

UV Printing Made Simple

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Understanding UV Digital Printing Technology

May 23rd, 2008

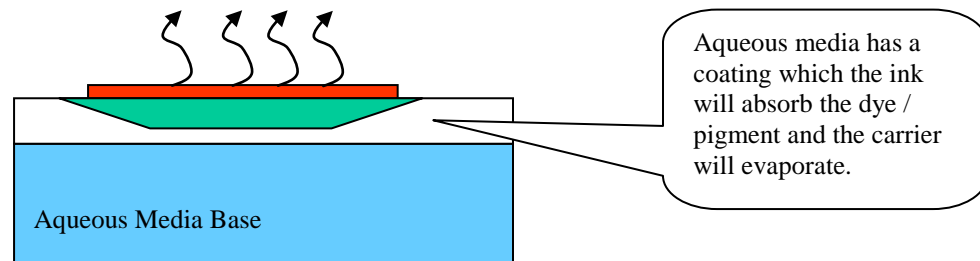
What is UV Digital Printing?

What we are talking about in this paper is *not* the traditional terminology used in aqueous or solvent printing which “UV” is actually talking about the ability of the ink to resist fading from the “UV rays emitting from the Sun”.

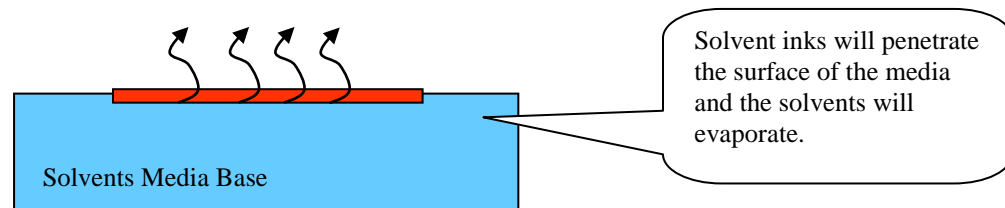
What we are going to discuss is the use of digital printing inks which are cured during the printing process with a UV light source. These inks are also resistant to the UV rays of the Sun, but this terminology in this printing method is only referring to the curing process of the ink.

UV curing inks print much like all other ink jet printers but require “curing” or “fixing” of the ink by using specific wavelengths of light, specifically the UV portion of the light spectrum. This “Curing” or “Fixing” process would relate to drying on other inkjet processes such as solvent or aqueous printing but instead of drying by the use of air or heat, these UV inks are “dried” by using a UV light source.

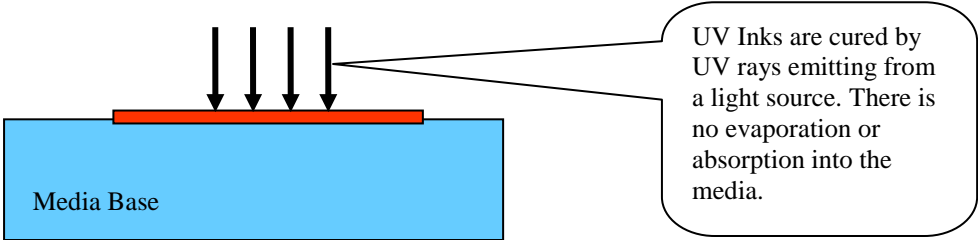
Aqueous inks rely on special coatings to help control the ink absorption into the media and also help with the drying capability of the media. Aqueous inks rely on air to evaporate or dry and stabilize the image.



Solvent inks are used traditionally to print on un-coated media, typically vinyl type media, by using solvent carriers to penetrate the actual material. The solvent evaporates by air and by heat to control the curing of the ink. The solvent fumes can be toxic and therefore should be vented to the exterior of the building.



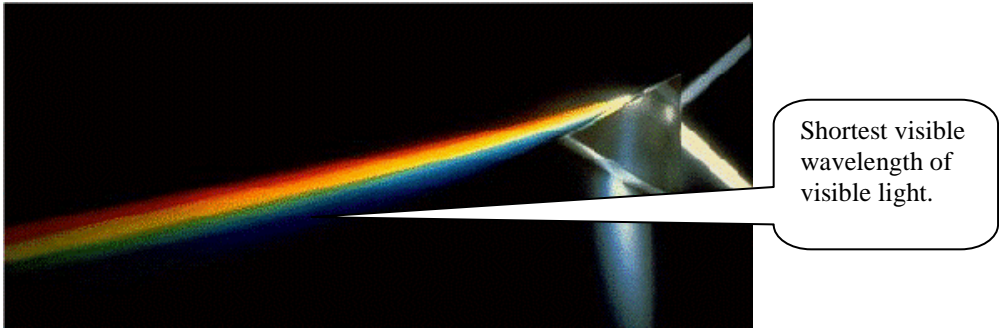
UV inks do not penetrate the surface and do not require any coatings. The UV inks are cured or hardened on the surface of the media. The carrier does not evaporate but are changed from a liquid to a solid during the curing process.



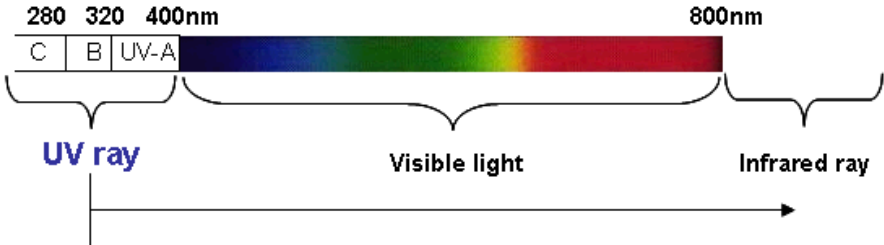
One of the major benefits with UV curing inks is that there are no VOC, Volatile Organic Chemicals emitted as the ink is cured to a solid without any evaporation. Rastek UV inks are also RoHS compliant, this is a new worldwide compliance ensures that there are no harmful ingredients such as Cadmium, Lead, Chromium, Mercury, Polybrominated Biphenyl (PBB), and Polybrominated Diphenyl Ether (PBDE).

Terminology

The original Latin name “Ultra Violet” or the abbreviation “UV” stems from *ultra* which means “beyond” and *violet* which is the color of the shortest wavelengths of visible light.



For UV digital printing, the spectrum of light is typically in what is called the “Near” UV range which is between 400nm to 200nm. (Nanometers)



Typically digital printing lamps actually have a spectrum range from 600nm to 200nm. Caution must be used as eye or skin damage can occur from direct exposure to UV light sources.



Common Terminology of UV Inks

Acrylate Monomers

Molecules with acrylate functionality. The word monomer is derived from the Greek words *mono* meaning one, and *meros* meaning parts. A monomer is a small molecule that may become chemically bonded to other monomers to form a polymer.

Acrylate Oligomers

Partially polymerized monomers, 2 to 3 units long.

Acrylate polymers

A group of polymers which could be referred to as plastics generally. They are noted for their transparency and resistance to breakage when compared to conventional window glass. Commonly called as acrylics or polyacrylates, acrylate polymers. A form of acrylate polymer that may be familiar to consumers is a clear break resistant sheeting sold in hardware stores under the trade name Plexiglas acrylic glass.

Some acrylate monomers (the components of the polymers) used to form acrylate polymers may be acrylic acid, butyl acrylate, 2-ethylhexyl acrylate, methyl acrylate, ethyl acrylate, acrylonitrile, n-butanol, methyl methacrylate, and TMPTA.

Initiators

Typically a “package” of initiators. The initiators are active to various wavelengths of UV light, usually 2 to 3 are chosen with various active absorbencies across the UV spectrum.

Surfactants (Surface Active Agent), Wetting Agents

Surface active molecules that lower the surface energy and improve wetting.

Pigments

The pigment is basically the colorant package.

Inhibitors

Radical scavengers that help reduce thermal and low light cure.

Polymer

A polymer is a substance composed of molecules with large molecular mass composed of repeating structural units or monomers connected by covalent chemical bonds. The term is derived from the Greek words: *poly* meaning many, and *meros* meaning parts.

Additional Ingredients

- Polymerization Inhibitors

- Anti-formers

- Dispersants

UV Digital Printing Process

There is a lot of science involved in digital UV printing. We will attempt to cover the printing process in as much detail as possible yet hopefully with enough visual explanations to help simplify the technology in more easily understandable terms. The math involved is used here for emphasis as the basic background mechanics directly relates to topics such as printer environmental temperature.

So there will be a lot covered in this section but will hopefully make sense by the end of this discussion.

There are two basic types of UV curable inks

1. “Free Radical” Type UV Ink

The propagating species is a free radical.

The curing stops when the UV light source stops.

2. “Cationic” Type UV Ink

The propagating species is cation [H⁺].

Will continue to cure after the UV light source stops.

In our digital UV inkjet process the main type of UV curable ink is the “free radical” type. Ok so what is a radical? Simply stated, radicals are molecular species with unpaired electrons. These unpaired electrons are usually highly reactive, so radicals are likely to take part in chemical reactions.

With the ink chemistry made up with such items called, monomers, oligomers, initiators, inhibitors, surfactants, pigments, and polymers, what actually takes place during the curing process?

Basically the UV light source takes the liquid ink and turns it into a plastic. This is the simplistic process.

The more detailed explanation is that the components in the liquid ink are going to react to the UV light source and convert the individual components into a different final product.

In chemistry, free radicals take part in radical addition and radical substitution as reactive intermediates. Chain reactions involving free radicals can usually be divided into three distinct processes: *initiation*, *propagation*, and *termination*.

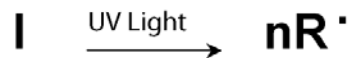
- **Initiation** reactions are those which result in a net increase in the number of free radicals. They may involve the formation of free radicals from stable species or they may involve reactions of free radicals with stable species to form more free radicals.
- **Propagation** reactions are those reactions involving free radicals in which the total number of free radicals remains the same.

- **Termination** reactions are those reactions resulting in a net decrease in the number of free radicals. Typically two free radicals combine to form a more stable species, for example:
 $2\text{Cl}\cdot \rightarrow \text{Cl}_2$

Ok so what does this mean?

Free Radical Polymerization

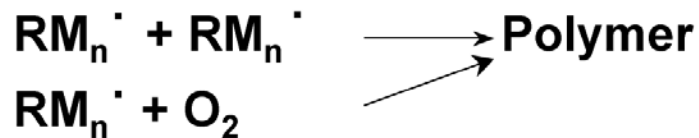
Initiation:



Propagation:



Termination:



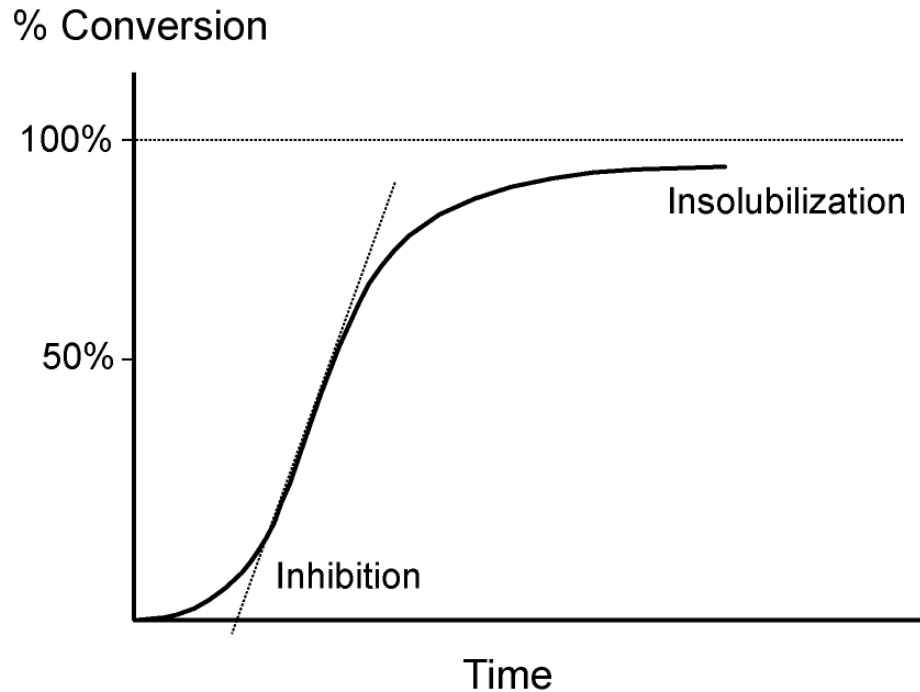
In the above diagram, the DOT next to the letters is indicating the free radicals.

During the initiation phase, the UV light source is starting the chain reaction of the free radicals. This is called the photo polymerization initiation phase. The photons from the UV light source are starting the initial phase or change from a liquid to a solid polymer or plastic.

The propagation phase takes the free radicals by taking the single or one part monomer and increasing the molecular weight. Monomers are small molecules which will become bonded to other monomers to become polymers. During this propagation, the monomers are changing from the single molecule monomer to partially polymerized monomers which are 2 to 3 units long. These will now become oligomers. Monomers are single molecules; oligomers are a finite number of monomer units, while polymers consist of an unbound number of monomers. So this is the process of binding together the individual molecules into a completely different element using the UV light source as the initiator.

The termination process is taking the grouped monomers which are now oligomers and these will reach the final cure state turning into the polymer. The termination is basically the removal of the UV light source. The UV light source must have the proper wavelength and light intensity to properly form the polymers. Once the termination process is completed, the ink is now converted to an insoluble or not able to be dissolved polymer or plastic.

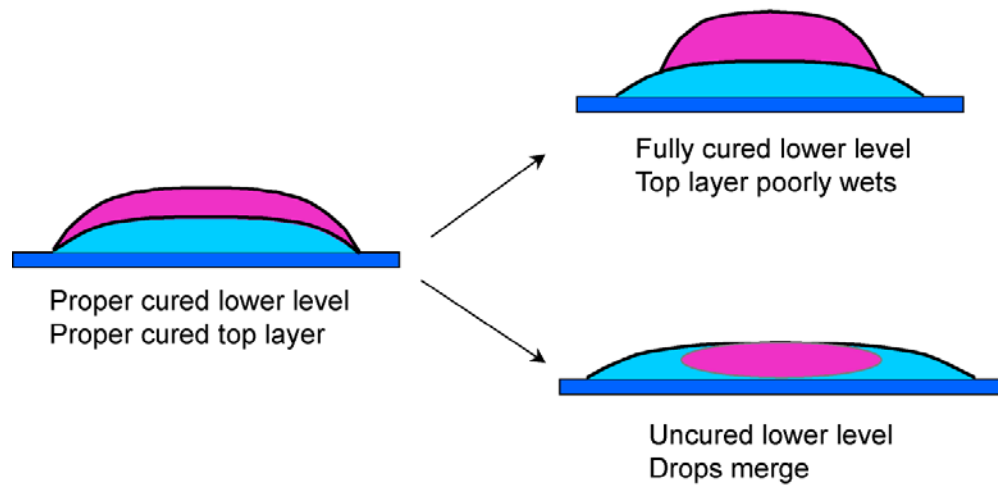
Typical Cure Conversion Chart



The curing process is very critical as it will determine not only the solidification of the ink, but also is very important in the dot formation on the surface of the media. The straight dotted line represents the UV light source converting the ink from a liquid to solid. If the UV light source is too intense, the polymer will become brittle and crack and also lose adhesion properties. Over curing will also keep secondary drops from blending in properly. If you are trying to achieve a Blue color and you place Cyan down and over cure, the Magenta drop will not lay down properly on the first drop.

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Effect of Second Ink Layer

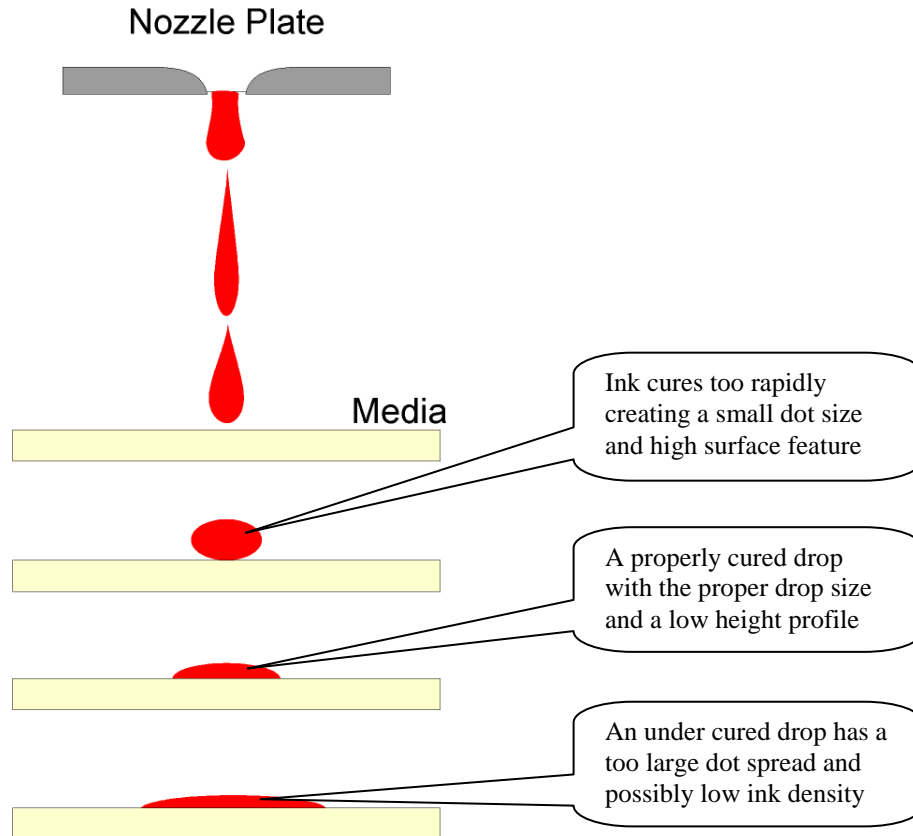


There are several factors in properly curing of the ink

- Carriage Speed or Dwell Time
- Lamp Power or Intensity
- Number of Lamp Passes
- Dot Size and Placement
- The Ink Chemistry

Typically any liquid being jetted by digital methods will have a specific viscosity and a surface tension property. The viscosity and surface tension are part of a drop spread control process.

Drop Spread Control



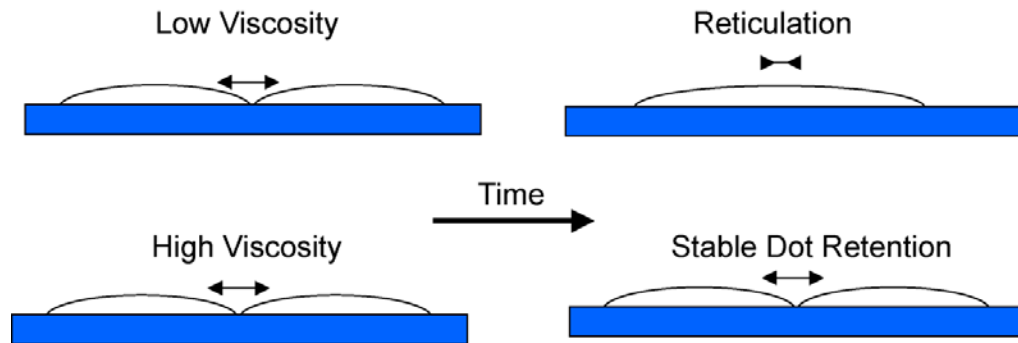
If you remember the graph of the “Typical Cure Conversion Chart”, there will be a time where the ink will be on the media and start forming the drop before any curing will take place. The ink must be formulated properly so that the time before curing takes place, there is a nominal drop spread. This relates to the surface tension of the ink and media contact area. In other words, will the ink bead up and form a small drop or will the ink spread too much. The formulation of the ink is very important in controlling the surface tension or how much the ink will spread or bead up.

The ink must form the proper dot spread and no more or less before the UV light source converts the liquid into a polymer. This is because once the UV light initiates the photopolymer process; the ink will become more stable in dot formation. If the ink does not spread enough, there will be gaps between the dots and there will not be a proper fill of colorant. If the ink spreads too much, the colorant will bleed into the other dots.



Viscosity Effects

Definition: The resistance to flow of a liquid



Piezo ink jets require low viscosity inks. However, high viscosity inks are required on the substrate to control drop spread.

In the above diagram, you will see the importance of having the proper viscosity of the ink. If the viscosity is too low, then the dots will merge or reticulate. Having a high enough viscosity will keep the dots in the proper place before the curing process.

So if we read the above diagram, piezo print heads require a low viscosity ink to jet, but the surface must have a high viscosity ink in order to keep the dots from merging. OK, how does that work!

The most common method of controlling the viscosity in digital UV inks is by heating up the ink in the print head.

The Rastek UV printers use water and special “anti-freeze” liquid heating system in order to maintain the proper jetting of the ink, yet its therefore able to jet a higher viscosity ink because the high temperature lowers the viscosity. Once the ink leaves the print head it cools on contact with the surface and is able to maintain the proper dot spread. The typical temperature is around 120 degrees F or 50 degrees C.

The Rastek **T660** uses heaters for the print head and head ink tank to maintain the ink viscosity. The head temperature it typically set for 42.5⁰ C and the tank temperature is set at 32⁰C.

Surface Energy and Wetting

Young's Equation

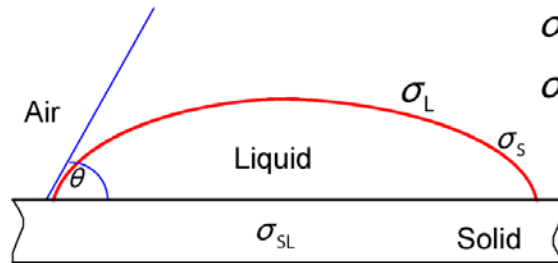
$$\cos \theta = \frac{(\sigma_s - \sigma_{SL})}{\sigma_L}$$

θ = Contact Angle

σ_s = Surface Energy of the Solid

σ_L = Surface Energy of the Liquid

σ_{SL} = Energy of the Solid-Liquid Interface



So the secret in controlling the drop spreading is by heating the ink in the print head. So the printer is capable of printing with a higher viscosity ink than would normally be jetted through the print head.

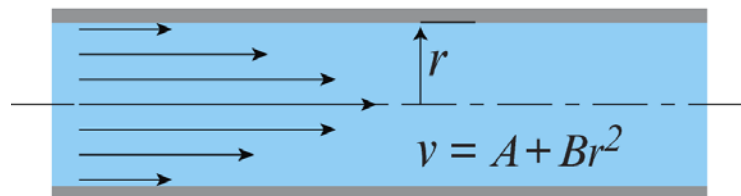
Because of the higher than normal ink viscosity, the temperature of the room where the printer is located is more important. In the winter time, the printer must not get too cold as the higher ink viscosity ink will become more difficult to flow through the ink lines.

Because of this viscosity requirement, the printing room must not fall below 64 degrees F or 18 degrees C.

Velocity Profile for Tube Flow

The relationship governing the velocity as a function of distance r from the center of a tube under conditions of laminar flow is:

$$\frac{d^2 v}{dr^2} + \frac{1}{r} \frac{dv}{dr} = - \frac{1}{n} \frac{\Delta P}{\Delta x}$$



The general form of the solution to this differential equation is $v = A + Br^2$ where A and B are constants which must be fit to the boundary condition of the flow: $v=0$ at $r=R$.

Substituting the general solution by taking the derivatives gives:

⋮

$$2B + \frac{1}{r} 2Br = -\frac{1}{n} \frac{\Delta P}{\Delta x} \quad \text{evaluated at } r=0 \text{ gives } B = -\frac{1}{4n} \frac{\Delta P}{\Delta x}$$

$$v = 0 = A - \frac{1}{4n} \frac{\Delta P}{\Delta x} R^2 \quad \text{evaluated at } r=R \text{ gives } A = \frac{1}{4n} \frac{\Delta P}{\Delta x} R^2$$

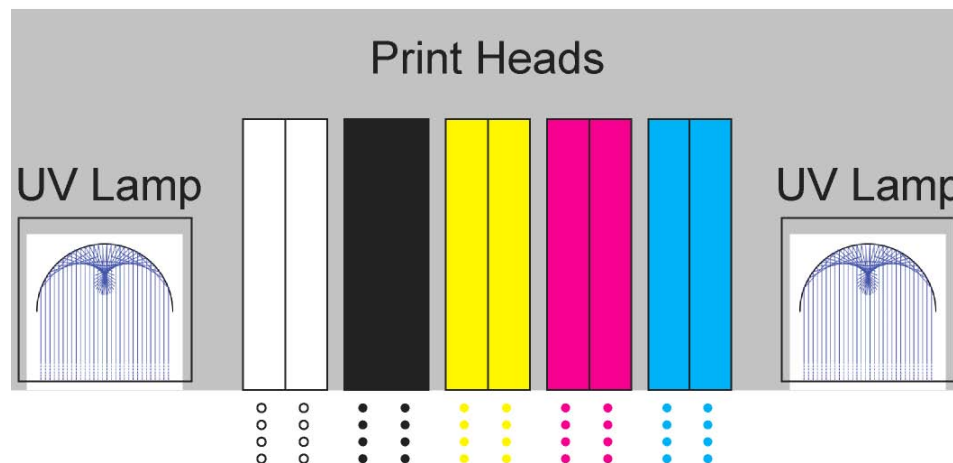
The velocity profile is $v = \frac{1}{4n} \frac{\Delta P}{\Delta x} [R^2 - r^2]$ and the maximum velocity is $v_m = \frac{1}{4n} \frac{\Delta P}{\Delta x} R^2$

Great more math which makes no sense! So what does this mean? Well the more viscous the ink, the harder it is going to flow through the tubing. As the temperature decreases, the viscosity will increase causing the ink to flow at a slower or restricted rate. This could lead to ink starvation at the print head.

You may be able to print at slower firing rates, but not at production speed. This is typical with most digital UV printers and even solvent or aqueous printers. The printer's environment is very important.

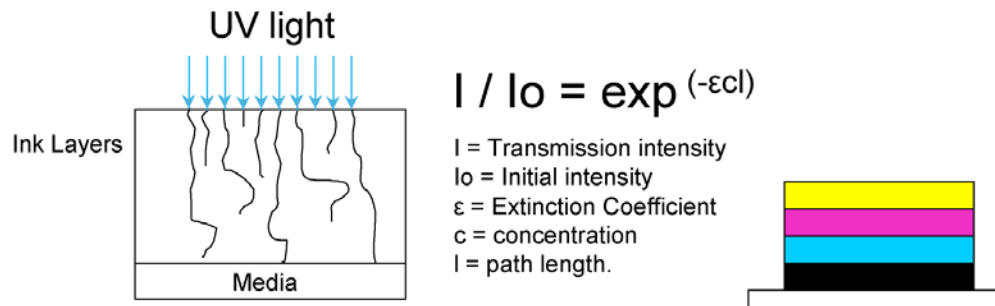
Ok what about the UV Lamps?

T660 Carriage Assembly



In the Rastek UV printers, we use a metal halide lamp which does not produce any Ozone. The typical UV wavelength is 200nm – 600nm and is user replicable. The type of UV lamp must be matched to the ink properties. The concentration of radicals will determine the lamp type. Low concentrations of radicals need a diffuse UV light source. High concentrations of radicals require a focused UV light source. The intensity of the UV light can be controlled by the printers GUI with settings of OFF, 0% to 100% with 10% increments, Trailing Lamp, Leading Lamp, or both lamps.

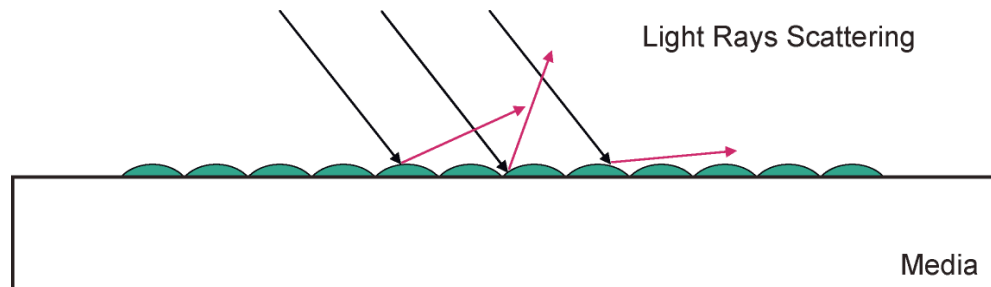
Through Cure and Adhesion



Note: Depending on ink formulation, too much curing will reduce the adhesion of the ink. Some ink types require high lamp setting for good adhesion.

This printing requirement may be the number of passes, lamp intensity, and carriage speed. Naturally the higher of the lamp intensity, the faster the ink will cure. However as we have seen, we do not want to over cure the inks. On super fine high resolution printing such as 1200 x 900 dpi, there may be a higher number of passes required for your particular application. At these high resolutions, a higher number of passes such as 12 pass are available. With this high number of passes, the UV lamp will go over the same area more times and for a longer duration than at lower resolutions which may print a higher speeds and a lower number of passes.

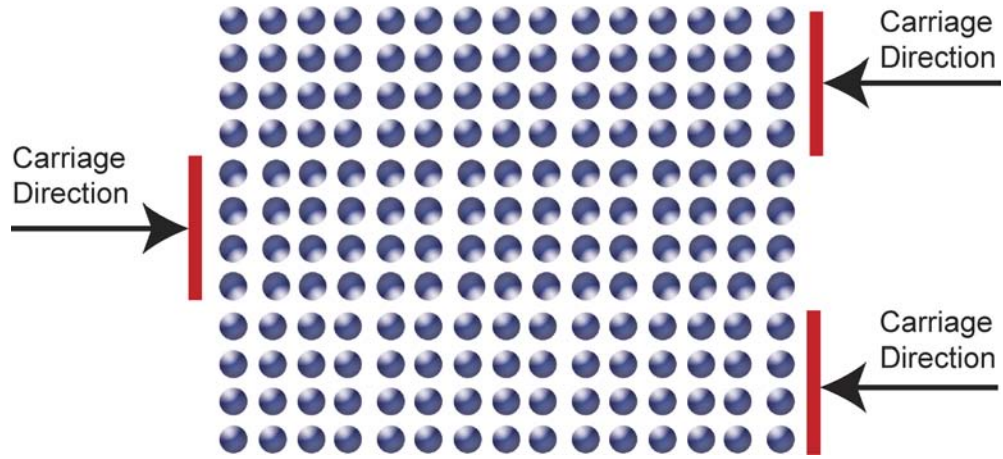
At the higher resolutions, lower lamp intensity may be needed so as not to over cure the ink. Care also must be taken not to damage the media as the heat intensity could be too great. This leads to buckling of the media or even melting of some sensitive media if the lamp is set too high.



Because UV inks form a solid droplet on the media, this creates a surface texture. The UV inks are fairly glossy and reflect light easily. Because of the textured surface, the light rays can scatter. If the drops are formed in a random pattern, the scattering is also random. However if the ink droplets form in repeatable patterns, the light scattering will show up as what is called “Cure Banding”.



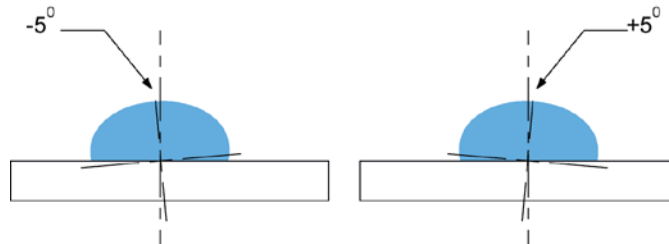
Cure Banding in Bi-Directional Printing



Note: The ink drops cure with a slight angle shift depending on the direction of the carriage / UV lamp assembly. This causes the reflected light to reflect in a repeatable pattern and appears as banding.

The optimum cured drop has a minimum surface texture or height, yet will have enough colorant to fully achieve the proper color intensity or depth. As we see in the drop formation and drop spreading illustrations, the buildup of the ink droplet must not be too small or too large. If the drop is too small, there will not be the proper ink fill. If the drop is too large, the colors will not be intense enough or will be too thin showing the surface of the media.

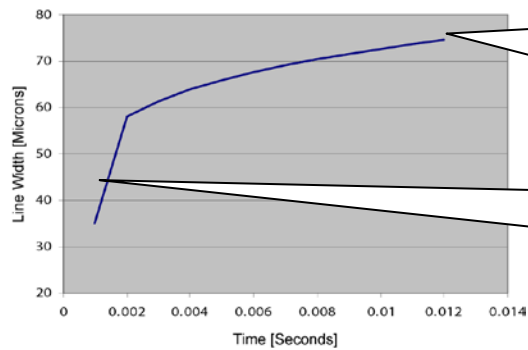
The dots cure at a slightly different angle depending on the direction of the cure pass.



On difficult media or for critical applications, printing in Uni-Direction may be required.

There is also a drop spread vs. time which is needed to optimize dot size. In certain applications, we can take advantage of the drop spreading beyond normal especially with a clear overcoat.

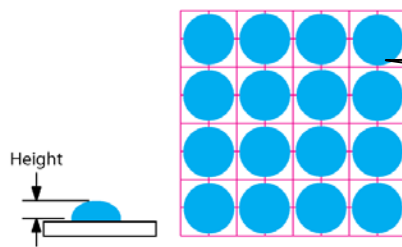
Drop Spread Vs. Time



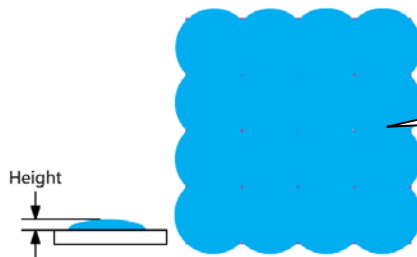
By taking advantage of curing after a longer time, the drops become evenly distributed giving a smooth gloss coating. This would be used with leading lamp.

This time period is when the inks would normally be cured by the UV lamps set to trailing.

Dot Gain or Spread



If the dots are too small, gaps in the print could look like banding.



The proper dot size will fill in the gaps but not create a dot which has a too high profile.

The size of the drop can be a function of the ink and curing process, but the size can also be controlled in the ICC Profile or the RIP Software. This is very important in maintaining the proper dot formation on the media and reduces the amount of “curing banding”.

This becomes important especially with variable drop UV printers which can offer very high quality print images.

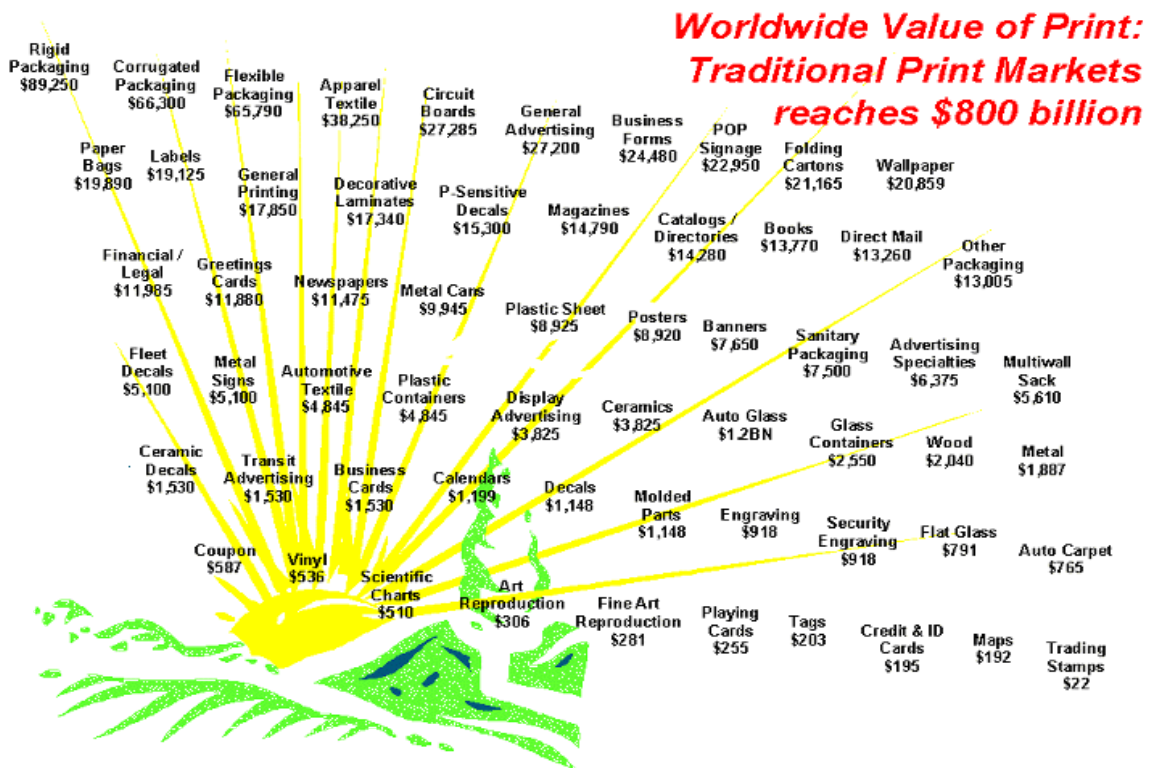
Many people have heard that one of the benefits to UV digital printing is that you do not need to profile. Because the ink is opaque and sits on top of the media, the brightness of the color is maintained over a wide range of media types compared to aqueous or solvent inks. However we can see by all of the information on controlling the dot spreading as well as dot height, these both can relate to curing banding. Therefore proper profiling is very important to obtain the highest print quality.

If you were just printing long distant viewing banners, the importance of ICC profiling is reduced. However the Rastek UV printers offer much greater printing applications because of the higher resolutions and therefore the ICC profiling becomes more important.

UV Digital Markets

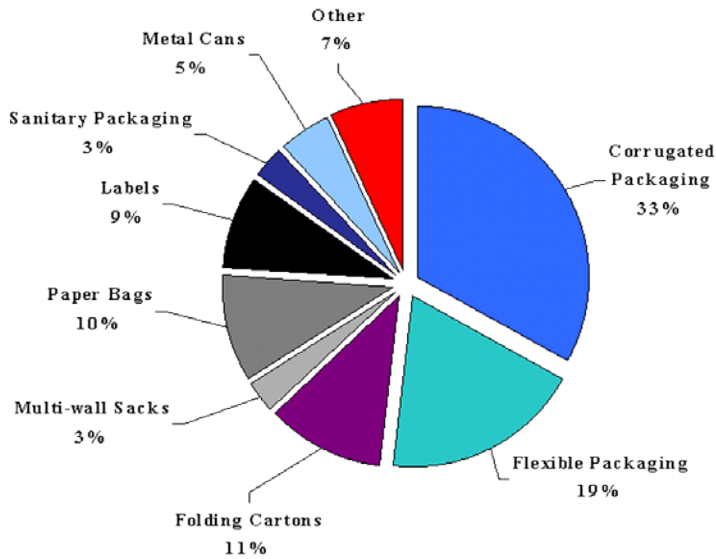
There are many markets using traditional screen printing UV methods. Many of these markets are adaptable for digital UV printing methods.

Of the worldwide traditional print market, UV printing can be utilized in almost all of these markets. The following diagram is provided by I.T. Strategies.



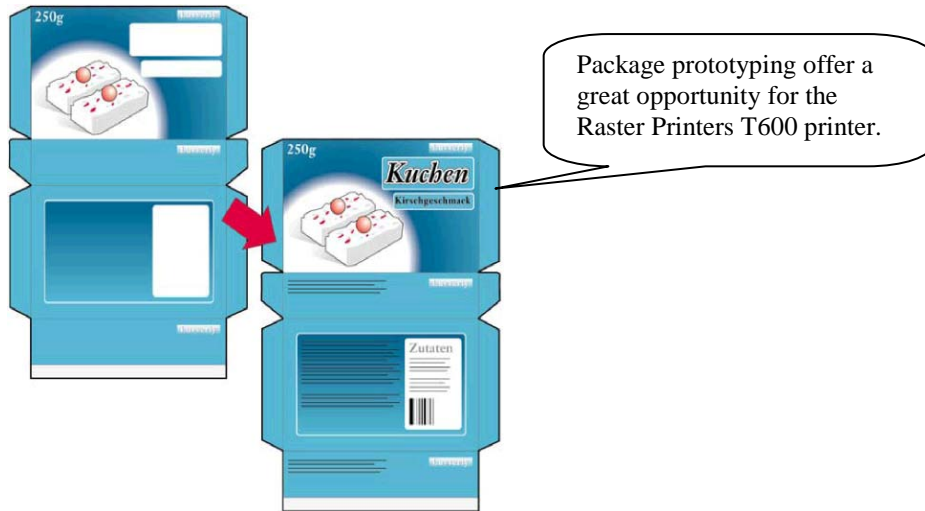
If we look at the above diagram we see a very large market opportunity in the packaging and carton industry which can typically require UV printing. The opportunity with Rastek UV printers is great in the prototyping area and is a great system by incorporating a flatbed cutter. By not requiring the preparation of screens for development will save the customer in both time and money.

US Packaging Printing % of Shipments by Type of Packaging 2000



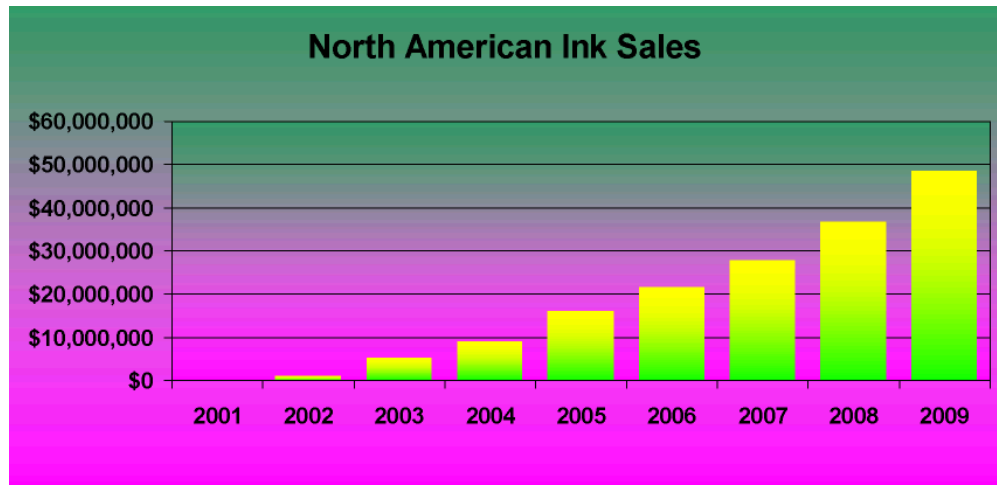
Total Market: \$83 billion

By breaking down the packaging market to the US percentages, we can see that the opportunity in the corrugated, flexible packaging and folding carton are the largest areas. The Rastek UV printers and a flatbed cutter are perfect for this market.

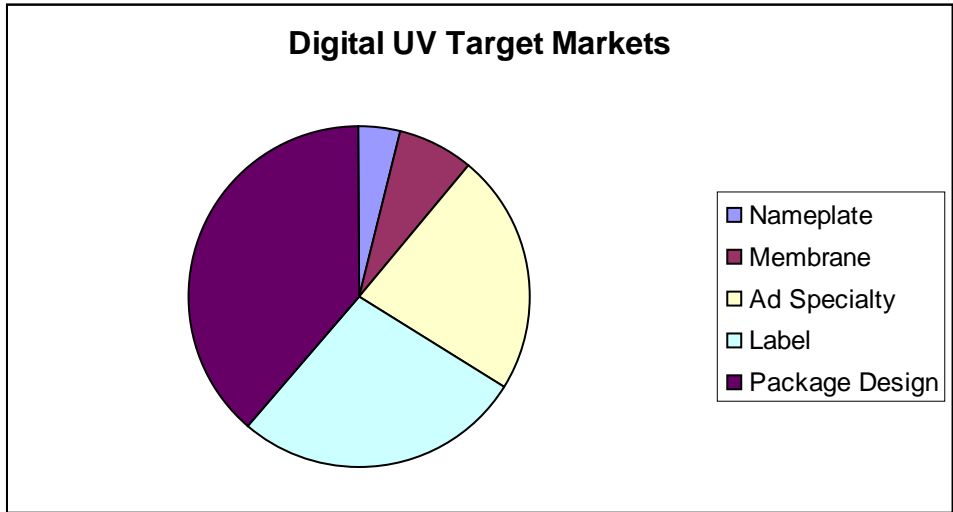


Let's take a look at the UV ink usage projected for 2009. We can see that the usage of UV inks is the fastest growing segment in digital printing today.

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Because UV inks do not require any coating, and does not penetrate the media, difficult to print items such as corrugated cardboard or other ridged paper bases are a great opportunity.



The above graph depicts the typical digital UV target markets. The breakdown is follows;

Nameplate – 4%

Membrane – 7%

Ad Specialty -23%

Label – 27%

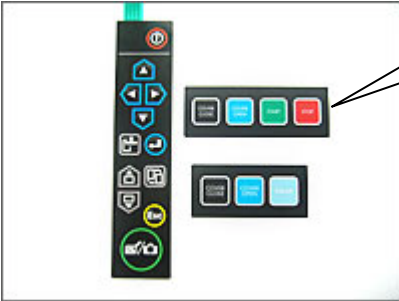
Package Design – 39%

All Rastek UV products offer several printing resolution options which allow a wide range of market options. Typical banner imaging can be printed at a resolution of 529 x 540 DPI, while

nameplate, membrane, label, and most packaging can be printed at 1058 x 720 dpi. With the high resolution of 1080 dpi, the Rastek UV printers are capable of offering very small detail work which is perfect for the ad specialty market.



Cell phone overlays.



Control panel / membrane switches.



Solvent resistant labels and decals.



Package prototyping on flexible materials

Any package prototyping will save the customer valuable time and money.

Other large UV digital markets:

Interior Design

Kitchen Worktops

Doors

Wall Coverings

Flatpack Furniture

Product Decoration

Automotive Dashboard and Trim

Automotive Instrumentation Panels

Architectural Goods

Furnishings

Fine Art Reproductions

Metal

Glass

Wood

Electronics

PCB Printing with White or other colors

Displays

Sporting Goods / Toys

Skateboards

Snowboards

Surfboards

Skimboards