Image Quality in UV Curing Jet-Ink Technology

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Abstract

UV curing inks based on 100% solids free-radical chemistry are finding increasingly wide application in inkjet printing. Such inks offer high jetting reliability and multi-purpose end-use properties, and much ink development effort has gone into these two requirements. However, a third but perhaps equally important requirement has not previously received the same attention – image quality.

Substrate, printing process and ink formulation variables may all play a key role in controlling image quality. However, whilst more established ink technologies such as water and solvent based inks will dry by penetration or evaporation, the drying mechanism for UV curing inks is quite different requiring a new understanding of the role of the UV ink formulation in image quality. This paper examines some of the issues from the perspective of UV curing inks, and looks at how tuning the chemistry of the ink formulation could modify image quality in a variety of applications.

In addition, there is a huge number of substrate and process variables in the latest UV curing inkjet applications, together with a frequent need to match the appearance of the printed output to conventionally printed materials. Improved understanding of the link between UV ink formulation and image quality will become part of a more generic approach to coping with this complexity. Ultimately, success in this area could help speed up the time to market of new UV curing inkjet printing systems.

Introduction

The wide variety of UV raw materials at the disposal of the jet-ink formulator is mostly responsible for the multi-purpose end-use properties that can be achieved on a range of media. This includes most chemistries available to conventional printing technologies such as flexo and screen, including multi-functional monomers and oligomers and state of the art photoinitiators.[1] In combination with the advantages of printing digitally in a highly reliable manner, the choice of UV technology is very attractive, reflected in the number of new machines entering the market.[2] Despite this, there is considerable challenge in designing UV jet-inks that can match the image quality achieved by these alternative printing processes. An ability to do so would raise the technology to a higher platform and in some cases compliment or gain market share from these segments. To address this, it is vital to understand how some of the key components in the formulation can affect ink wetting (or spread) and how these interact with media.

This paper looks at the role of some chemical constituents in the formulation that have a strong influence on wetting, together with some consideration of media and process properties, such as substrate roughness and print to cure time.

UV Jet-Ink Media Wetting – The Challenge

The ability to control UV jet-ink wetting on media is key to satisfying image quality requirements. For example, excessive or insufficient spreading can be problematic depending on the application. In the case of a highly dense area of print, insufficient wetting can lead to mottle, lack of fill and consequently low optical density. See **Figure 1a**. Conversely, in some situations it is important to prevent ink spread to give sharp character definition, as shown in **Figure 1b**. In many applications, a balance in both these aspects is needed to achieve high image quality. To do this, an understanding of key ink and media parameters are necessary as well as some consideration of the interface formed between ink and media.

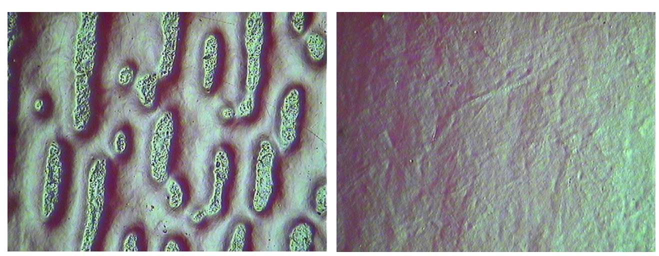

Figure 1a. Inadequate (LHS) & highly (RHS) wetting UV jet-inks A & B on coated paper. Optical microscopy (x100).

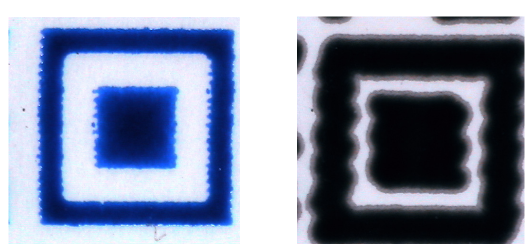

Figure 1b. Sharp UV jet-ink definition (LHS) and blurred (RHS) on vinyl media. Optical microscopy (x100).

Key Ink Characteristics

General UV Jet-Ink Formulations

While water, solvent and oil based jet-inks do perform well in many media segments, they suffer somewhat from a broad base of adaptability. Chemistry-wise, 100% UV free-radical jet-inks differ significantly from these types. There are generally no humectants, solvents or components that evaporate from the ink once printed. In essence, the entirety of the formulation contributes to the wetting characteristics and end use properties.

In this discussion, the UV jet-inks are composed of monomer(s), oligomer(s), photoinitiator and pigment. In some cases, surfactant is included. Raw material choice is constrained by the need for low viscosity at jetting temperature (approx 8-22 cPs), small particle size (<1μm) and storage stability. In addition, the nature of the application and its market may present some further restrictions on chemical choice. For example, in some packaging segments, the level of residual odour is important with particular care needed in monomer and photoinitiator selection. However, an increasingly popular practice is to undertake curing in a nitrogen (or similar inert gas) environment. In doing so the inhibiting effect of oxygen on the polymerisation mechanism may be minimised.[3] As a consequence of this, it is possible to use lower levels of materials that might impart strong odour to the film, thereby influencing chemical selection.

There are further restrictions placed on surface tension values. These need to balance wetting that is optimum on the media but minimized on print-head face-plate material, which could give rise to ink pooling and ultimately poor jetting reliability.

In terms of wet ink features that could impact on image quality, several key ones are apparent: surface tension, viscosity, speed of cure and particle size. Within this there are differences according to pigment type, photo-initiator selection and monomer blend.

In the following section, surfactant and monomer are chosen as two examples that provide widely different wetting properties.

Equilibrium and Dynamic Surface Tension

In general, it is considered that for adequate spreading, the fluid's surface energy should be less than that of the media.[4] For a dynamic process, such as ink-jet printing, measurement of ink surface tension at short time intervals is critical, rather than at longer, equilibrium values.

Table 1 highlights an example of some UV jet-inks that have similar equilibrium surface tensions but provide markedly different degrees of spread when printed on aluminium foil.

Table 1. Equilibrium Surface Tension (DuNuoy Ring) and Printed Dot Size for Surfactant Modified UV Jet-Inks

	Standard	Mod C	Mod B	Mod D
Equilibrium Surface Tension (dyn/cm)	26.5	27	34	27
Dot Size (μm)	105	108	100	137

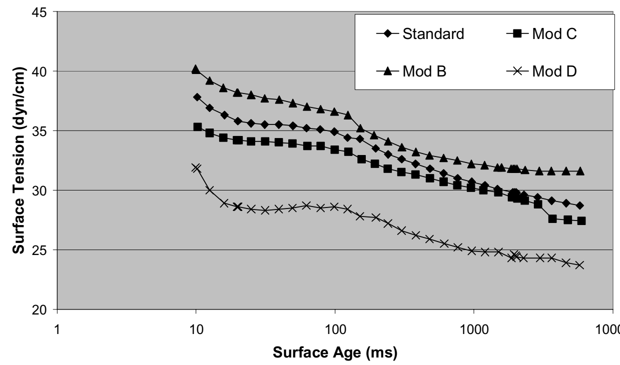

Figure 2. Dynamic surface tension of four surfactant modified UV jet-inks

Measurement of the inks' surface tension with a bubble pressure tensiometer shows clear differences in their dynamic behaviour, helping rationalise their wetting characteristics. See **Figure 2**.

Previous work has shown that modifying the chain length of some acrylic monomers can dramatically alter their dynamic surface tension profiles.[5] In addition, **Figure 3** shows that incorporation of surfactant to an acrylic monomer can also change this property in a variety of ways. Therefore, the selection of raw materials with appropriate dynamic surface tension profiles can be useful in controlling ink-media wetting. In particular, monomer and surfactant can have a strong influence on this characteristic.

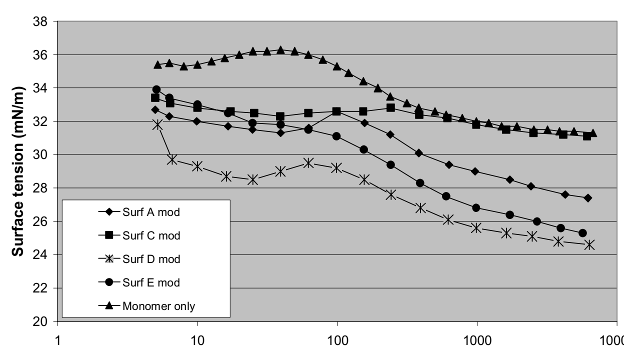

Figure 3. Dynamic surface tension of acrylic monomer (propoxylated neopentyl glycol diacrylate) with surfactant modifications.

Advancing Contact Angle

The degree of spread of an ink droplet on media is readily measured in terms of advancing contact angle. This allows rapid screening of ink formulations and media types to help predict wetting performance in a print engine. **Figure 4** shows some monomer modified UV jet-inks that offer differing degrees of contact angle on a paper media over the same time scale. In this example, it would be expected that ink B would provide superior spread than ink A. This shows strong agreement with the image quality shown with these inks in **Figure 1a**.

Therefore, by controlling the contact angle via formulation development, it is possible to achieve desired wetting properties.

As **Figure 4** illustrates, the contact angle measurement, like surface tension, is time related. Print to cure time will therefore have a significant effect on image quality. As new printers emerge, with the general trend for increased printing speed, an understanding of these dynamic effects will be vital. A re-look at **Figure 4** shows that for a print to cure time of 0.2s, the two inks behave in an approximately similar manner. However, at the time of 2.0s there are some clear spreading differences. Image quality would thus be affected accordingly.

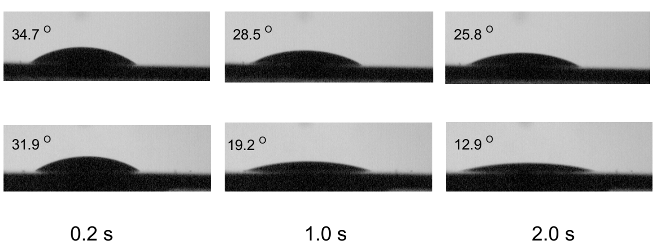

Figure 4. Advancing contact angle with time of UV jet-inks A (top) and B (bottom) applied as 3.9μL drops on clay coated paper.

Ink-Media Considerations

As UV jet-inks expand into new market areas such as packaging, textile and signage, as well as showing growth in diverse areas including credit card, circuit boards and CD printing, the range of media expands accordingly. A range of materials from highly porous packaging papers to rigid non-porous plastics, which contain a host of different coating chemistries are known.

While surface energy can be a good indicator of expected wetting properties, there are other relevant considerations such as roughness, porosity and chemical constituency that should be taken into account. In terms of media roughness, there is a huge variance across materials. For example, many treated plastics have surface treatments or coating modifications applied to them to help achieve ink adhesion. In doing so, fluid spread can be effected due to variations in wetting over peaks and valleys, partly due to the small drop volume (10-100pL) inherent in ink-jet printing. In contrast, highly porous papers, such as used in many packaging applications, are particularly difficult. The main challenge therein is the control of penetration of UV jet-ink. As well as a contributor to insufficient or excessive ink spread, high porosity can also lead to poor cure and low optical density. **Figure 5** shows a plot of droplet volume versus time for a UV jet-ink applied as large drops to three different papers. Differences in penetration are observed through droplet volume measurement over time. In the case of the three papers, significant differences are noted between coated and uncoated but also within the two coated types. In turn, **Table 2**, shows the corresponding variances in printed line width.

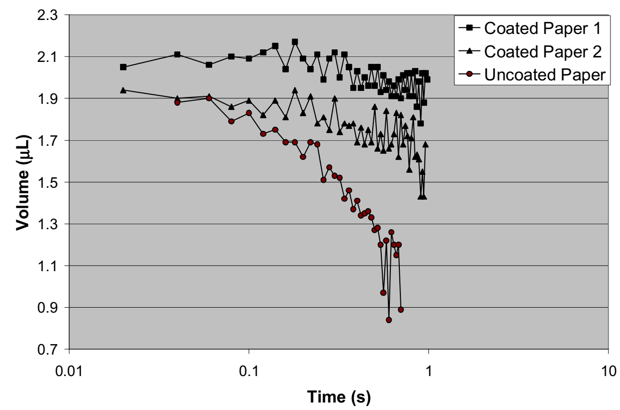

Figure 5. Droplet volume vs time for UV jet-ink drops on coated and uncoated papers.

Table 2. Printed Line Width of UV Jet-Ink on Coated and Uncoated Paper.

	Coated Paper 1	Coated Paper 2	Uncoated Paper
Line Width (μm)	148.14	258.4	278.18

In addition, the chemical nature of the media has been shown to be critical to ink wetting behaviour. Recent studies have shown that high degrees of hydrophilic or hydrophobic species can help control drop spread to a very high level.[6] Acid-base interfacial matching is a further example that shows dot sizes can be controlled on demand by appropriate media treatments.[7]

As part of this need for a more generic approach to understanding image quality issues, SunJet are involved in the IMAGE-IN project. This is a multi-partner collaboration funded by the EU, bringing together partners from a diversity of backgrounds to focus on the challenge of improving ink-media understanding. A key output of this project is how image quality can be improved and controlled in an ink-jet process, utilising UV technology.[8]

Conclusions

Several key areas have been identified that need careful consideration when developing UV jet-inks to perform on a range of media. This includes hard-ware aspects such as print to cure times and nitrogen inertion but also chemical and physical properties such as media porosity, surface energy and monomer type. Dynamic surface tension has proven to be a useful tool for correlating image quality data with the wetting characteristics of individual ink components, such as monomer and surfactant. The emergence of several new printers in the market indicate that the appreciation of these factors can lead to output that can meet increasingly demanding image quality requirements.

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Biographies

Alexander Grant received a PhD from Cambridge University in 1995 in the synthesis of liquid crystalline polymers for coatings and holds several patents in ink-jet ink formulations. He is currently Project Leader at SunJet, at their headquarters in Bath, UK. This followed the position of Scientist at SunChemical in Carlstadt, NJ, USA, working on ink-jet for computer-to-plate and packaging. Before this he worked as Polymer Scientist with National Starch, synthesising emulsions for paints and coatings.

Hugh Allen is Research Manager in SunJet, a division of Sun Chemical focused on the development and manufacture of ink jet inks. He joined the international printing inks manufacturer Coates in 1985 after graduating in chemistry from Cambridge University. After 13 years in product development and customer service roles for flexographic and gravure inks in both the UK and France, he transferred to SunJet in 1998 and into the new world of digital printing. SunJet is based near Bath, England and Hugh lives in Wells, England's smallest city.