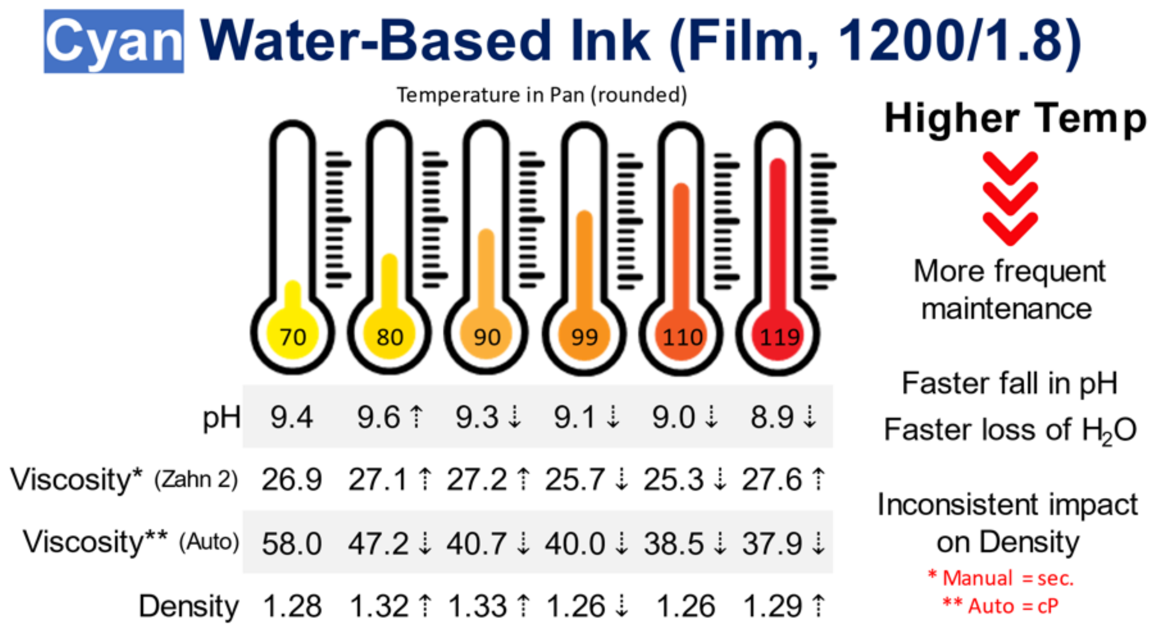


Figure 10. Results Summary – Cyan water-based on film

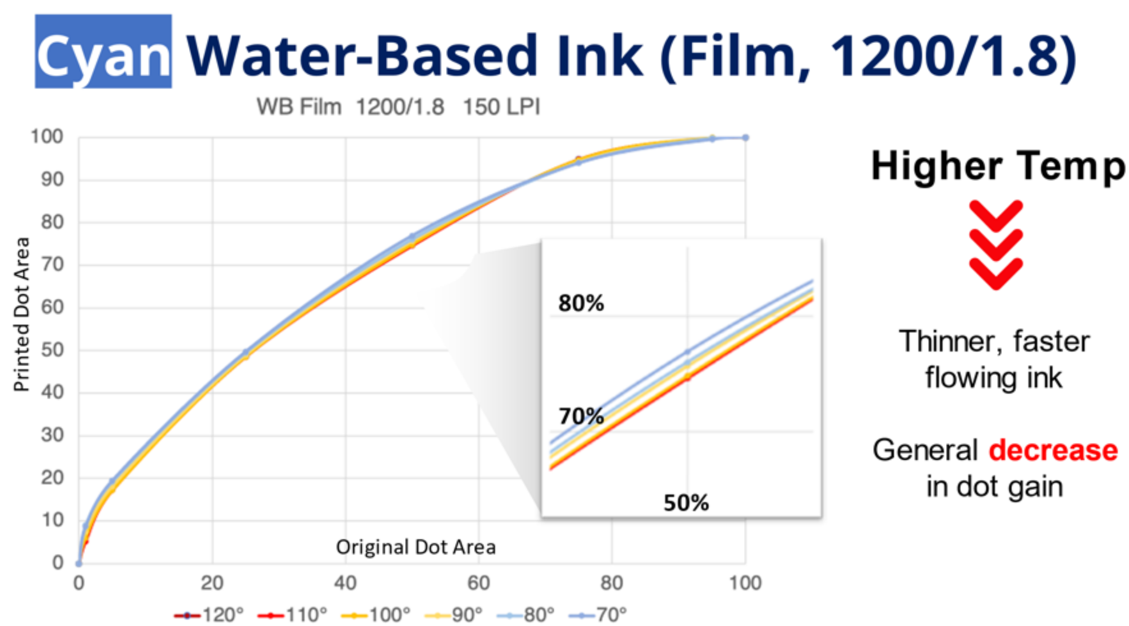


Figure 11. Results Graph – Cyan water-based on film

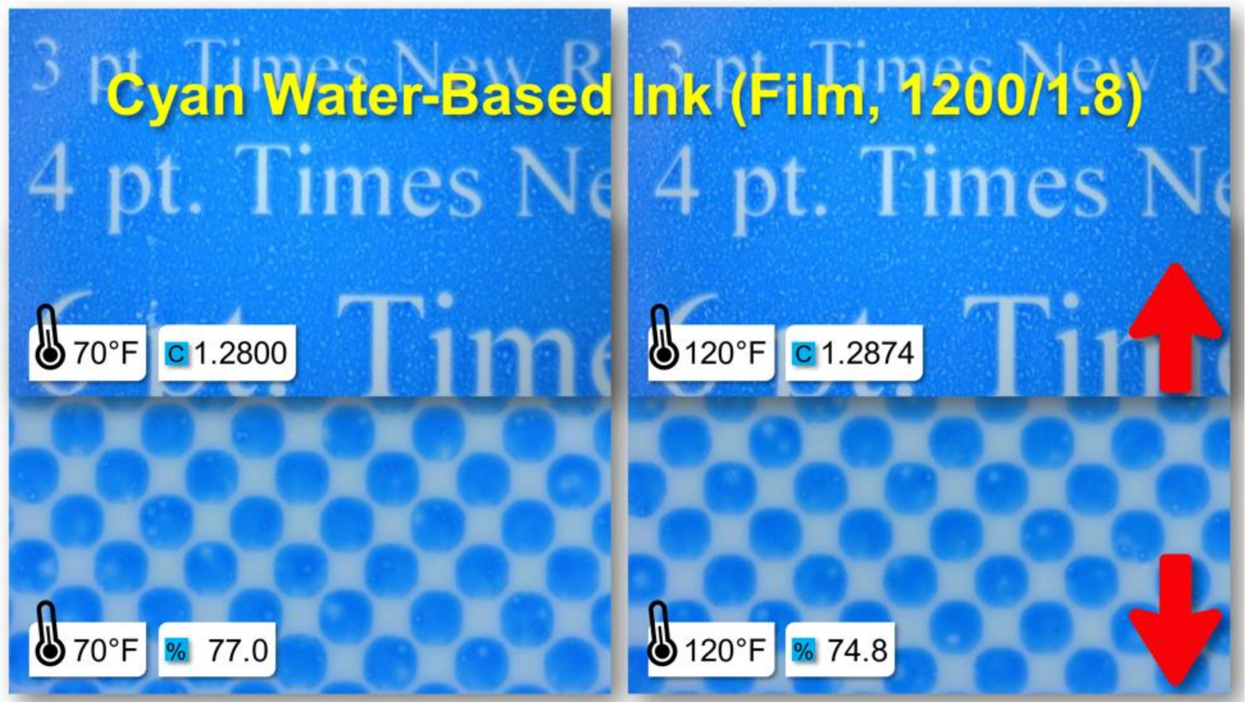


Figure 12. Print Sample – Cyan water-based on film

Data Analysis - UV Inks

For the Green UV ink on paper (Figure 13), we saw a more significant effect on viscosity. As the temperature increased, the viscosity decreased. We did notice a general increase in density. Higher temperatures led to lower viscosity. Also a general increase in dot gain. In summary an increase in both density and dot gain (Figures 14 and 15).

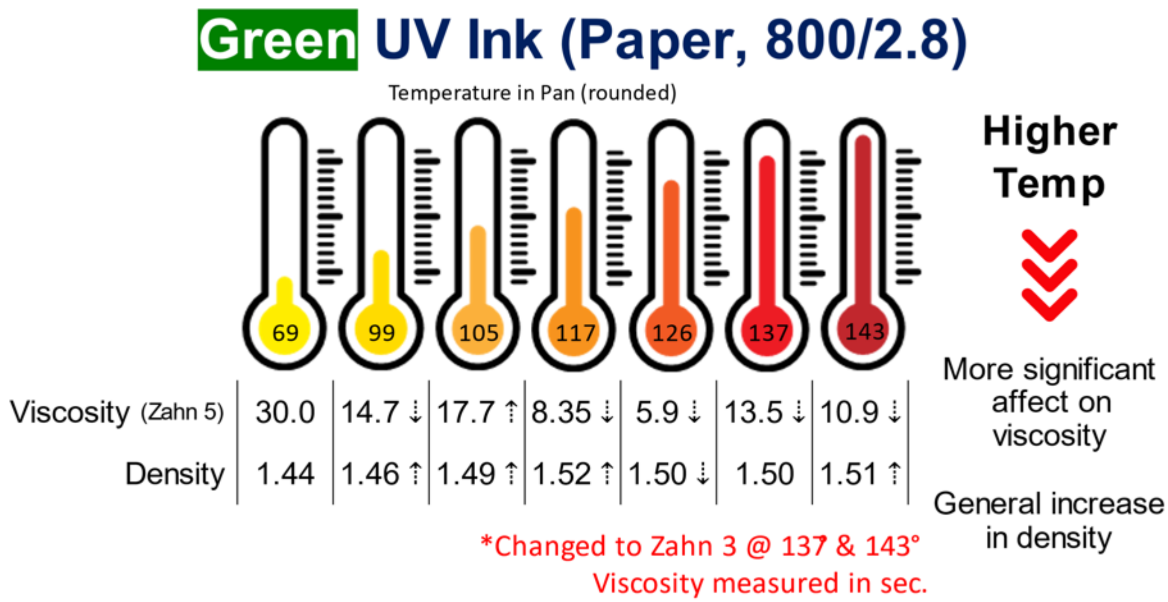


Figure 13. Results Summary – Green UV on paper

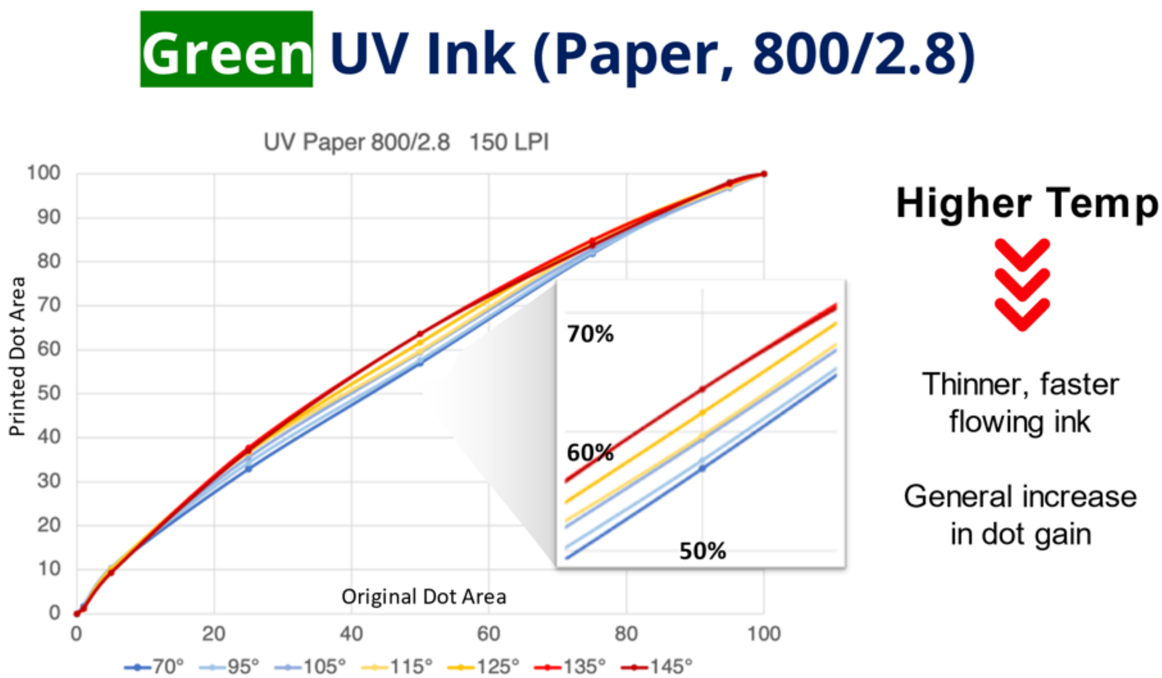


Figure 14. Results Graph – Green UV on paper

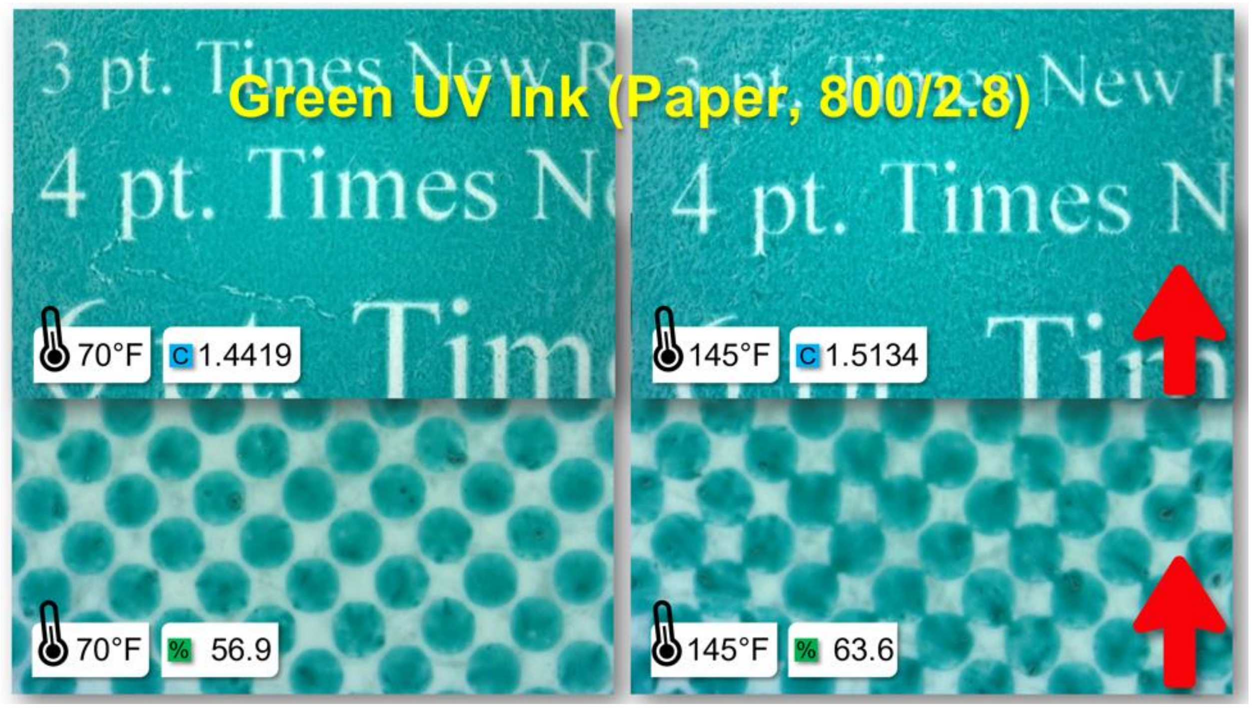


Figure 15. Print Sample – Green UV on paper

Similar to the green, the cyan had a significant impact on the viscosity (Figure 16). As the temperature increased the viscosity decreased. Also a general increase in density as temperature increased. In summary an increase in both density and dot gain (Figures 17 and 18).

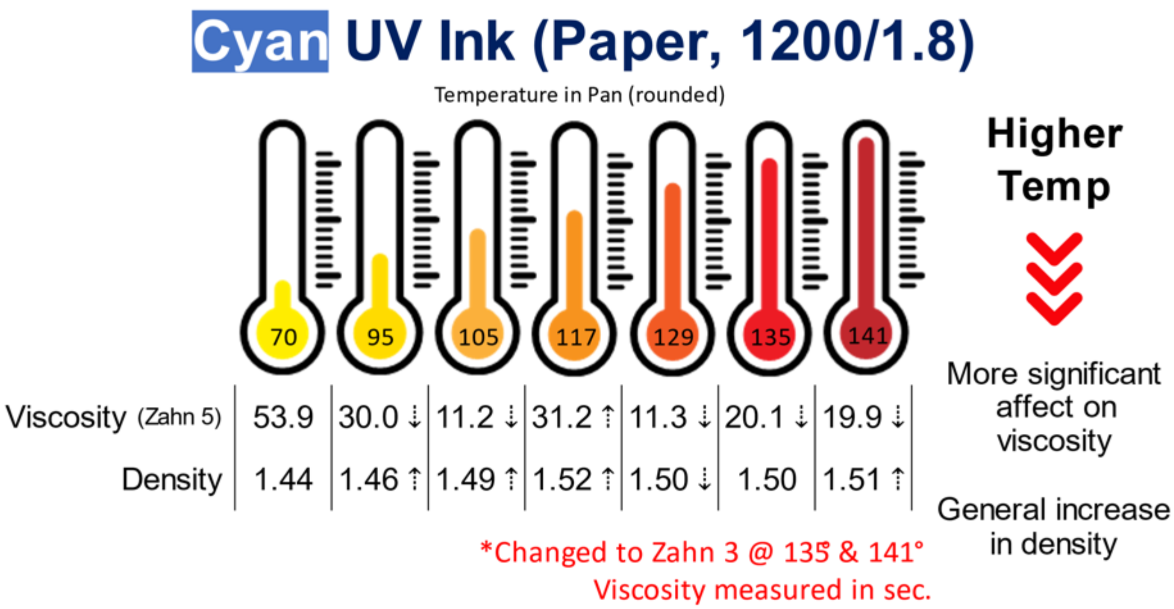


Figure 16. Results Summary – Cyan UV on paper

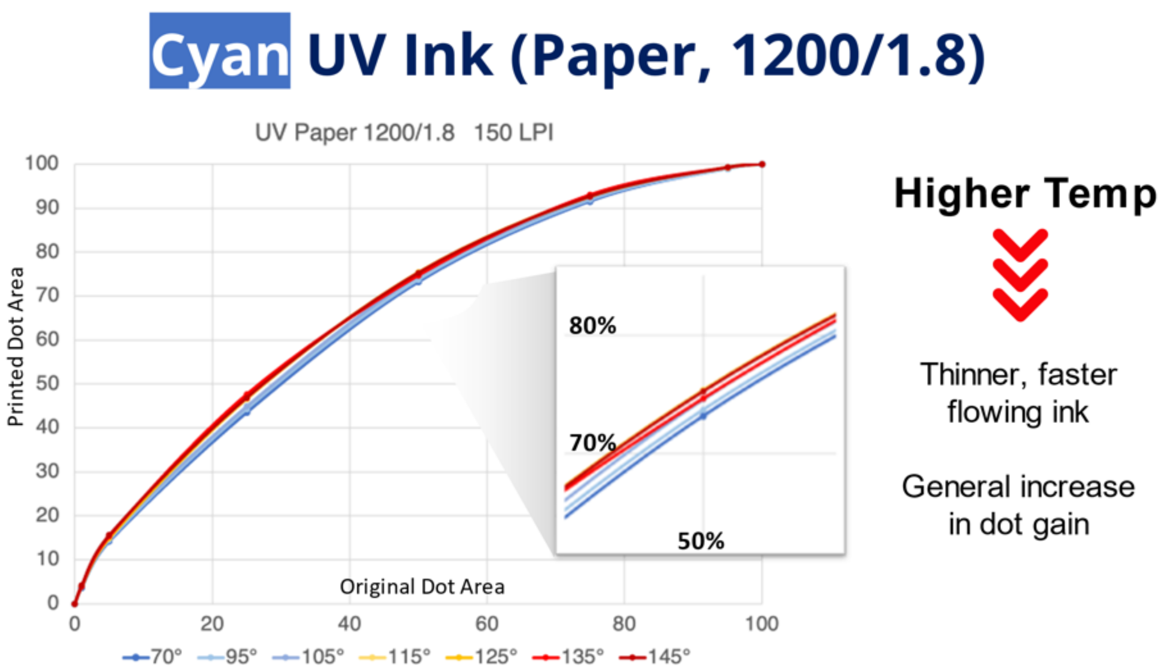


Figure 17. Results Graph – Cyan UV on paper

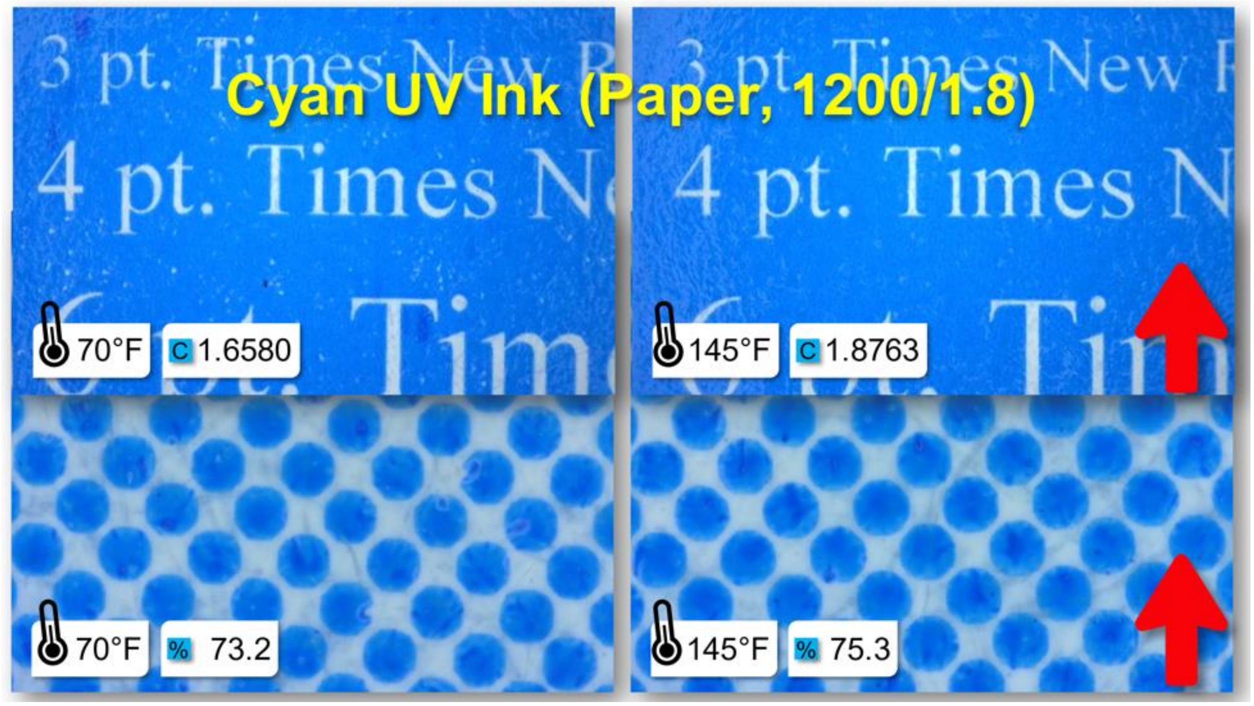


Figure 18. Print Sample – Cyan UV on paper

For the Green UV ink on film (Figure 19), we saw a more significant effect on viscosity. As the temperature increased, the viscosity decreased. We did notice a general increase in density. Higher temperatures led to lower viscosity. Also a general increase in dot gain. In summary an increase in both density and dot gain (Figures 20 and 21).

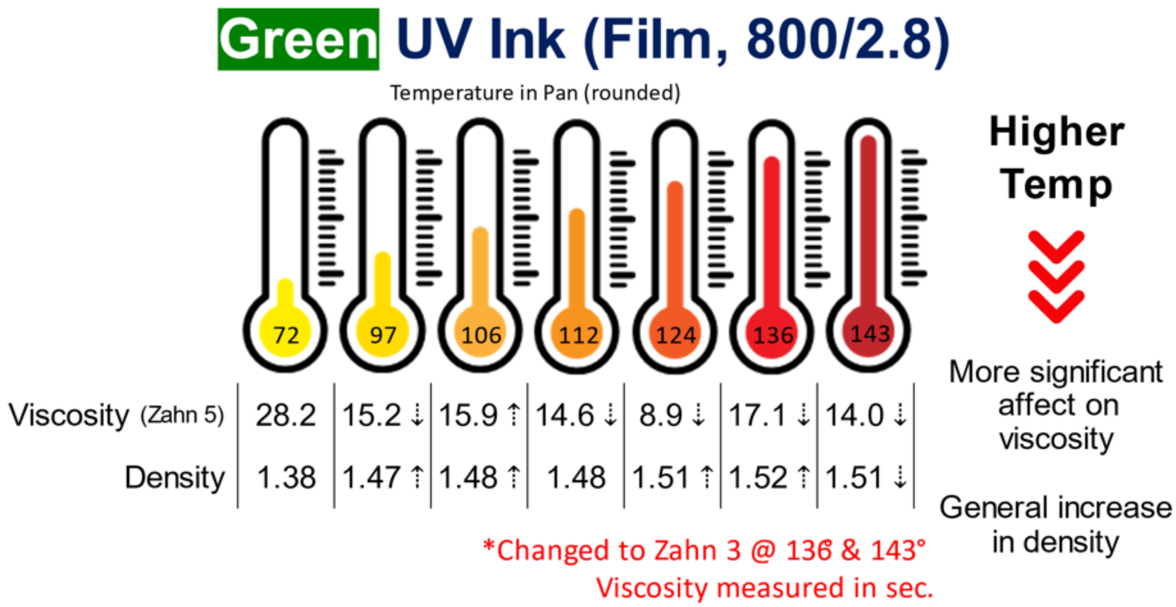


Figure 19. Results Summary – Green UV on film

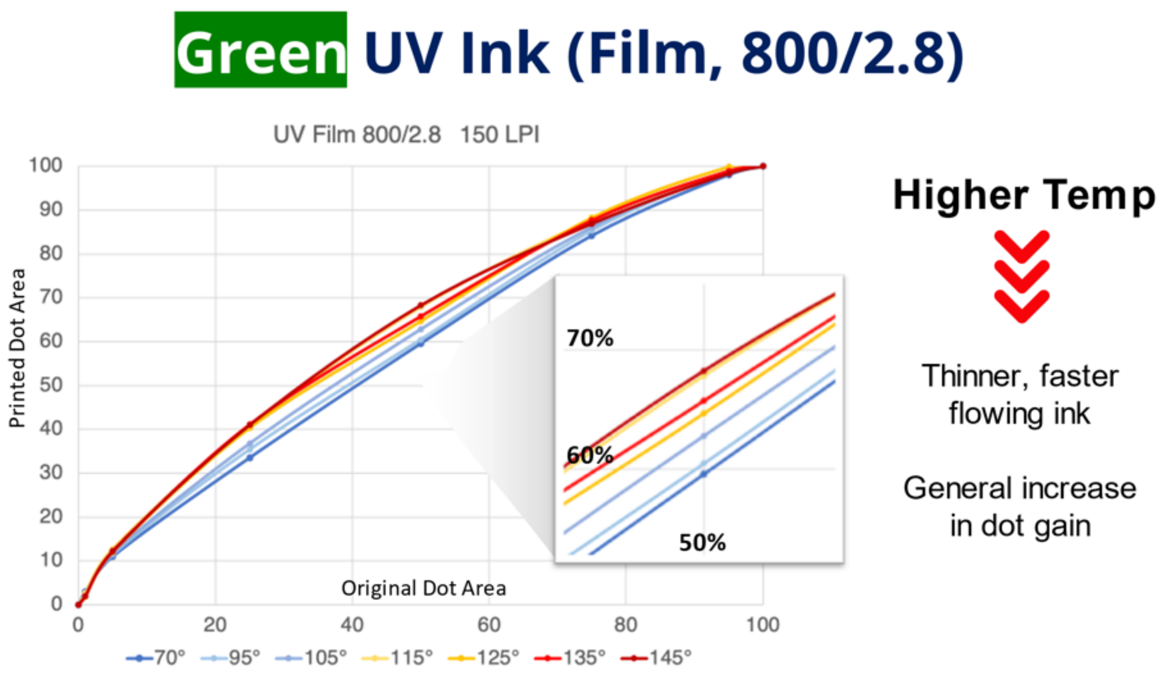


Figure 20. Results Graph – Green UV on film

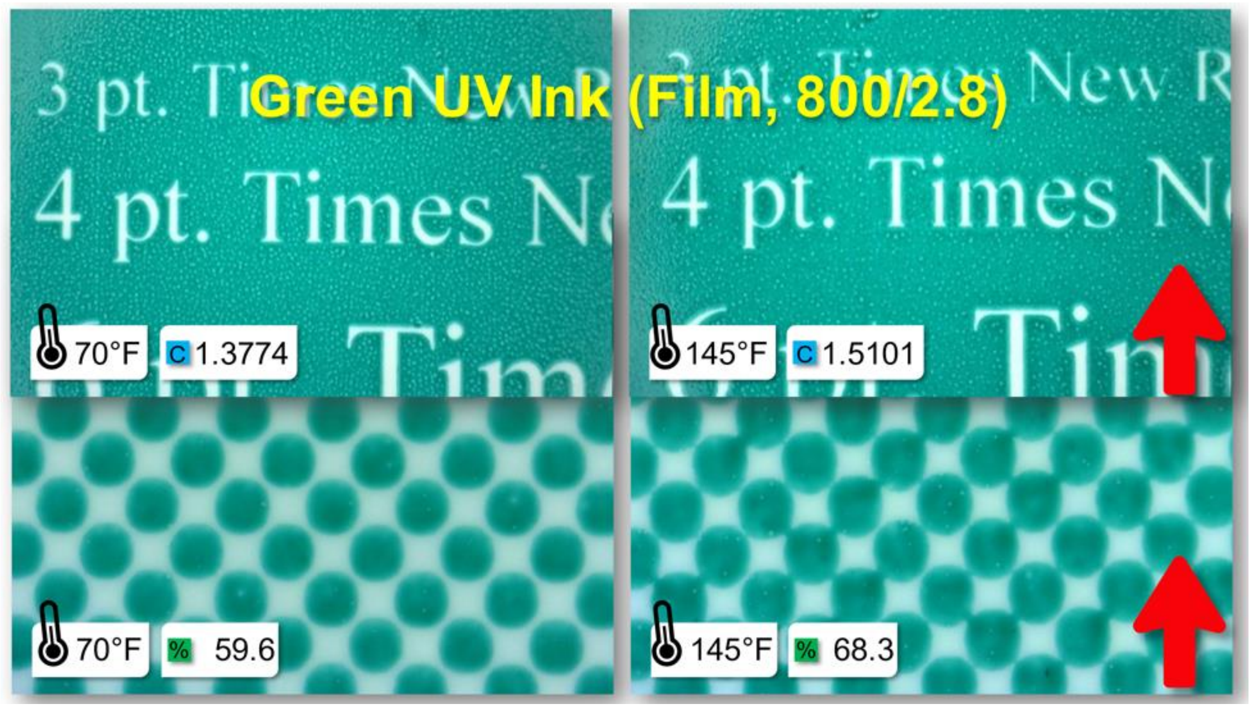


Figure 21. Print Sample – Green UV on film

For the Cyan UV ink on film (Figure 22), we saw a more significant effect on viscosity. As the temperature increased, the viscosity decreased. We did notice a general increase in density. We did notice a general increase in density. Higher temperatures led to lower viscosity. Also a general increase in dot gain. In summary an increase in both density and dot gain (Figures 23 and 24).

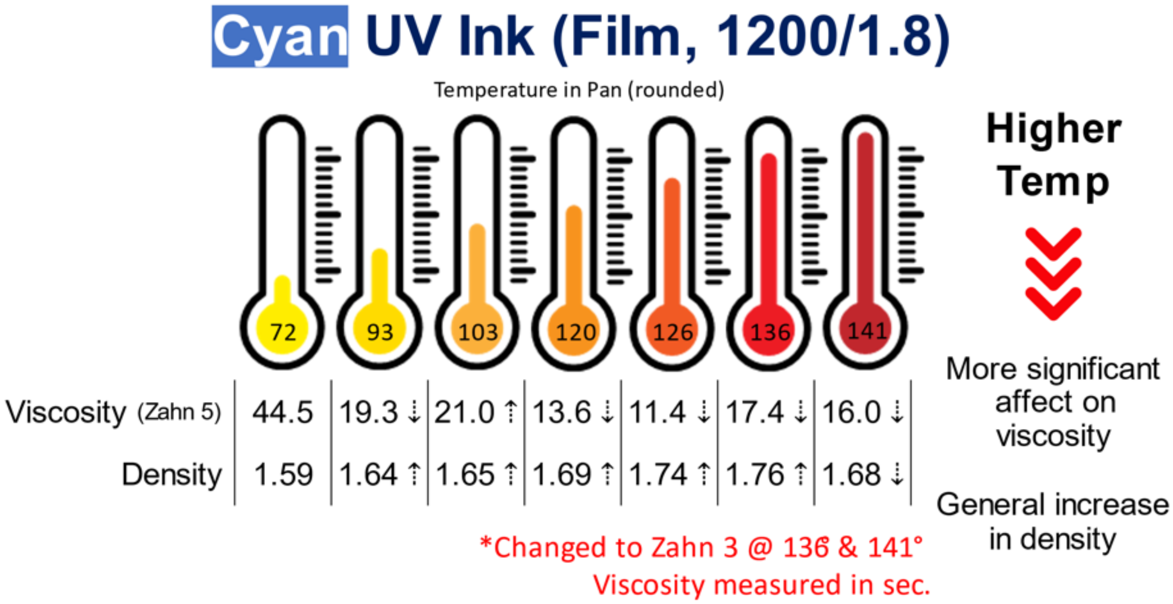


Figure 22. Results Summary – Cyan UV on film

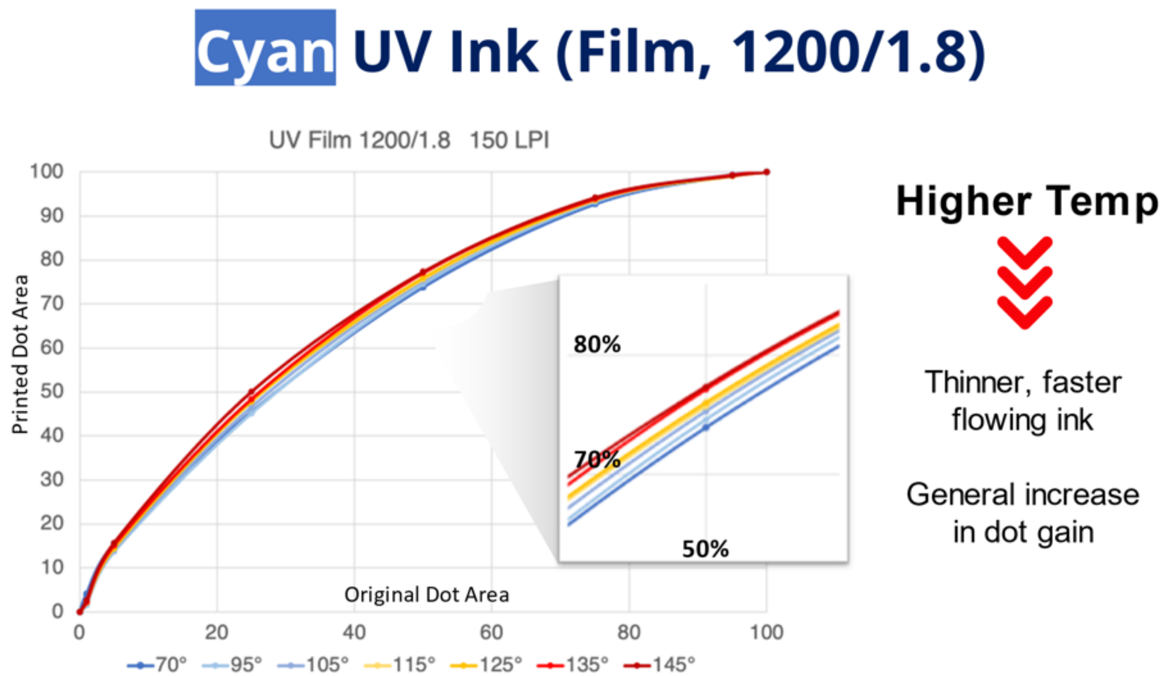


Figure 23. Results Graph – Cyan UV on film

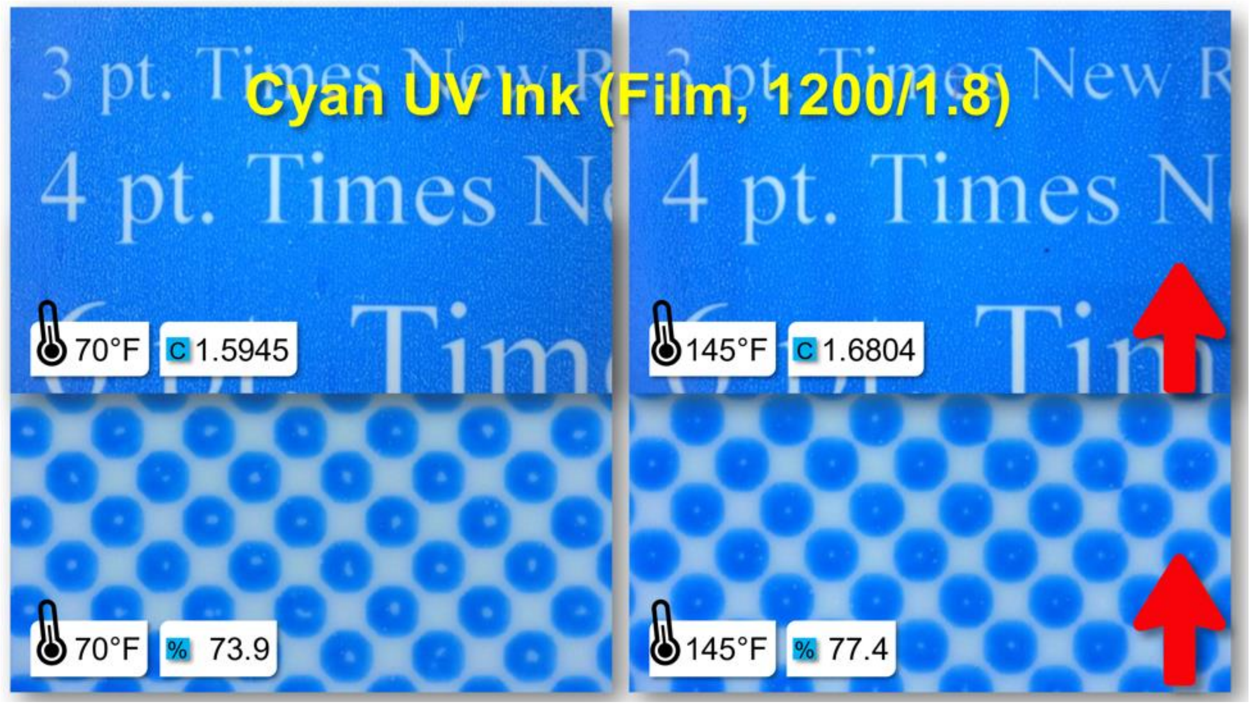


Figure 24. Print Sample – Cyan UV on film

Interpretation of Results

Water-Based Ink

- Increase in temperature means:
    - Decrease in viscosity for Water-Based inks
        - Thinner, faster flowing ink
    - Dot gain changes
        - Spot Green Ink- Increase in dot gain in midtones and shadows
        - Process Cyan Ink – Decrease in dot gain
    - Ink pH Drops
        - Flash off of amines and water
        - Requires more ink management to keep the ink stable
        - Increased additive consumption
    - No major density shift

UV Ink

- Increase in temperature means:
    - Significant decrease in viscosity for UV inks
        - Thinner, faster flowing ink
    - Increase in the ink density
    - Dot gain changes
        - Spot Green Ink- Increase in dot gain in mid-tones & shadows

- Process Cyan Ink- Increase in dot gain in mid-tones & shadows
- Increase in ink density
- Dirtier* appearance in highlight areas, seemingly to be concentrated between 5%-25% range.
    - **FIRST* defines dirty print as "A print defect which appears as fuzzy extensions of image into non-image area." And it can be further described as the appearance of dot bridging, dot tails, trash/debris, hickeys, and dry ink in halftone areas and around the edges of solids, fine line art and reverses.

Overall

- The UV Inks showed more variations than the Water-Based Ink related to the temperature change
- Spot Green Ink had more overall print variation than the Process Cyan Ink
    - Anilox Volume of 2.8 BCM/in^2 versus 1.8 BCM/in^2
- In order to further assess and understand the temperature impact on dot formation and viscosity, 2 important concepts of surface energy and rheology need to be used.
    - Specifically for dot gain impacts, surface energy (or surface tension) will play a role on how that ink lays on the surface of the printed substrate (contact angle). Liquids bead on a substrate due to having higher surface energy than the substrate. The bigger the differential, the more pronounced the beading. The beads of ink are effectively the dots that get printed. So a lower surface energy in the green could result in worse dot formation. Figure 25 below shows contact angle, bead formation on top of a solid surface, and wetting impacting laydown (dot formation).

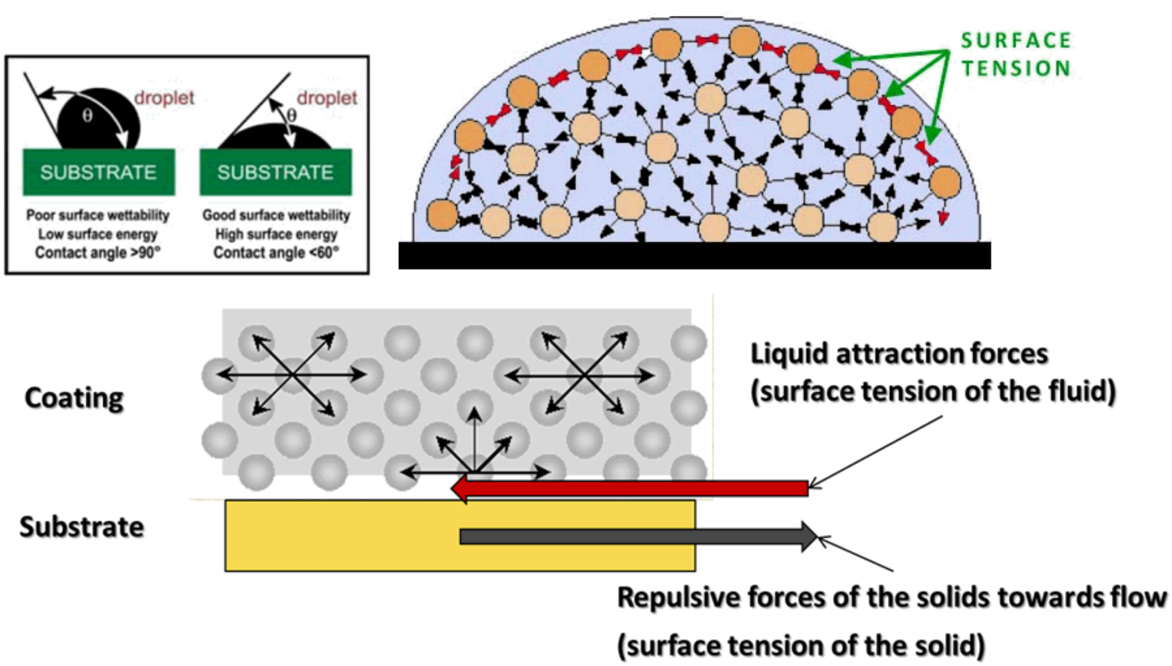


Figure 25. Dot formation impact by surface tension.

- To understand the differences on dot formation between colors, ink systems and film or paper, looking in more details on the pigment difference, the pigment themselves would not make a difference, but it is important to remind that these pigment are in dispersion form, which means a grind vehicle composed of resins and surfactants (dispersing and wetting agents) that will bring differences to the table, and even though the vehicles are the same, dispersing agents and their quantity (affected by pigment % concentration), will impart on differences on surface energy of the inks and how they relate to the surface energy of the substrates (paper and film)

- In regards to viscosity, it can be observed that when assessing temperature vs viscosity for water [$\eta=f(T)$], the decrease with temperature starts to flatten out around room temperature. It's still decreasing but not as fast for every ΔT. Meanwhile, the monomer curve is much steeper at this point. That can be explained by looking into the rheology of both systems, waterborne tends to be more Newtonian (less affected by shear/temperature) than UV (more Thixotropic, which explains the big drop in viscosity with temperature).

Industry Impact & Conclusions

As the industry continues to seek out improvements for efficiency in managing inks in the press room, this project provides a sufficient amount of data. Managing ink temperatures and creating consistency from morning to night and season to season, is essential for the consideration in establishing standards and protocols. The data shows that heat alone has enough effect on the printed product to be acknowledged and controlled in certain circumstances.

- Understanding and managing temperature in the pressroom
  - Pressroom and storage conditions-
    - Heating and A/C and seasonal weather
  - Press and inking system
    - Fugitive heat / cooling sources – dryers or fans
    - Mechanical friction creating additional heat

Membership interest in environmental conditions affecting print performance in the pressroom initiated this FQC Project. The team has done a great job designing this experiment to yield actionable results. At *this time, further study on this topic is not planned. Any further interest from the membership on potential next steps can be submitted to the FQC Executive Committee for consideration.*

- *Jean Engelke, Chair, FQC Executive Committee*