Newly developed UV-curable inkjet technology for forming high quality image with high productivity

Toshiyuki Takabayashi,[1] Hirotaka Iijima,[1] Akio Maeda,[1] Masashi Ikeda,[1] Tadashi Hirano,[1] and Toshiyuki Mizutani [2]
1 R&D Division, IJ Component Business Unit, Material & Component Business Headquarters, Konica Minolta, Inc.; Hino, Tokyo, JAPAN,
2 Products Development Division 13, Products Development Center, R&D Headquarters Business Technologies, Konica Minolta, Inc.: Hino, Tokyo, JAPAN

Abstract

We have developed a new and unique UV-curable inkjet technology for a sheet-fed inkjet digital press AccurioJet KM-1, which achieves offset like high quality image with high productivity; 3,000 sheets per hour. A number of AccurioJet KM-1 have already run in the production lines of customers, and have gained reputation as "Real Digitalization Pioneer" for commercial printing industry.

The single-pass inkjet printing technology, one of the key technology for the high productivity, is still a big challenge for image processing. To avoid the dots coalescing, we developed a new ink formulation and curing process which can control the ink viscosity precisely in the print head and on the recording media. We also improved the technology which can control the gloss level of the image. Combining them, we succeeded to develop a printing system which achieves offset like high quality image with high productivity.

Introduction

Nowadays printing field has started to transform from analogue to digital printing because it is essential to realize quick delivery, high-mix low-volume production, and personalization.

In drupa 2012 some inkjet digital presses were introduced to adapt such transformation, and we proposed a sheet-fed inkjet digital press AccurioJet KM-1.

One of the big challenges of AccurioJet KM-1 was to develop a new print head "KM1800i" and a new UV-curable ink formulation and a process, which was able to achieve extremely stable jetting performance necessary for single-pass printing and aptitude for wide range of paper without pre-conditioning liquid. [1] [2] [3]

In terms of high quality image, we also developed various image compensation/ correction techniques to reduce the undesirable image defects. [3]

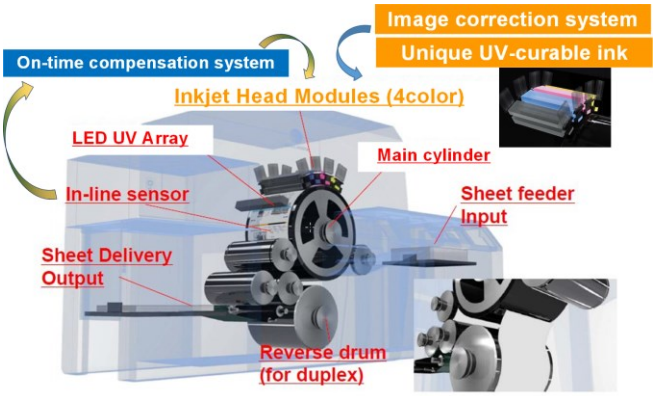

Figure 1. *Structural illustration of AccurioJet KM-1 system*

We aim to provide the real digitalization tool to the commercial printing market.

Fundamental requirements are:

1. Image quality: As excellent as the offset
2. Media range: As wide as the offset
3. Productivity: As high as the offset
4. Simultaneous duplex printing
5. Connectable to existing finishing devices

There are still big challenges for image processing to realize offset like high quality image with high productivity. To resolve these issues, we have developed a new and unique UV-curable ink, "HS (High-quality Single-pass) ink." We will report its development process and features.

Achievement technology

Forming high definition image

1. Selection of the ink type

The inkjet inks can be classified into an oil ink, a water-based ink, and a UV-curable ink depending on the solvent to be used. Each ink has advantages and disadvantages, and we adapt an appropriate ink into the printers according to application.

The oil ink has low volatility and drying at the nozzle of the print head is very little, so it has high jetting reliability and enable the simple head maintenance. Thanks to this feature, the oil ink is preferably used for the single pass printing. But then, it is difficult for the oil ink to print on non-absorbable papers (coated paper and

art paper, etc.) because it has no fixing mechanism on paper. As a result, the oil ink is mainly used for the office printer which prints on uncoated papers.

On the other hand, the water-based ink can form a thin film with the fixing resin after drying and make it possible to fix the pigment on the paper. In addition, some ionic materials can coagulate pigments of the ink and utilizing such materials as a pre-conditioner can avoid dots coalescing. It becomes possible to print high definition image by the water-based ink with a pre-conditioner. The water-based ink and the pre-conditioning liquid, however, effect adversely on some papers, especially uncoated papers, to cause paper-deformation, curling and/or waving. [4] The paper-deformation will not appropriate for the commercial printing market where a wide variety of paper is used.

The UV-curable ink contains polymerizable compounds as solvents and the ink is cured by the irradiation of UV light quickly on the paper. Therefore, simultaneous duplex printing is possible, and furthermore it is possible to perform post-processing steps such as folding and cutting without extra drying time. In the commercial printing market, most of the jobs are post-processed, so it is very important that no extra drying time is required. In addition, the UV-curable ink does not cause paper-deformation and can be printed not only on a wide variety of papers, absorbable or non-absorbable (coated paper, art paper, uncoated paper, etc.), but also on some plastic films. On the other hand, the landed ink droplets can easily start to coalesce together in high-speed single-pass printing, so an additional technology is necessary to avoid the image deterioration.

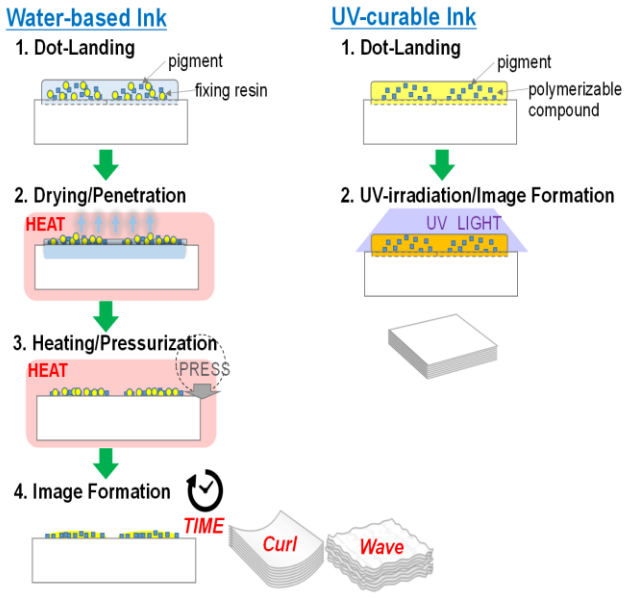

Figure 2. *UV ink dries quickly and minimizes adverse effect on the paper*

Under these circumstances, we chose the UV-curable ink for AccurioJet KM-1 targeting the commercial printing market. For the reason,

- It can be printed on as a wide variety of paper as the offset
- It can do simultaneous duplex printing
- It can perform post-processing steps promptly

2. Necessity of the rapid "pinning" technology

"Pointillism" is a keyword to express the image made by inkjet technology. A print head ejects ink droplets and they form dots on a medium to give an image. To reproduce image precisely, it is necessary to record dots of a desired color and size at a desired place.

The inkjet ink is a low viscosity liquid because of the high frequency driving of the print head (ejecting more ink droplets over a certain period of time from one nozzle). When low viscosity liquid droplets come into contact with each other, the droplets easily coalesce due to the surface tension and then that cause the image deterioration. This image deterioration is so-called beading and bleeding and such deterioration is emphasized with a single-pass printing technology and the image becomes streaky.

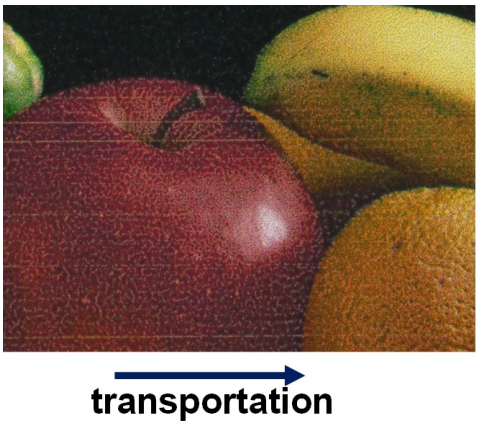

Figure 3. *Streaky image by dots coalescing*

In the multi-pass printing system, it is possible to prevent beading and bleeding by the interleave recording, in which the time interval for recording adjacent ink droplets are made long and dots are fixed by drying.

In the single pass method, however, the time interval until adjacent ink droplets land is very short. For example, in the case of printing at a linear speed of 1000 mm/s with two staggered print heads, which are equipped with 20 mm space, the minimum landing time-interval of two adjacent ink droplets is only 0.02 seconds. In the case of printing at a same linear speed with 4color head arrays on the drum of the printer, the minimum landing time-interval of different color ink droplets is only 0.15 seconds.

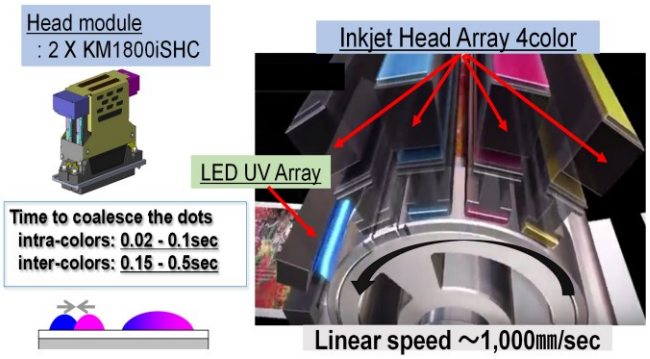

Figure 4. *The landed ink droplets can easily start to coalesce together within milliseconds*

As described above, the rapid "pinning" technology which can avoid dots coalescing and bleeding within milliseconds is necessary for realizing the high definition image printing with high productivity.

Ink technology

1. Rapid "pinning" technology for UV-curable ink

Utilizing the UV-curable ink is well known means to avoid the image deterioration by such coalescing and bleeding. Irradiation of UV light just after landing of the UV-curable ink can "pin" the ink to avoid dots coalescing and bleeding. It gives high definition image by using slow multi-pass printing system. With the high-speed single-pass printing system, however, the curing of conventional radically polymerizable UV-curable ink is easily suffering from inhibition by atmospheric oxygen and polymerization inhibitors in monomers and that hinder the rapid "pinning." The landed ink droplets can easily start to coalesce together within above-mentioned short seconds and it is impossible to avoid the image deterioration accordingly. [2]

We investigated various mechanisms, such as fast chemical reactions, physical changes, etc., to cause the rapid "pinning" by some triggers. Finally we focused our interests on a high speed phase change phenomenon triggered by temperature. We thought an ink that changes its viscosity by temperature, e.g. lower at elevated temperature and higher at room temperature, can avoid the dots coalescing and bleeding. The ink is heated inside the print head to decrease the viscosity for jetting. The temperature of the ink decreases and the viscosity increases as much as an offset printing inks within 0.01 seconds just after the ink droplets land on the paper.

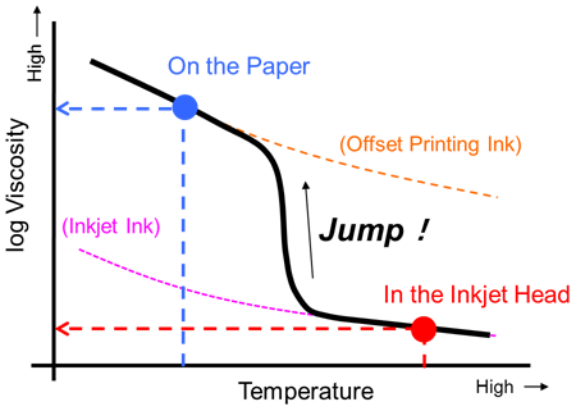

Figure 5. *A phase change (temperature-viscosity) diagram of the newly developed ink*

2. Selection of the organogel type

Then we focused on organogels, which are known to cause such phase change. The organogels are classified into three types, <1> Low molecular type gels, <2> Oligomer type gels, and <3> Wax oil gels (crystalline gel), depend on a gelling mechanism. [5]

For the low molecular type gels, amino acid derivatives having hydrogen bonding groups are used as gellants. These gellants can form a nano-sized fibrous network by intermolecular hydrogen bonding and make the whole ink gelate with a small added amount. However, since the sol-gel transition with these gelling agents is very slow, the effect of the dots "pinning" in the inkjet printing is limited.

For the oligomer type gels, polyacrylic acid, fatty acid, and sugar derivatives are widely used as gellants. These gellants have a large molecular weight and the viscosity of the sol state becomes high, so it is difficult to use them as gelling agents of inkjet inks.

For the wax oil gels, crystalline compounds such as amide-wax, aliphatic alcohol, aliphatic acid ester, aliphatic ketone, etc. are used. These gellants crystallize out as plate crystals at a low temperature and these crystals are self-organized three-dimensionally to form a card house structure. The card house structure "absolve" the ink inside the "gap" of its structure, and it is possible to make the whole ink gellate with a small amount of gellants. In addition, the sol-gel transition with these gellants is very fast and these gellants are suitable for the dots "pinning" in the inkjet printing.

The following table summarizes the above descriptions.

Table 1 Comparison of Organogels

Organogels	Pinning	Jetting
Low molecular type gels	Poor	Good
Oligomer type gels	Good	Poor
Wax oil gels	Excellent	Excellent

Fig. 6 shows the difference in dot diameter of inks depending on whether the wax oil gels are added or not. It was confirmed that the gelation with the wax oil gels pinned the dots rapidly after the ink has landed on the paper and the expansion of dots was suppressed.

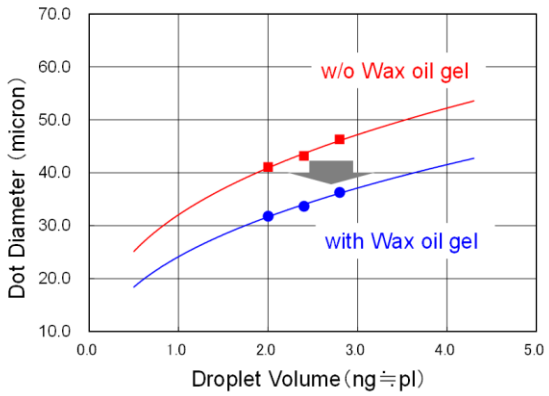

Figure 6. *Dot diameter on coated paper*

3. Ink formulation

We then developed a new ink formulation with wax oil gels; it can make the viscosity high at room temperature rapidly. The rapid viscosity change "pins" the dots and it avoids the dots coalescing and the bleeding accordingly.

Wax oil gels can make the whole ink phase transition by adding only a few weight percent of the whole ink, and so it is possible to select various compositions (photoinitiators and monomers, etc.),

freely for the curing speed and the physical properties of the cured ink.

Figure 7 shows the cross-sectional STEM image of the cured ink. From this image, it can be seen that a small amount of wax crystal is distributed uniformly throughout the cured ink.

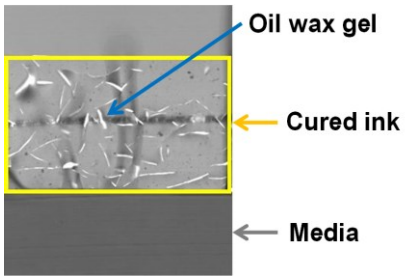

Figure 7. *Cross-sectional STEM image of the cured ink*

After researching a wide variety of wax oil gel and designing ink formulation, we finally found how to control the phase transition temperature and the viscosity at the gel state individually by controlling the crystallization behavior. We have succeeded to control the crystallization behavior by using two or more kinds of wax oil gels in combination. As a result, it became possible to adjust the gloss value of the image with the hafltone process, and we achieved real high quality image like offset.

Furthermore, by irradiating UV light on the high-viscosity gel state ink, it becomes possible to reduce the influence of oxygen inhibition in radical polymerization and cure the ink completely with low dose. Figure 8 This is a great merit in designing a UV curable printing system.

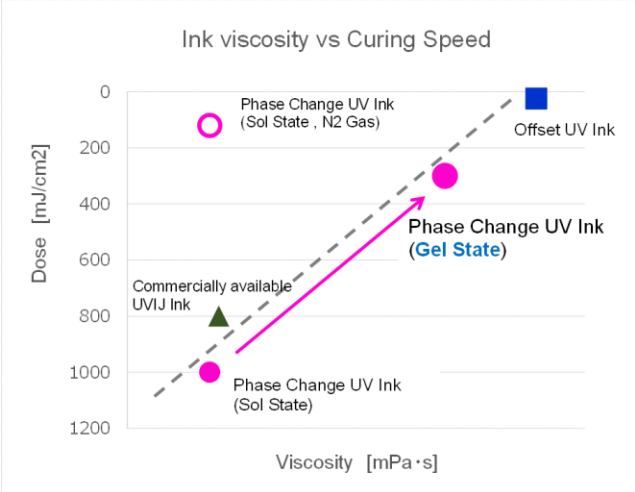

Figure 8. *Reduce of oxygen-Inhibition*

AccurioJet KM-1

We will introduce "AccurioJet KM-1" as an example of product equipped with “HS ink” technology of this report.

Figure 9. *Front view of “AccurioJet KM-1”*

With “HS ink” technology we can print high definition image at a high speed 3,000 sheets/hour on a wide variety of paper, absorbable or non-absorbable. And owing to utilizing the UV-curable ink, the simultaneous duplex printing is possible via the inverting drum. AccurioJet KM-1 is the real Digitalization tool to the Commercial Printing Market.

Conclusion

We have succeeded to develop a new and a unique UV-curable inkjet technology. “HS ink” technology enable dots to be fixed rapidly on the media, which avoid coalescing the dots and realize high quality image with high productivity. These features proved the newly developed technology are appropriate to commercial and packaging printing markets. We started to offer the technology to those markets by adopting it to AccurioJet KM-1 and will improve the technology continuously.

References

[1] Development of the 23”x29.5” Sheet-fed Inkjet Press KM-1, Mitsuru Obata, Toyoaki Sugaya, Toshiyuki Mizutani, Hideo Watanabe, Toshiyuki Takabayashi, and Hirotaka Iijima, Proceedings of NIP 30 and Digital Fabrication 2014 (2014), pp. 372 - 374.

[2] Newly developed UV-curable inkjet technology for Digital Inkjet Press “KM-1”, Toshiyuki Takabayashi, Hirotaka Iijima, Katsunori Goi, Mitsuru Obata, Toshiyuki Mizutani, and Hideo Watanabe, Proceedings of NIP 31 and Digital Fabrication 2015(2015), pp. 251 - 255.

[3] Development of Image quality and reliability enhancing technology for 29 x 23 size digital inkjet press “KM-1”, Toshiyuki Mizutani, Kenichiro Hiramoto, Mitsuru Obata, Toshiyuki Takabayashi, and Toyoaki Sugaya, Proceedings of NIP 32 and Digital Fabrication 2016(2016), pp. 237 - 240.

[4] A New Water-based Inkjet Ink for Plain Paper Printing, Hirotaka Iijima, Atsushi Tomotake, and Yasuhiko Kawashima, Proceedings of NIP 22 International Conference on Digital Printing Technologies (2006), pp.201-203.

[5] Masashi Shibata, J. Jpn. Soc. Colour Mater., 85〔8〕, 339–342 (2012)

Author Biography

Toshiyuki Takabayashi received his Bs. degree in 1993 from Kyoto University. He joined Konica Corporation in 1993. He belongs to the R&D Division, IJ Component Business Unit, and engaged in the development of inkjet inks.