An Aqueous UV Curable Inkjet Printing for Graphic Output

Hiromichi Noguchi and Masako Shimomura
Canon Inc., Kanagawa, Japan

Abstract

The material design concept for aqueous UV curable inkjet inks and quality of graphic output are explained. The UV fixing in inkjet printing has already been realized by several kinds of products. Almost all these printing systems are based on the piezo electric print head by non-aqueous UV inks and designed to print on non-absorbing substrates. The ink system of this article is characterized as composition of water-soluble photo-initiator and water-soluble oligomers in aqueous pigment dispersions. The objectives of the system are to adopt the bubble & thermal inkjet system and to print mainly on absorbing substrates. How we design the water-soluble materials and design parameters are discussed. How we can control and realize the quality of graphic output by pigmented inks is also presented. Although the aqueous based system has disadvantage on curing speed; it will enable us to realize printer which is more environmental and also to create a graphic output close to current commercial printing.

Introduction

The UV curing in an inkjet printer has long history in the industrial marking and coding applications. There are, in recent several year, new UV inkjet printers, which give full color, high speed, wider print width output for packaging and wide format graphic print applications. In these printers UV curing is used to print especially on the non-absorbing materials such as plastic films, packaging papers ceramic, and vacuum deposited metals. There are basically 3 types of UV curable inkjet inks; they are (1) almost all the components are polymerizable, (2) polymerizable materials are in the emulsified state in water, (3) polymerizable components are water-soluble. This article deals with type (3); the aqueous UV curing system. The primary reason of our choice is to print absorbing materials including plain paper. Aqueous inks are favorable to this application. It is needless to say the aqueous UV inks contain water, so how & when remove water after printing is important design factor on an inking process. The existence of water gives some limitation on the curing speed. The advantages of aqueous UV system are; (1) no VOC ink system, (2) giving sharp image on plain papers, (3) suitable for bubble & thermal print head, (4) can be used on print heads of highest resolution. The printing on absorbing materials usually does not require removing water by a dryer. The apparent drying speed will increase by UV & also thermal energy from UV source and absorption in paper. The another reason to apply UV curing is to solve the compromised problem in current pigmented inks. The higher OD and poor adhesive force of pigmented inks on plain paper is well known compromised problem. The high light fastness but lower gloss and weak adhesion in graphic output are serious in the pigmented inks on graphic output. The low gloss and narrow gamut in pigmented ink jet picture is coming from the uneven surface of the ink layer and aggregated pigment. The UV curing may overcome these problems by introducing the enough amount of liquid binder. The soluble UV curable materials minimize the aggregation of pigment particles in the course of fixing and decrease the light scattering from the particle. It is apparent that the cause of the low chroma and low gloss is coming from the lack of binder in the pigmented inks. We have demonstrated this concept by creating the many aqueous materials. The aqueous system give also the new opportunities towards practical applications by the bubble and thermal inkjet printers.

Curing Model on Absorbing Material

The aqueous inks ejected on the paper immediately start to penetrate into the paper. Usually liquid ink goes perpendicular deep into the fiber and horizontally wide, so the shape and width become irregular especially on the plain paper. UV curable ink is totally different. The polymerization of component give rises to the sudden increase of viscosity. The heat flux from the UV tube promotes the drying water from the ink layer. When blower cools the UV tube, the air blow promotes also the removing water. Therefore in real occasion UV curing accompanies heat dry and air dry. By rapid curing of components ink layer is expected to get the following characteristics; (1) flat top surface, (2) fixing near surface, (3) improved adhesion, (4) higher optical density, (5) improved chroma, (6) restraints a cockle & curl of paper.

Aqueous Photo-Polymerization Catalyst

The water miscible photo initiator is rare in the radiation curing material market. The anionic or nonionic water-soluble photo initiators are proposed, which is compatible with the aqueous dyes and pigments for inkjet inks.[1] The sensitivity to UV light is kept after the chemical modifications of this kind. They can be derived from the existing materials towards water soluble ones. The ways for the chemical modification are (1) to attach the several ethylene oxide units, (2) to attach the acids such as sulfuric acid, carboxylic acid, and phosphoric acid and (3) to attach the solvent-like water-soluble molecular group.

The practical curing speed is affected from following factors; (1) life of the radical, i.e., recombination probability and thermal dissipation, (2) concentration of the dissolved oxygen in an ink, (3) light absorption and scattering by colorant, (4) impurities, (5) concentration of solvent and polymerizable materials, (6) spectral matching with UV source.

Chemical Modifications to water-soluble type were tested on the two types of photo-initiators. The photo cleavage types such as alfa-hydroxy phenyl ketone and hydrogen abstraction type such as thioxthanthone were tested. Both of these groups of materials were compatible with typical aqueous pigment dispersions for inkjet.

Aqueous Photo Polymerizable Oligomers

The aqueous polymerizable materials are also not so much in the market. The aqueous photo-polymerizable oligomers should have following properties as; (1) high solubility & stability in water, (2) hygroscopic property like a solvent, (3) rapid curing in water: such as polyfunctional acrylate, (4) compatibility with pigment dispersions, (5) solid state properties after cured such as hardness, rub-resistance, and water & moisture resistance, (6) optical properties after cured such as transparency, light stability, and no effect on the light stability of the pigment.

Figure 1 (a)(b) are two examples of water-soluble polyfunctional oligomers.[2] They are polyhydroxy acrylic compounds (PH type) and compounds having a carboxylic acid in the molecule (CA type).

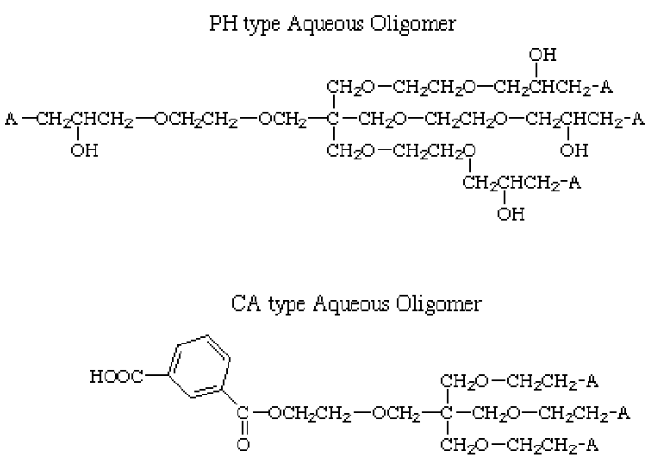

Figure 1. PH type (top) and CA type (bottom) polyfunctional aqueous photo-polymerizable oligomer

A: (meth) Acrylic Moiety

The stability of oligomers in water is not easy, because there are several causes to breakdown itself or to destroy the properties of inks. The dissociation, reaction on the unsaturated bond in a dark, a molecular interaction with dispersed particles of pigment, impurities in the course of synthesis. The oligomeric materials have hydrophilic moiety and hydrophobic moiety in the molecule, so the adsorption to the pigment particle is possible to occur. It must greatly be taken into account to the material design on the compatibility & long term stability because small change on viscosity, pH, and surface tension give rise to wrong performance in print head.

The transparency of the cured film has a specific importance for the high image quality and also to widen the applications. The pixel by inkjet printer is composed of from 1 to 3 droplets of same and/or different color on the same area in the paper. Therefore the each dot needs to be transparent. This spectroscopic transparency is the principal requirement of the process color printing. The enough amount of oligomers fill the vacant space between the pigment particles, which results in decreased light scattering.

In some case cloud occur in the cured layer by the micro phase separation in the course of polymerization.

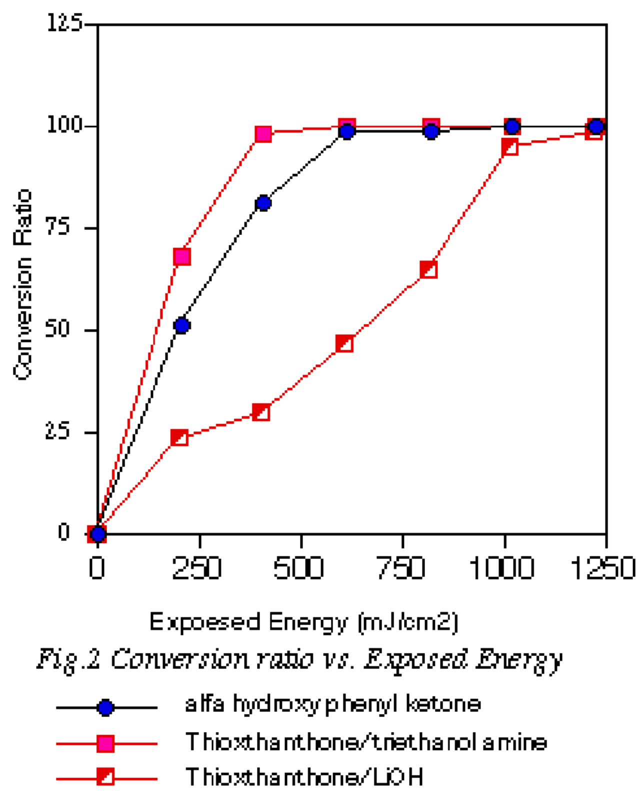

Fig.2 Conversion ratio vs. Exposed Energy

Figure 2 shows conversion vs. exposed energy of high pressure UV light on draw down coating on glass. The ink composition in Fig. 2 is tri-functional PH type epoxyacrylate, yellow pigment, and 2 types of aqueous photo initiators. The aliphatic amine works as accelerator for thioxthanthone, which is same as in an ordinal photo polymerization system.

Printing for Graphic Output

One of the unsolved problems of color inkjet printer by pigmented inks is image quality and adhesive strength on glossy substrates. The weak adhesive strength and low gloss in printed region are pointed out in most of pigmented inkjet printers. In some case even the water/moisture fastness is not good. Usually the glossy papers designed to dye-based inks for graphic output do not fit for pigmented inks. The origin of the lower chroma, decreased gloss are opaque layer and scattering in the layer. The rough & uneven surface structure decreases gloss. The low adhesive strength is in practical occasions is serious drawback. Other factors controlling the quality, i.e., graininess, sharpness, and tone gradation, can be controlled to same level as dye-based inks. UV curable ink resolves these drawbacks by enough amounts of binder and rapid solidification.

Cured Layer Thickness

The inks containing water give thinner layer thickness on the paper than 100% UV curable inks. Table 1 shows the calculated thickness of the solidified ink layer. 600X600 dpi, 10pl/drop, 200% full address printing under 20% of oligomer concentration gives about 2 nm thickness of the solidified ink layer. This value is almost same as traditional printing inks. Small thickness of the ink layer is important for the homogeneous gloss and feeling of the prints for graphic output. A few micron thick layers are same as offset printing.

Table 1 Thickness of Solidified Ink Layer

Calculated thickness of the polymerized ink layer		Concentration of Polymerizable component in in		
		20%	50%	100%
Unit: micron	1 color	1.1	2.8	5.6
	2 color	2.2	5.6	11.2

Print head: 600 x 600 dpi nozzle 10pl
Nozzle: 10 pl/drop ratio 1

Gloss

The gloss increases after fixing by UV light, which is same as in other UV curable inks for inkjet. As seen in Fig. 3 UV cured pigmented ink layer has increased gloss than original paper surface. The adhesive strength of the ink layer also becomes enough. The system will widen the usage of inkjet printer for such as clear over coating, and photographic-like printing and finishing.

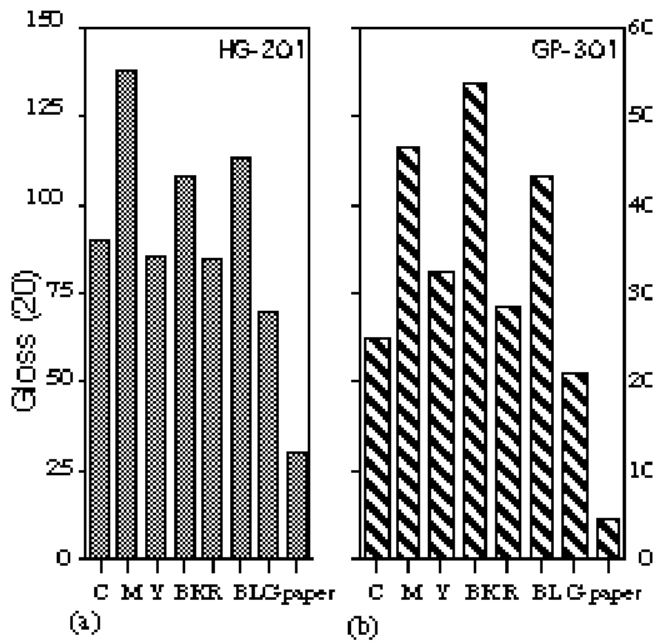

Figure 3. Gloss value on glossy substrate (a) HG-201 & (b) GP-301 with UV Cured Pigmented Inks

Color Reproduction

This benefit is proved in the Fig. 4 (a) and (b) as high chroma of RGB secondary colors. The color reproduction on L*-a*-b* space becomes well wide and balanced. The particle sizes of pigment dispersion used in inks for Fig.4 is shown in Table 2, which shows mean particle size is around 100nm. This denotes that in UV cure system particle size is not major factor to get enough chroma at least on glossy substrate for graphic output.

Table 2 Weight Average Mean Particle Size of Pigment in each ink measured by ELS-800(Ootsuka Electric Co.)

	P.Y.138	P.R.122	P.BL15:3	P.Bk7
weight average mean particle Size (nm+-s.d.)	83.8 +- 23	130.2 +- 17	117.0 +-33	73.5 +-20

Conclusions

The technology on UV curable inkjet ink and printer are presented. The several benefits of aqueous system are verified by using aqueous photo initiator and aqueous photo polymerizable oligomers. The system may clear the problem in pigmented inks in graphic output such as adhesive strength incorporating enough gloss, and hue & chroma of secondary colors.

The concept of aqueous UV curing will enable us to produce printers satisfying of high speed & high quality both for commercial & office use. To realize it, materials design & development of light source is important keys.

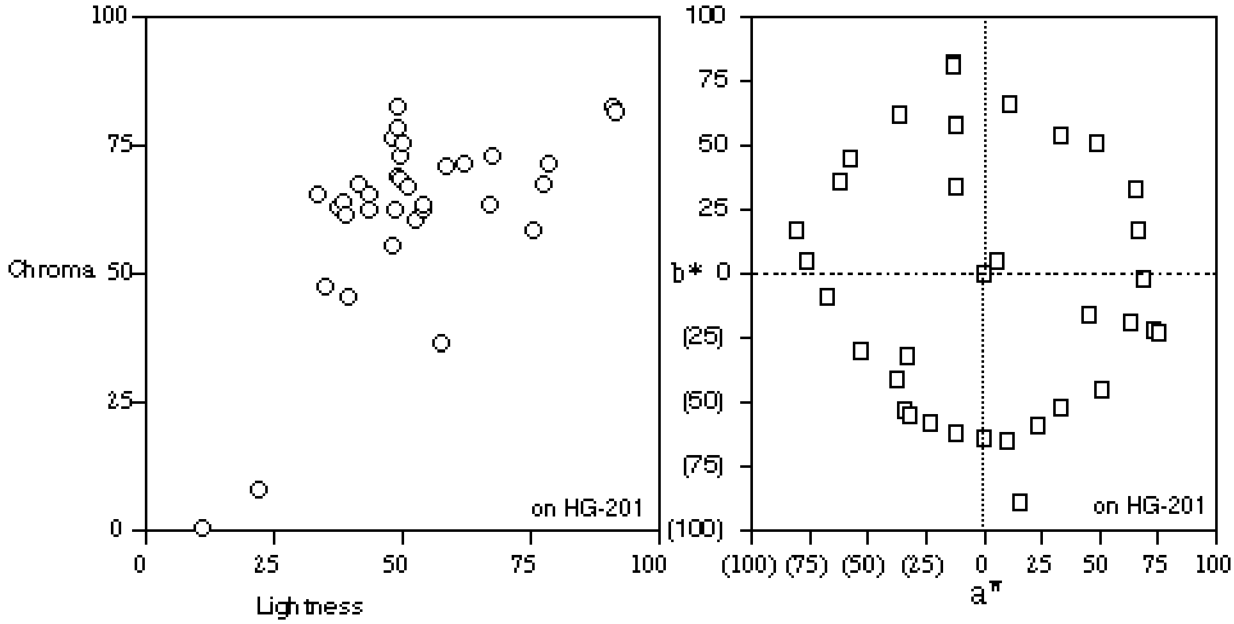

Fig.4 (a) Chroma vs. Lightness of UV *Fig.4(b) a*-b*Projection Color Space*
Color of Pigmented Ink Layer on Glossy Film

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Biography

Hiromichi Noguchi received his Dr. of Engineering from the Tokyo Institute of Technology (polymer science) in 1977. He worked in DIC for 7 years and joined Canon Inc. in 1985. He has worked on R/D of digital imaging materials in BJ technology. E-mail: noguchi.hiromichi@ canon.co.jp

Masako Shimomura graduated from Tokyo Metropolitan University and has worked in Canon on R&D of materials design and analysis for bubble jet printer. Shimomura.masako@canon.co.jp