Newly developed UV-curable inkjet technology for Digital Inkjet Press “KM-1”

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Abstract

We have developed a new and unique UV-curable inkjet technology for a sheet-fed off-set like inkjet printer “KM-1,” which will bring a new wave of digitalization into the commercial printing world. There were many technical challenges to realize both high-speed and high-quality recording process in a system. We studied the imaging process thoroughly and reached a new and unique UV-curable ink formulation and a process that can cure images at extremely high speed with extremely high definition. To support the ink and the process, we also developed a variety of technologies such as a new durable print head with high nozzle density, an image correction system, and so on. Combined these new technologies, as a synergy of inks, print heads, and system, we have succeeded to develop a new inkjet printing system for digital press market.

Introduction

Nowadays ICT, e.g. internet, SNS, and e-book, has become popular and been expanded throughout the world. Such technology does not need paper as a medium for communication and promotes so-called “paperless” environment rapidly. Accordingly it forces the commercial printing market to transform; to adapt much effective communication, to change marketing method from “mass-” to “one-to-one” communication, and ephemeralization. It is essential to realize quick delivery, high-mix low-volume production, and personalization for such transformation.

In Drupa 2012 we proposed an answer for the transformation; a sheet-fed inkjet digital press “KM-1.” [1] Its vision is “Real digitalization Pioneer for Commercial Printing.”

Fundamental requirements are:

1. Quality: Close to offset
2. Flexibility: Wide variety of paper is available
3. Duplex
4. Productivity
5. Utilizing existing peripheral equipment.

We aim to provide real Digitalization tool to the Commercial Printing Market. Its specifications are summarized in Table 1.

Table 1 KM-1 specifications.

	Specifications
Printing type	Single pass inkjet printing
Transportation	Gripper transportation
Speed	Simplex: 3,000 sheets/hour Duplex: 1,500 sheets/hour
Number of colors	4 colors (Y, M, C, K)
Number of heads	2 Heads/module 8 Modules/color (Total 64 heads/color)
Resolutions	1,200 dpi x 1,200 dpi
Maximum print media size	585 x 750 mm
Media thickness	Simplex: 0.06 - 0.6 mm Duplex: 0.06 - 0.45 mm
Media type	Coated paper Non-coated paper Embossed paper etc.
Ink	UV-curable ink
RIP	Full variable

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One of the biggest challenges of the KM-1 was to develop a new UV-curable inkjet technology, which can achieve extremely stable jetting performance necessary for single-pass printing and aptitude for wide range of paper without pre-conditioning liquid. We will report the technologies of the ink, printing process, and print head of the KM-1.

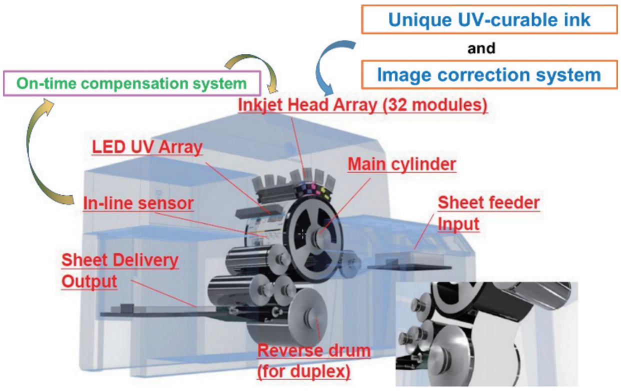


Fig. 1 Structural Illustration of KM-1 System.

Achievement technology

Forming high definition image

In the commercial printing market, a wide variety of papers, absorbable or non-absorbable (coated paper, art paper, uncoated paper, embossed paper, etc.) are used. When we print on a non-absorbable paper with a conventional ink (non-adjusted/customized to non-absorbable papers), image deterioration is caused by dots coalescing and bleeding. Such deterioration is emphasized with a single-pass printing technology and the image becomes streaky.

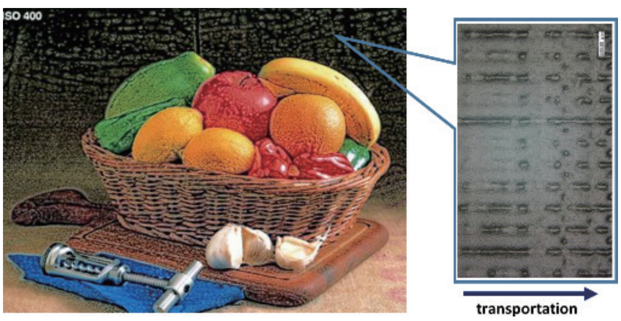


Fig. 2 Streaky Image by Dots Coalescing.

For avoiding the image deterioration, many ideas have been proposed. Utilizing UV-curable ink is one candidate. Irradiation of UV light just after landing of the ink can "pin" the ink to avoid dots coalescing and bleeding. With conventional radically polymerizable UV-curing ink, however, its polymerization are easily suffering from inhibition by oxygen that hinder the "pinning." Figure 3 illustrates the inhibition; there is an induction period of ca. 0.5 seconds and the polymerization starts after the period. The landed ink droplets can easily start to coalesce together within such period and it is impossible to avoid the image deterioration in high-speed single-pass printing technology.

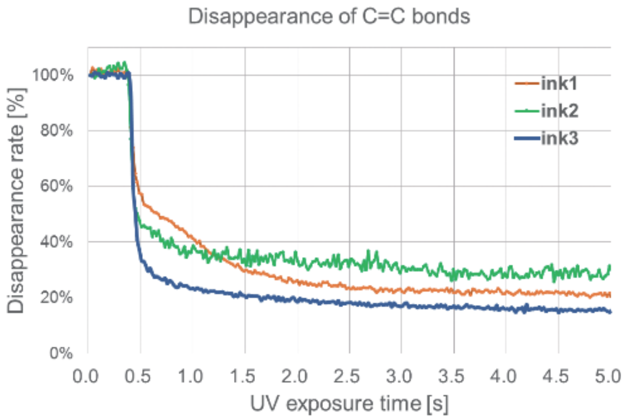


Fig. 3 Induction Period of Radical Polymerization. FT-IR spectroscopy: λ=1626cm^{-1}

A pre-conditioner is another candidate. Some ionic materials can coagulate pigments of the water-based inks. Utilizing such materials as a pre-conditioner can avoid dots coalescing and bleeding. Water-based inks and pre-conditioning liquid, however, effects on some papers to cause paper-deformation, curling and/or waving, and it hinders simultaneous duplex printing.

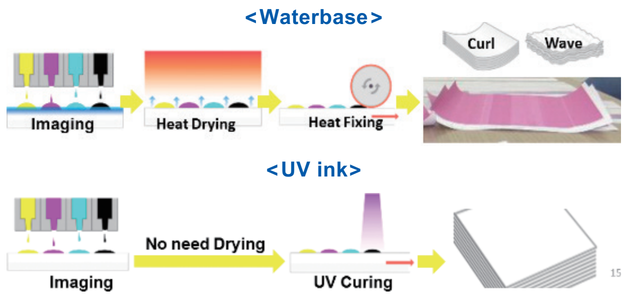


Fig. 4 UV ink minimizes effect on the paper.

Under these circumstances, we chose UV-curable ink to avoid such paper-deformation. To avoid the dots coalescing and the bleeding, we then developed a new ink formulation and curing process. The ink was designed to have relatively higher viscosity at room temperature and lower viscosity at elevated temperature. The ink is heated inside the print head to decrease the viscosity for jetting. When the ink droplets land on the paper, the temperature of the ink decreases and the viscosity increases rapidly. The rapid viscosity change "pins" the dots and it avoids the dots coalescing and the bleeding accordingly. With the ink we can print at a high speed on a wide variety of paper, absorbable or non-absorbable with high definition image.

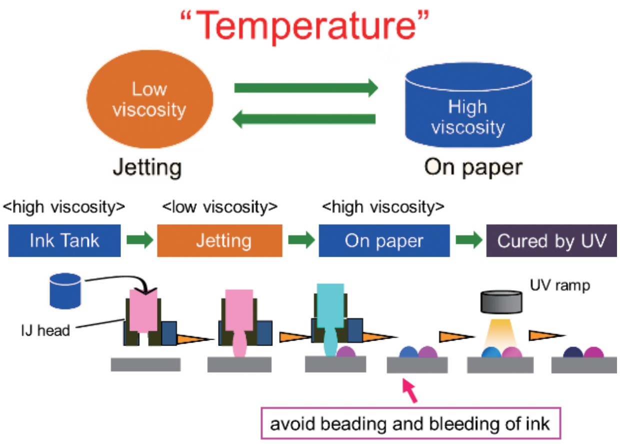


Fig. 5 Making High Quality Image by Controlling Ink Viscosity.

The point of the development was to attain higher stability at elevated temperature with keeping higher curing speed. We designed new ink formulation to fulfil such characteristics. To jet the ink stably, we developed a new print head that has heat resistance with highly controlled jetting driver. Another challenge was to gain excellent glossiness. The rapid “pinning” can avoid the dots coalescing but can yield bumpy surface that gives uneven gloss. We developed a new halftoning process to improve the gloss. Combined, we finally achieved to develop the innovative and reliable digital inkjet printing system “KM-1.” Each Technology is described below in detail.

Ink Technology

1. Development of Pigment Dispersion Stability

To attain higher stability at elevated temperature, we carried out thorough investigation of the dispersion-stability of pigment particles in ink.

It is said that the adsorbability of dispersant is an important factor to control the stability. When the surface of the pigment particles are adsorbed by the dispersant appropriately, the particles gain higher stability. It has been used the acid-base interaction between the surface of the pigment particles and the dispersant to select the best dispersant for a given pigment. The best dispersant has been seeking by measuring the acid- and base-values of the dispersants and comparing them with those of the pigment. [2] It is convenient way, however, it is essential to evaluate the dispersion behavior at elevated temperatures over a long period. It takes long time to confirm the validity of the selection.

We tried “Pulse NMR Measurement” as an easy and short time method for evaluating the pigment dispersion stability. Principle of measurement is based on the different behavior under the change of magnetic field between the molecules adsorbed on the particles and the free molecules in the bulk liquid. This effects can be detected by NMR relaxation time measurements. We suppose that the molecular movement of the dispersants steadily adsorbing on the surface of the pigment particles are limited and NMR relaxation time becomes short. Conversely the free dispersants in the dispersant medium have long relaxation time.

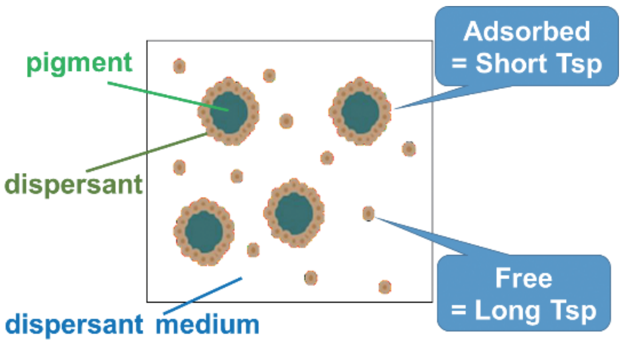


Fig. 6 Expectation of the NMR relaxation time of adsorbed and free dispersants.

We experimented the combination of the pigment, the dispersants, and the dispersant medium according to Table 2 and compared the relaxation time of “Pulse NMR Measurement” with the fluctuation of average particle diameter over as an actual dispersant stability.

Table 2 Experimented samples of the stability test using NMR measurement.

sample	pigment	dispersant	dispersant medium
No.1	A	a	1
No.2	↓	b	↓
No.3	↓	c	↓
No.4	↓	d	↓
No.5	↓	a	2
No.6	↓	↓	3
No.7	↓	↓	4

The results are shown Figure 7. The dispersant stability had a strong correlation with the NMR relaxation time. More specifically if the samples had the short relaxation time (Tsp), the fluctuation of the average particle diameter of samples became small.

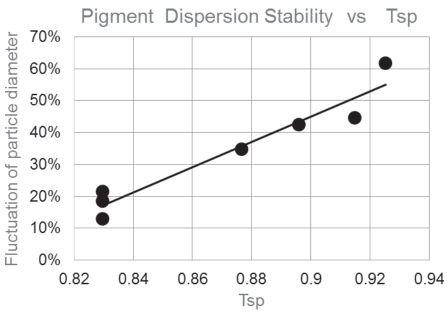


Fig. 7 Correlation between NMR relaxation time and Dispersion stability. Tsp=Ts/Tb, Ts: NMR relaxation time of sample, Tb: NMR relaxation time of bulk liquid (dispersant and dispersant medium).

By using this evaluation method, we achieved to attain higher stability of the ink. It was stable even after storage for 12 months at 60 degrees C.

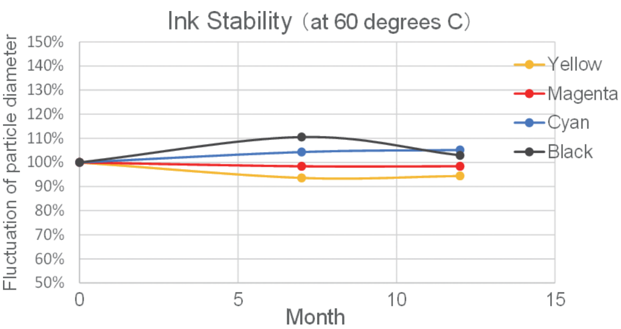


Fig. 8 Stability of the inks at 60 degrees C.

2. Ink formulation

The next target of our ink-development was to keep higher curing speed. It is well known that formulating multi-functional monomers are effective to improve the speed due to higher ratio of cross-linkage in the cured ink. When the ratio of the multi-functional monomers increases, however, the flexibility of the cured ink decreases significantly. The cured film can curl and can even be cracked by folding. [3] We then tried to formulate the ink with keeping both the speed and the flexibility.

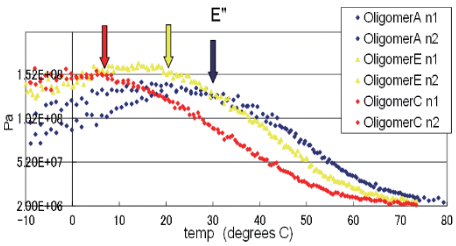
We prepared inks with 10wt% oligomers (=multi-functional monomers) according to Table 3, and evaluated scratch resistance and adhesion to the paper surface as a means of curing speed. We thought the scratch resistance corresponded to the curing speed at the surface. The curing reaction at the surface is in competition with the oxygen-inhibition; the tougher the resistance is, the higher the speed is with oxygen. We thought the adhesion to the paper surface corresponded to the curing speed at interface between the ink-dots and the paper. Due to the absorption of pigment particles, the intensity of the UV-light is quite low deep inside the ink-dots. The more excellent adhesion is, the higher speed is with low-light. Combined the formulation that show excellent performance of both shall have higher curing speed. As a result, inks with oligomer-A, oligomer-C, and oligomer-E showed excellent performance.

Table 3 Result of curing speed tests.

		Fastness to rubbing by paper *1	Tape peel off test *2
free	–	Good	Poor
OligomerA	Hyperbranced-polymer	Excellent	Good
OligomerB	Hyperbranced-polymer	Excellent	Poor
OligomerC	Polyester acrylate	Excellent	Good
OligomerD	Polyester acrylate	Excellent	Poor
OligomerE	Epoxy acrylate	Excellent	Good
OligomerF	Urethane acrylate	Good	Poor
OligomerG	Urethane acrylate	Poor	Good

10 wt% contain : the total weight of ink is 100 wt%
*1: weight: 500g/cm^2, paper : OK Top Coat plus, Good is equal with oil off-set printings
*2: tape: 3M scotch tape, paper : OK Top Coat plus, Good is not peel off from paper

We then evaluated "Dynamic Viscoelasticity" of the cured films with oligomer-A, C, and E, to access the flexibility. The thickness of the cured films were 20 μm. As shown in Figure 9, E"-values of the films were different depending on the oligomers. We determined the tanδ values and calculated the dynamic glass transition temperature (Tg). Finally we chose the formulation with the oligomer-C that showed the lowest Tg. It satisfied both the curing speed and the flexibility. We achieved high productivity of 3,000 sheets-per-hour using UV-LED light with giving excellent flexibility with this ink.



	tanδ peak Tg(degrees C)
OligomerA	56
OligomerE	50
OligomerC	45

Fig. 9 Dynamic viscoelasticity measurement of cured film (thickness: 20 μm).

Image correction system

The next challenge was to gain excellent gloss. When the ink was jetted and cured on a non-porous media such as a coated paper, the surface of the image became bumpy and gave uneven gloss by using a conventional halftoning process. The gloss value was strongly correlated with the dot pattern. The single-pass printing process emphasized the pattern because it printed for just one direction. More specifically, the gloss value of the image in a parallel direction to the transportation was relatively higher compared to the gloss value in a perpendicular direction.

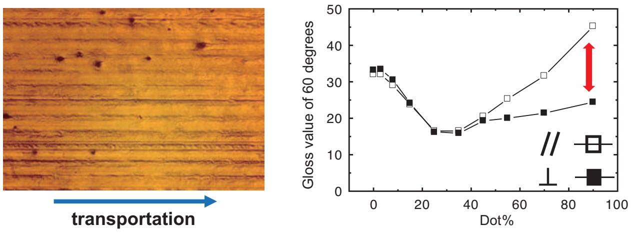


Fig. 10 Conventional Halftone.

To improve such gloss-unevenness, we developed a new halftoning process that provided redundancy in a dot arrangement and controlled the gloss value by using multi-sized dot with keeping a dot coverage on paper. [4] By using this improved halftoning process, we achieved to reduce the differences of the gloss value between the perpendicular and parallel direction in high-density dot-recording area. The ratio of the gloss value, perpendicular gloss/parallel gloss, was improved from 2.2 to 1.2.

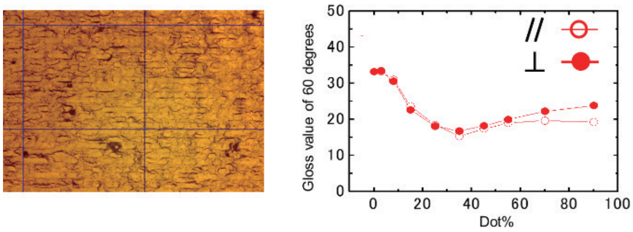


Fig. 11 Improved Halftone.

During the development, we found another issue of the gloss. The gloss value increased rapidly in accordance with the dotrecording ratio from 30 % to 100 % by using the conventional halftoning process. Such increase gave discontinuous gloss change and gave uneven feelings to viewers. The new halftoning process made it possible to improve the issue. We can control the gloss value of the image in a certain range by controlling the spatial frequency of the multi-sized dot pattern.

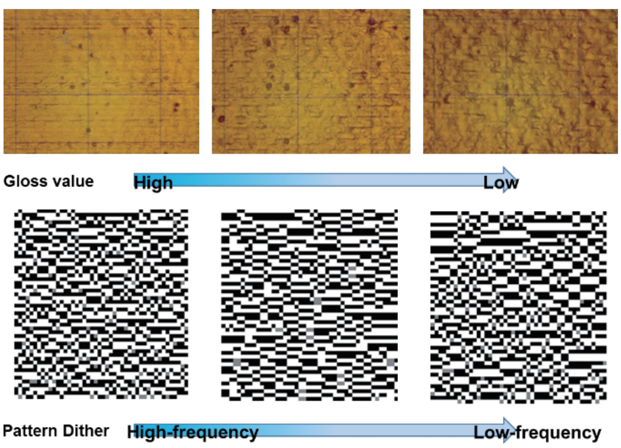


Fig. 12 Control the gloss value of image by pattern-dithering.

Head technology

To achieve stable, accurate, and high-speed jetting at elevated temperature, we developed a new print head KM1800iSHC for "KM-1."

Fig. 13 Newly Developed Print head KM1800iSHC.

Table 4 KM1800iSHC Specifications.

	Specifications
Number of nozzles	1,800 nozzles
Resolutions	600 npi (Nozzle pitch 40.3μm)
Actuator	Piezoelectric shear mode; HA structure
Frequency	41 kHz (2-Drop driving mode)
Internal Heater	Available

The print head KM1800iSHC is designed based on "HA" structure. [5] To control the influence of heat on the jetting performance, we carried out designing of total heat conduction passage. We designed the driving circuit to control its heat generation, the internal heater to maintain the ink temperature without affecting to jetting, and the structure of the head to exhaust heat to outside. We also designed the structure to reduce the stress and the strain at the actuator from the heat.

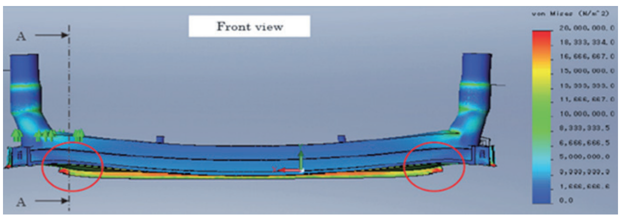


Fig. 14 Simulation of stress and strain at the actuator/ink supply channel under heating.

We developed a new line head module that can mount 16 print heads in the length of 585 mm in 1,200 dpi resolution. The chassis is simple and rigid, and has the head positioning structure which enabled print heads to be mounted in a proper position simply and accurately.

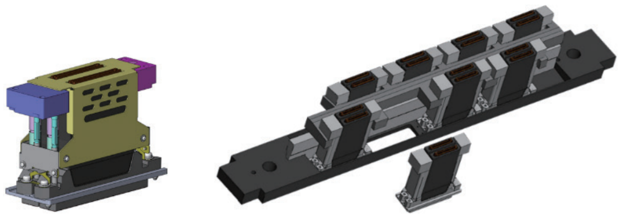


Fig. 15 Line Head module.

We also designed a new driving waveform and a new structure of pressure chamber that enable high productivity and stable jetting property.

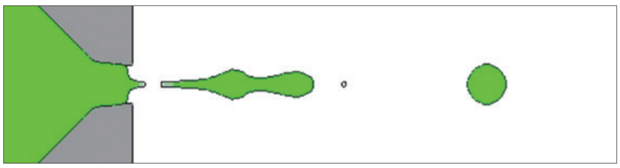


Fig. 16 Simulation of the ink ejecting by newly developed driving waveform and pressure chamber.

Conclusion

Commercial printing market is now required drastic change to digital. There are many technical challenges to fulfill the requirement by high-speed single-pass inkjet. We want to open new world by the newly developed UV-curable inkjet technology not only reported this report but also improved continuously. Sheet-fed off-set like inkjet printer "KM-1" is "The First Ball" and we continue to challenge ourselves.

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