Industrial Application of UV-Curing Jet Inks

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Abstract

UV- curing inks are an important and growing sector of traditional printing, in processes such as flexography, gravure, offset and screen. The benefits of UV curing inks, including low or no VOC emissions, fast "drying" and excellent final print properties on a range of substrates, means that this type of ink technology will be critical to the expansion of ink jet in digital production printing in various industrial applications, including packaging printing.

Ink jet printing of UV-curing inks raises interesting and significant challenges, for ink maker, head manufacturer and system integrator. This paper reviews some of these issues with reference to packaging printing, from an ink standpoint. Issues such as print quality, cure, adhesion, flexibility and health and safety are considered and the approaches being adopted to enable the implementation of UV ink jet systems.

Introduction

Use of UV-curing inks in traditional printing areas such as flexo, gravure, offset and screen is growing rapidly. The rate of growth depends very much on the specific sector and the flexographic market is thought to offer most potential for growth [1]. Table 1 shows the growth of UV-curing ink in some of the flexo market areas in the United States. These growth rates are put into context by the fact that the total flexographic ink market for labels is projected to grow at 3% per annum, whilst UV-curing ink is growing at 17%.

Table1. UV-Curing flexo inks in packaging applications – USA [2]

	1999	2004	AGR
	'000 kgs	'000 kgs	%
Folding Cartons	23	45	15
Labels, Tags	1181	2591	17
Flexible Packaging	45	91	15
Other	68	136	15
Total	1317	2822	15

Some of the advantages and disadvantages of UV-Curing inks are summarized in Table 2. Many of the benefits of UV-curing inks are already well understood in the packaging industry, with lack of solvent emissions and higher productivity probably being the most significant.

Table 2. Some Advantages and Disadvantages of UV-Curing Inks in Packaging Printing

Advantages	Disadvantages
No solvent emissions	Curing equipment expense
High flash	Higher raw material costs
Minimal Waste	Handling and health and safety issues.
High productivity	Inert atmosphere may be required for highest line speeds
Rapid "drying"	
Reduced equipment footprint	
Superior print performance eg product resistance properties	
Easier handling on press/screens as no solvent evaporation	

Continuing product development has meant that many of the disadvantages have been overcome and so the growth of use of this type of ink continues.

With strong drivers, both technical and commercial, pushing the growth of UV-curing inks in the traditional printing fields, it is clear that many digital production printing systems will utilize this technology since a return to solvent based systems would be considered retrograde and unacceptable to end users. Additionally, UV-curing inks offer a critical benefit in ink jet systems – that of nozzle stability. Due to their non-drying nature UV-curing inks can generally remain "open" in the nozzles longer than solvent or water based inks. This is in fact one of the largest drivers for use of UV-curing inks in digital devices.

Current Implementations of UV-Curing Systems

Much work is currently underway to develop DOD piezo based printing systems using UV-curing inks. Many of these are aimed at the screen printing market for display graphics and operate with scanning print head assemblies, printing onto either flexible or rigid substrates. However, two recent and significant introductions have more relevance to digital production printing in a packaging environment: - the Chromas

"Argio" and the Barco Graphics "DotFactory". Both of these systems work in a "single-pass" mode whereby the substrate passes underneath arrays of ink jet nozzles and is printed and cured in one motion. Of course in principle these "presses" could be used with various ink types but it is with UV-curing inks that initial market implementation will occur.

UV-Curing Ink Jet Challenges

Print Quality Issues

Liquid UV-curing inks will flow on a non-porous substrate such as a packaging film. This is in contrast to a solvent-based ink where evaporation of the carrier solvent leads to viscosity rise and cessation of flow. The extent of the flow will be determined by various factors including: the surface tension and chemistry of the ink, surface energy and chemistry of the substrate and surface texture. The ink spot will continue to spread to a limiting size which is dependent on these factors and the drop volume. Exposure to UV light will of course cure the ink ceasing flow out. If the time to UV exposure is long compared to the speed of spot flow then the spot size obtained may be larger than acceptable for the desired print quality. Figure 1 shows the spread of a drop of acrylate based UV-curing jet ink on a polyester label stock. As can be seen the majority of the decrease in contact angle and increase in spot size is achieved in the first 0.1 seconds. On a press operating at, for instance 30 metres per minute, this would equate to only 5 cm of web travel. Thus it can be seen that absolute control of spot size by the UV-Curing lamps in line with the printheads is difficult. However, as well as the issue of spot size there is also the possibility of spot merging and mixing, leading to print quality or colour gamut issues. If all the curing is carried out after all the ink has been laid down this may lead to print quality problems. For instance the ink laid down in the printheads nearest the UV lamps will have had less time to spread before being cured. Where these colour spot mixing/merging issues become unacceptable, it may be necessary to introduce UV-curing lamps (or UV light "piped" by light guides) to cure in between the different colour print stations. This inter-station curing will enhance the print quality, but it is important that each layer is not fully cured before the next, since the subsequent layers may have poor wetting and adhesion onto fully cured ink. In practice, often a very low dose of UV energy is required (of the order of 1-5% of the energy required for full cure) to "freeze" the drop by starting the cross-linking reaction. This low level of cross-linking will still be sufficient to increase viscosity adequately to prevent further dot gain, mixing and merging.

Another approach to controlling drop spread and merging is to use an UV-curing hot-melt ink [3], where the ink is a solid or paste at room temperature but a low viscosity liquid at the jetting temperature. The liquid drop will rapidly solidify upon contact with the substrate and so flow out of the spot will be arrested. This solidified ink can then be cured with UV light in a conventional manner bringing about the cross-linking and resulting in a tough film. This kind of ink approach may be of special value where printing is onto porous or semi-porous stocks.

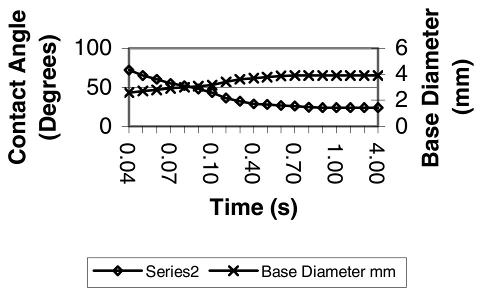

Figure1. Change in contact angle and base diameter of ink spot on polyester label stock. Data obtained on a Fibrodat system with a 12.5cps (at 50Deg C) UV-Curing ink

Cure Issues

The layer of ink laid down in ink jet devices can be relatively thick compared to flexographic ink films – in the order of 8-15 microns compared to 2-5 microns for flexo. Although ink jet layer thicknesses will be driven down as the capability of firing smaller drops from devices with higher nozzle densities becomes available, layer thicknesses are likely to be remain in the 6+ mcron region.

The current layer thicknesses utilized though can lead to some significant cure issues. The most significant of theses is the oxygen inhibition of formulations based on acrylate chemistry. Oxygen inhibition is the adverse effect of the presence of oxygen on the rate and extent of the cross-linking reaction. Ink jet inks are particularly susceptible to oxygen inhibition because of their low viscosity.

This inhibition can be overcome to some extent by use of high photoinitiator levels but this has a deleterious effect on odor and extractables which may be an issue in packaging and especially food packaging contexts. Additionally, high photoinitiator levels contribute considerably to formulation cost. The levels of initiator currently being used in some ink jet products for graphics applications would probably not be viable in a packaging printing because of this formulation cost issue. One way to overcome oxygen inhibition is to carry out the curing in an inert or partially inert atmosphere. Most commonly this is achieved by "blanketing" the substrate and print in an atmosphere of nitrogen. Curing under these conditions can dramatically reduce the photinitiator levels required and increase line speed achievable. Nitrogen inerting is growing in importance in conventional printing, especially flexo, for the same reasons. It is likely that it will form an important part in high-speed digital production printing where the implementation of nitrogen systems within an industrial environment can easily be envisaged.

Other approaches to higher cure speed could be via cationic curing inks. These utilize a different curing mechanism, which is not inhibited by oxygen. These sort of inks are enjoying application in the conventional printing field, especially flexo. However, there has recently been a set back to the exploitation of the technology due to the possibility of the presence of trace levels of benzene in the cured film. This benzene can potentially be liberated by the breakdown of the most widely used photoinitiators. Currently there is much work in progress to develop alternative low cost initiators not prone to this same side reaction.

Water based UV-curing systems could also offer a route to superior cure speed. The ability of water to reduce viscosity and carry the UV-curing components either in solution or emulsion form, allows higher molecular weight and potentially more reactive species to be used. These water-based inks could be of special value on porous or semi-porous packaging substrates, where the water component will be wicked away and the UV-curing component (still containing some water) can be cured, in a conventional manner, by exposure to UV light.

Organoleptic, Health & Safety Issues

The issue of odor and the presence of extractable materials within the cured print is one of paramount importance in the packaging industry and especially in the food stuffs sector, because of the impact on the organoleptic properties of the food and the implications for food safety.

Odor in cured UV-curing inks originates from two main sources:- free or partially cured monomer and from photoinitiator and photoinitiator break-down products. As has already been indicated UV-curable jet inks can suffer more than conventional inks in these respects since they may contain higher levels of monomer than conventional inks (for low viscosity) and also higher levels of photoinitiator to overcome the oxygen inhibition effects.

It must be made clear that when considering these health and safety issues one must consider the system as a whole. These are not solely ink issues. The level of extractables from a certain print will depend on the ink, the layer thickness, the substrate and the curing regime.

Table 3 shows the variation in extractables with line speed, of an acrylate based UV-curing ink jet ink on a board-based food laminate material. This re-emphasises the importance of controlling the whole system and having adequate quality monitoring of the system and output.

As mentioned above, nitrogen inerting may allow photoinitiator reduction and improve cure quality so that there is less odor and fewer available migratables. Certainly, this has been one of the drivers for use of nitrogen in some conventional (flexo, gravure) packaging printing scenarios. Water based UV-curing inks may also offer benefits due to the higher molecular weight components that they can apply, as described above. However, other ink technology developments are also helping very considerably to address these issues.

Table 3. Monomer and Photoinitiator extractables from UV-Curing ink jet printed polyethylene coated packaging board

	Yellow Jet 1532	Magenta Jet 4539	Cyan Jet 5528	Black Jet 7537
Monomer Extractable (ppb)				
30m/minute	15	5	22	41
15m/minute	7	5	7	26
Photoinitiator Extractable (ppb)				
30m/minute	45	30	62	75
15m/minute	24	12	35	65

Considerable work is being carried out to develop low odor intiators [4] and also initiators which are better bound into the other materials in the ink, thus reducing odor and migratables. Additionally, advances in monomer technology have meant that materials are available that are of low viscosity whilst maintaining high reactivity.

Colour

Obtaining adequate colour strength on clear packaging substrates and articles (eg clear packaging films, clear food tubs etc) may be an issue given the much lower pigmentation of jet inks compared to flexo and offset inks. This is somewhat compensated by the higher film weight applied by ink jet. However, the trend in ink jet printing in general, and the packaging sector will be no different, is to drive down ink film thicknesses for cost reasons. It is thus likely that further development will be needed to increase colour strength of UV-curing jet inks within the constraints of viscosity. Heated print heads will allow jetting of more viscous and thus potentially higher pigmented inks but it is likely that novel pigmentation approaches will be critical to improving ink colour strength.

Adhesion and Flexibility

The issues with ink jet inks and packaging materials are similar to those faced in conventional printing inks with regards to flexibility and adhesion. Obtaining adequate flexibility at the higher film-weights of ink jets can be a challenge if the surface hardness and scratch/mar resistance is not to be lost. This can usually be overcome though by judicious selection of the monomers and oligomers used in the inks. Optimal adhesion on swellable plastics (eg PVC, ABS, Polystyrene etc) is usually achieved by incorporation of monomers which have some solvent effect upon the plastic in question. Non-swellable plastics, chiefly the olefinic type substrates will depend on obtaining satisfactory surface treatment levels via conventional means (corona, flame etc) and obtaining good wetting of the ink onto the surface. Additionally, in these cases it is very important that there is minimal shrinkage of the ink upon curing, since any shrinkage will introduce stresses between the cured ink film and substrate, undermining adhesion.

The above general points indicate that different ink sets will, most likely, be required for different substrates and applications. This of course is what all "traditional" printers are used to. It is highly unlikely that one ink set will ever be optimal on more than a limited range of packaging substrates. Digital production printing equipment will therefore have to be capable of achieveing quick ink change-overs and with minimal ink waste if the advantages of the digital system are to be fully realized.

Summary

UV-curing is an important technology for use in ink jet systems generally and may be of special value in digital production printing of packaging. The reasons for its likely widespread use are the same as those why UV-curing inks are widely used in conventional printing areas, coupled with the excellent nozzle performance of UV-curing ink. There are significant specific technical issues relating to the use of UV-curing inks in digital production printing equipment, but these can be overcome by ink development and careful system integration. Ink formulators and system integrators must be sensitive to the needs of the packaging printers in designing solutions for them. Packaging printers will require ink and system solutions that closely match their current expectations of conventional print presses but with the additional benefits of a digital system. Significant compromise in terms of print quality or printed film performance is unlikely to be tolerated.

References

1. J Howard, Proc. Radtech 1999, 13-25
2. Skeist Inc. NJ, USA Coatrings Report Dec 2000
3. GB Patent Application 2 336 594
4. M. Visconti , Proc. Radtech 1999, 117-122

Biography

Nigel Caiger received his degree from Oxford University in 1985. He joined SunJet (formerly Coates Electrographics) in 1989 and is now Development Manager – Ink Jet Products, overseeing activities of a development team working on various inkjet technologies including UV-curing, phase change, water and solvent based inks. He has several patents in the field of jet inks.