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Liquid Ink Development System for Production Printing Using Volatile Carrier Oil and Fine Toners

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Abstract

A liquid ink development system for production printing was developed using liquid developer consisting of volatile carrier oil with a high boiling point and fine toner particles. To obtain applicability to a wide variety of production print applications, such as commercial printing, labels, cartons and soft packaging, the system was aimed to achieve high image quality, high productivity, wide media versatility, low running costs, and high post-process capability. For the purpose, in addition to newly designed developer and additives, an image formation process using a contact development process and tandem type electrostatic multi transfer process, back heat-type oil drying process, roller fixing process, and developer circulation and dispersion process were developed. High image quality comparable to analog prints, printability onto a wide variety of media and high post-process capabilities were achieved.

Introduction

In recent years, development of digital printing technologies has been revitalized for production printing applications such as commercial printing, label, carton and soft package. [1,2] In these markets, high image quality, high productivity, wide media versatility (handle wide variety of media), low running costs, environmental safety and post-process capability are required. Ink Jet (IJ), Dry Powder Xerography (DX) and Liquid Ink Development (LID) technologies are used to satisfy these requirements. [3-7]

In the LID process, an external charger gives a charge to toner particles dispersed in dielectric liquid and the toner forms images by an electrophotographic contact-type development and transfer process. The LID process with the contacting process, fine toners and oil lubrication has the capability of satisfying various requirements of production printing application mentioned above. Also the LID process has advantages in terms of image quality for plain paper and wide media versatility, including film media, as compared to the IJ process. In addition, LID is supposed to have higher productivity and lower running costs as compared to DX.

The carrier oil used in the LID process is characterized by its volatility. Carrier oil with low volatility remains on print media after image formation, and degrades post-process quality such as lamination and varnish applications.

In this study, a tandem-type LID system that can be applied to a variety of applications was developed by adopting a liquid developer using carrier oil with high volatility in which fine toner particles is dispersed. In Table 1, the requirements for various applications and adopted technologies are listed. The adoption of the tandem-type electrostatic transfer technology is advantageous from the viewpoint of productivity; on the other hand, media versatility is an issue. In addition, although there is a drying process to remove the oil to obtain post-process capability, a high-speed oil drying process is required to achieve high productivity. Technology to handle the high-volatility developer is also necessary.

Table 1 Market requirements and adopted technologies.

Requirement / Application	Com-mercial printing	Label	Carton	Soft package
Image quality	◎	○	○	○
Productivity	◎	○	◎	◎
Run cost	◎	○	○	◎
Medium diversity	○	◎	◎	◎
Post process capability	–	◎	○	◎
Cut sheet/ Duplex capability	◎	–	–	–

Adopted technologies: Volatile oil/ fine toner; Tandem layout; Contact development; Electrostatic transfer; Roller drying; Roller fixing

◎ Highly important, ○ Important, – Less important
— Improving relation - - - Degrading relation

LID System

System Configuration

The developed LID system configuration is as described in Figure 1. In the LID system, four color engines are arranged and each engine has electrophotographic charging, exposure, development and transfer processes. The configuration and image formation process of each engine is described in Figure 2.

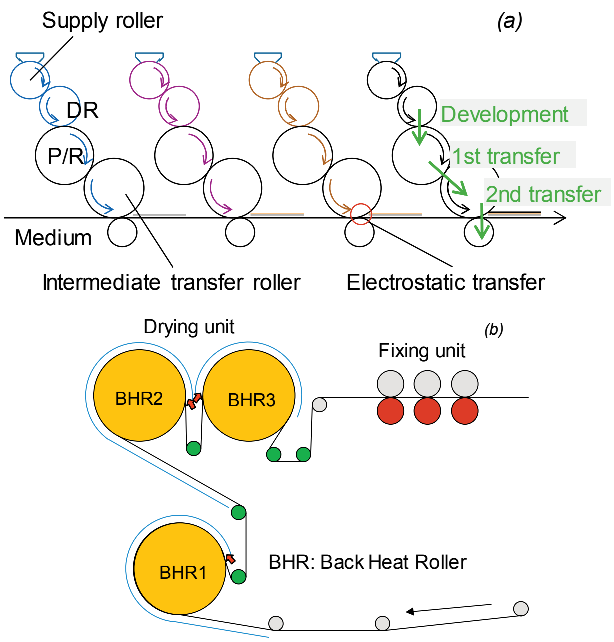

***Figure 1.** Developed LID system configuration. (a) Development and transfer process. (b) Drying and fixing process.*

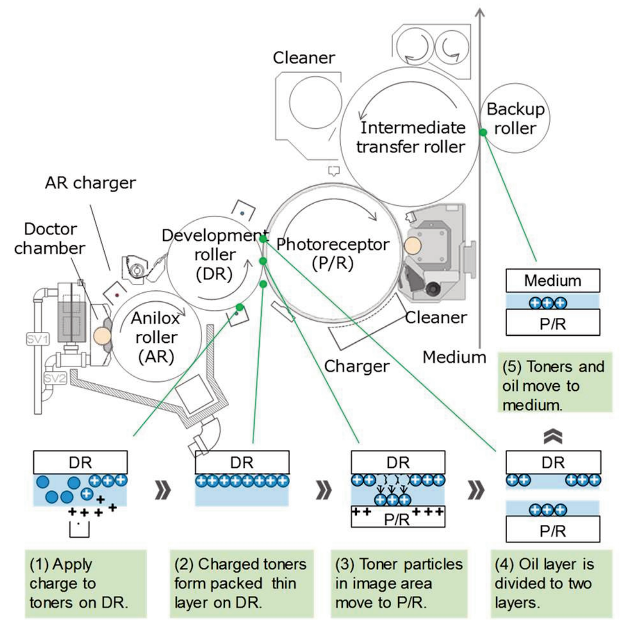

Figure 2. *Image formation process and configuration.*

As shown in Figure 1 (b), after the final transfer process, a drying process for removing the oil on media and a toner fixing process are arranged. In addition, a developer circulation process is needed to collect the excess developer transported to each part of the image formation area, and to adjust the solid concentration and supply it again to the development process.

The features of key technologies developed in this study are as follows.

1. Developer: Fine toner and additive technology to achieve high dispersibility, strong fixing property, high film adhesiveness and long term storability
2. Development: Optimization of a contact-type development process to achieve high image quality and volatile developer management
3. Transfer: Tandem-type multi-transfer process to a wide variety of printing media
4. Drying: High-speed removal technology of penetrated carrier oil from various types of media
5. Fixing: Roller fixing parameters to realize fixing quality and post-process capability
6. Circulation: Efficient circulation, recycle, redispersion and solid concentration control mechanism for stable developer properties.

Image Formation Process

The outline of the image formation process is described below with reference to Figure 2.

Liquid developer in the doctor chamber is adhered on the supply roller to form a thin liquid layer. For the supply roller, an anilox roller (AR) used for flexographic printing was adopted.

In the subsequent layer forming process, a corona charge is applied to the toner transferred from the AR to the development roller (DR) (Figure 2 (1)), and the toner is then attached and packed to the DR surface uniformly like a film by electrostatic force, making it possible to form a high-definition and uniform image (Figure 2 (2)).

In the development process, DR and the surface of the photoreceptor are brought into contact and DC development bias is applied to transfer the packed toner to the image region on the photoreceptor (Figure 2 (3)). Since the image formation is instantaneously completed, productivity is high. On the other hand, the unevenness of the thin layer of the developer directly affects the image structure, and thus, the abovementioned layer formation process is important. In the post-development nip region, the oil layer is separated onto both roller surfaces, preventing disturbance and high background density of the developed image (Figure 2 (4)). Reduction in development efficiency and high background image may occur due to a change in the charge amount of the toner layer and excessive aggregation of the toner. In addition, in the post-nip region, surface waviness (ribbing) of the carrier oil occurs as shown in Figure 3, causing streaky image unevenness, which is an issue peculiar to LID system.

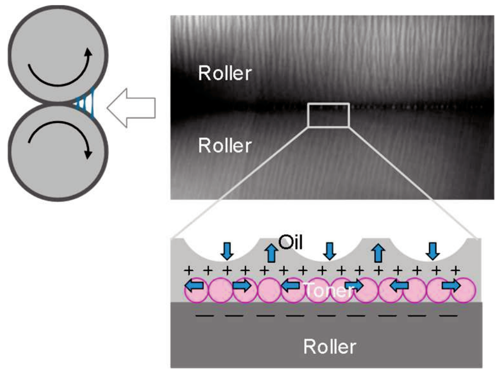

Figure 3. *Ribbing phenomenon in post nip area.*

In the transfer process, an intermediate roller is used, and in the primary transfer, the developed image on the photoreceptor is transferred to the intermediate roller by the action of an electrostatic field (Figure 2 (5)). Then, the image is transferred from the intermediate roller to the medium one in the secondary transfer process. The transferred image is affected by the electric properties and mechanical behavior of the media.

Key Technologies

Developer and Additive

As mentioned above, volatile carrier oil and fine toner smaller than ordinary dry toner were adopted. Resin and additives were newly developed. [8]

The structure of the developer is shown in Figure 4. For the toner base material, we developed a resin that considers affinity with volatile oil and adhesiveness to the film substrate. In order to suppress the influence of ribbing unique to the LID system, additives were used to increase the bonding strength of the toner.

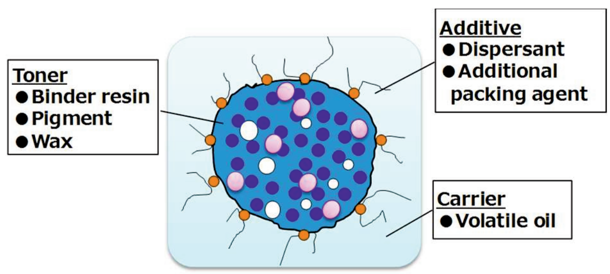

Figure 4. *Liquid developer configuration.*

Development Process

To supply the developer to the DR, the abovementioned AR is used. The AR is a hard roller with fine depressions (cells) on the surface; a desired amount of the liquid developer is retained on the rotating roller surface by the action of the doctor blade. There are various cell patterns on the AR surface as shown in Figure 5. The helical structure was adopted to avoid the effect of the ribbing. To suppress drying of the developer, a hermetically-sealed doctor chamber system was adopted for a storage tank to supply developer to the AR (see Figure 2). [9]

In the process of transferring the uniform developer layer from the AR to DR, it is necessary to control the amount of supplied toner according to the type of media. For this purpose, the amount of toner is controlled by varying the charge amount of the toners provided by the AR charger disposed opposite to the AR. The relation between toner charge amount and toner amount supplied to the DR is shown in Figure 6.

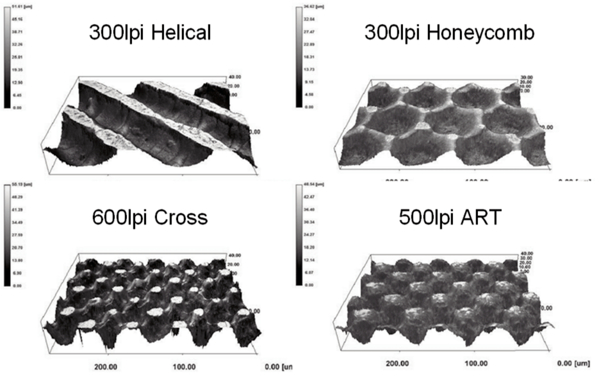

***Figure 5.** Cell pattern of AR surface.*

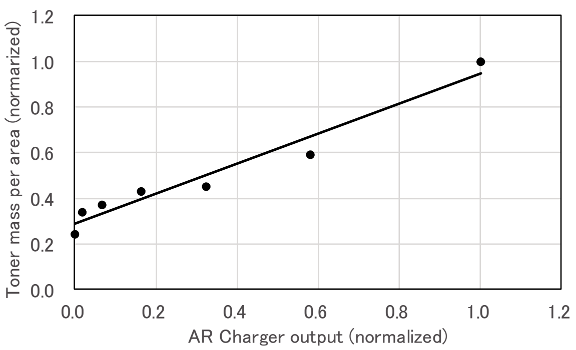

***Figure 6.** Toner mass per area on DR depending on toner charge applied by AR charger.*

DR charger output	Low	Mid	High	Mid	Mid	Mid
Development bias	Mid Low	Mid Low	Mid Low	Low	Mid High	High
Solid area						
Tail edge						
Ribbing defect	×	△	△	△	○	○
Development efficiency	○	△	×	×	○	○
Background density	△	○	○	○	○	×

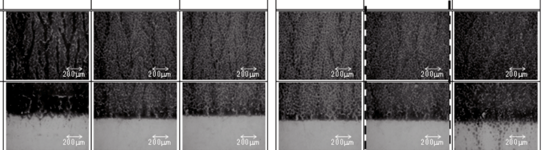

***Figure 7.** Effect of development parameter on ribbing defect, developing rate, and background density.*

For development parameters, which is most important factor to obtain high image quality, optimization was carried out focusing on ribbing defects, development efficiency, and background density. If the toner charge amount provided by the charger is low, deterioration of ribbing defects (streak, tailing) and high background density occurs due to deterioration of toner packing strength. On the other hand, if the amount of toner charge is high, image quality is improved due to improved toner packing strength, however development efficiency is lowered. Figure 7 shows the effect of charger output and development bias on ribbing defects, development efficiency, and background density. In the figure, the optimum parameter set is indicated. With this parameter design, ribbing defects was suppressed while maintaining high development efficiency and low background density.

Transfer Process

The structure of the transfer process is shown in Figures 1 and 2. Ensuring multiple transferability to various media based on a tandem-type electrostatic transfer process is an issue. Specifically, improvement of transfer efficiency onto thick media, such as cardboard or synthesized paper, with a small electrostatic capacity is important. One of the obstacles is that the toner charge amount before transfer is high (10 times or more of DX) because high charging and high bias is required in the development process for suppressing the effects of ribbing. [10]

In order to improve transfer efficiency, electric field analysis of the transfer area was carried out to investigate factors and measures, and the following policies were introduced:

1. Optimize media path to suppress discharge in pre-nip region, prevent reverse polarity of toner, and ensure high electric field.
2. Control the toner charge amount by primary transfer bias, and control excessive increases in secondary transfer bias.

As a result, a sufficient transfer efficiency could be demonstrated, even for a medium with a small electrostatic capacity, such as a synthetic label medium. Figure 8 shows the relationship between transfer efficiency and secondary transfer bias. Transfer efficiency of more than 90% could be demonstrated even with synthesized label paper with small electrostatic capacity.

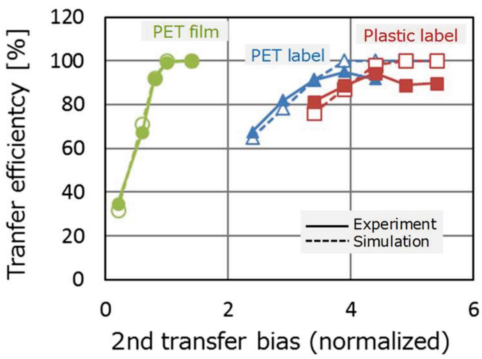

***Figure 8.** Relation between transfer efficiency and secondary transfer bias.*

Drying Process

To obtain post-process capability, a drying process is essential for removing oil that has penetrated into the medium after image formation on the medium. After toners and oil are transferred and applied on media, oil is absorbed in the toner layer, media coat layer and media substrate layer, and volatilizes from each layer at a certain rate. The abundance ratio of oil in these layers is determined by the elapsed time after oil coating and the capillary suction force of each layer. The volatilization rate is determined by the saturated vapor pressure, the ventilation resistance of each layer and the depth of penetration from the surface. Furthermore, since the molten toner deforms to cover the surface and change the ventilation resistance, the drying efficiency also depends on the amount of toners on the surface, heating temperature and time. [11]

Based on the above mechanism, the effects of factors were investigated, and it was found that the drying ability strongly depends on the media temperature. In order to raise the temperature of the media rapidly, we adopted the back heat roller heating method with hot airflow for continuous media. Figure 9 shows the relationship between the media temperature and the residual oil amount. It was found that to achieve the target residual oil amount, the media temperature should be one hundred and several ten degree Celsius or higher.

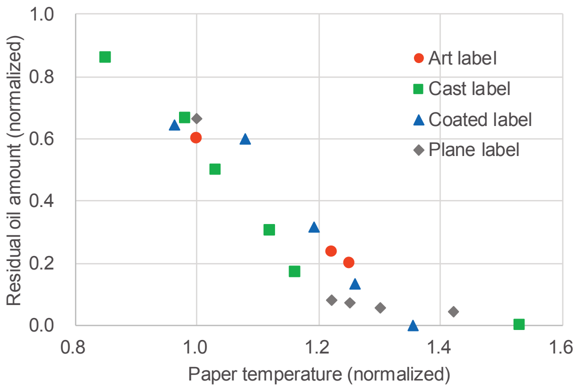

Figure 9. *Relation between residual oil amount and media temperature.*

Table 2 Fixing performance evaluation results.

Medium type	Gloss	Fixing strength/ crease score	Friction resistance score
Pure label	○ 15	○ G40	○ 3.9
Art label	○ 31	○ G50	○ 4.9
Cast label	○ 40	○ G20	○ 4.7
PET film	○ 48	○ G60	○ 5.3
Synthesized label	○ 24	○ G10	○ 4.3

Medium type	Lamination strength score	varnish application score
PET film	○ 2.5	○ No peeling

Fixing Process

For the fixing process, in addition to the basic function of gloss and fixing strength, it is necessary to obtain the laminate and varnish suitability required for labels and carton applications. To satisfy these requirements, toner binder, additives and two roller fixing parameters were optimized. As shown in Table 2, the required fixing performance was achieved; with respect to the post-process capability such as the laminate adhesive strength and the varnish coating property, satisfactory results were obtained. [7]

Circulation Process

In the image forming process, the developer is sequentially transferred between the rollers while changing the carrier oil amount and the toner amount. A developer circulation process was developed in which surplus developer transferred onto each roller was collected and mixed, and then the toner dispersibility and solid content concentration (SC) were reconditioned to appropriate values for reuse. [7]

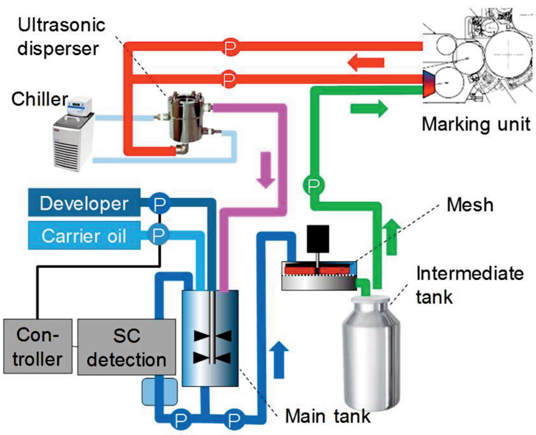

Figure 10. *Developer circulation process configuration.*

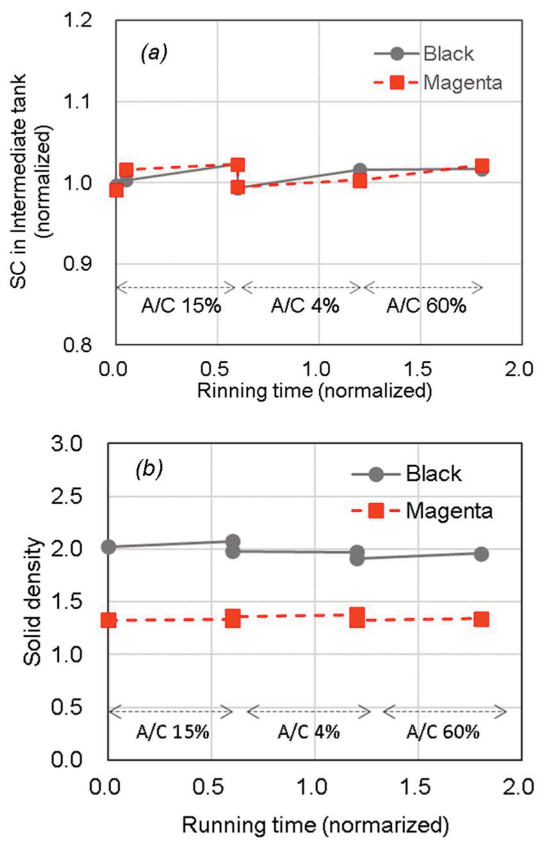

Figure 11. *(a) Relation between SC and running time. (b) Relation between solid density and running time.*

Figure 10 shows the configuration of the developer circulation process that was developed. The developer collected from each part of the image formation process is redispersed by ultrasonic agitation while cooling. Thereafter, in the main tank, it is mixed with new, condensed developer and carrier oil at a predetermined ratio. In this step, the condensed developer and carrier oil amount are controlled while detecting the SC in the collected developer. Developer with dispersibility and adjusted SC is supplied to the developer reservoir of the developing layer forming process via the intermediate tank.

Figure 11 shows the variation of SC in the intermediate tank when the image coverage is switched in the range from 4 to 60%. The fluctuation range can be controlled within the range of several% of target SC.

Performance Verification Results

Based on the abovementioned LID system, desired image quality, productivity, media versatility and post-process capability were obtained. Regarding image quality, the image disturbance (streak, density unevenness, trailing) due to the effects of ribbing were improved, as shown in the enlarged photograph shown in Figure 12. The low-frequency noise was also improved, as shown in Figure 13, reaching a level equivalent to analog printing. As a result, excellent reproducibility of small characters and highlight halftone images could be verified as shown in the enlarged photograph in Figure 14. Adoption of fine toner and suppression of the effects of ribbing were considered to have contributed. In addition, the image quality evaluation results are shown in Figure 15, together with the results of commercial printing presses. The vertical axis of the figure is the image quality score uniquely regulated. Image quality comparable to that of analog printing was achieved.

For the stability of image quality, short term period verification was carried out. As with the results in Figure 11, Figure 16 shows changes in image quality characteristics when image coverage is switched in the range from 4 to 60%.

Conclusions

A tandem-type LID system with volatile carrier oil and fine toner was developed, to which it can be applied commonly to a variety of printing applications. In addition to the development of developers and additives, development of a thin contact layer development process, tandem electrostatic multi-transfer process, back heat drying process, roller fixing process, and developer circulation process were also developed.

Satisfactory image quality, productivity, media versatility, and post-process capability were obtained. Image quality equivalent to that of conventional printing could be achieved by improvement of the resolution and graininess with fine toner and by preventing the influence of ribbing effect.

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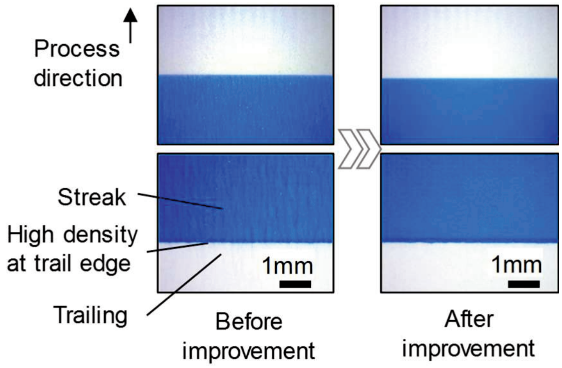

Figure 12. *Improvement of image defects caused by ribbing effect.*

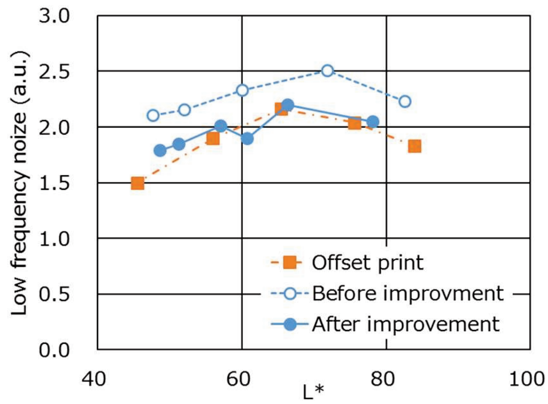

Figure 13. *Improvement of low frequency noise.*

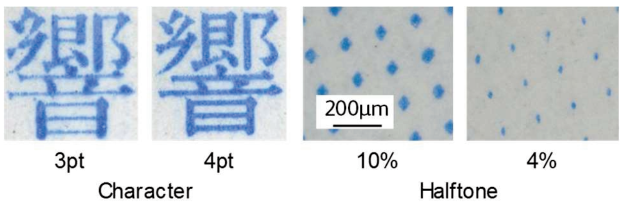

Figure 14. *Image obtained in present study.*

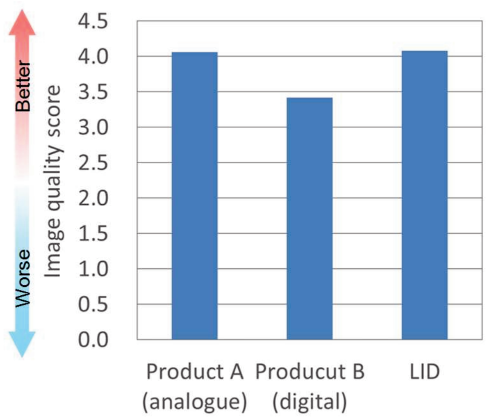

Figure 15. *Image quality evaluation results.*

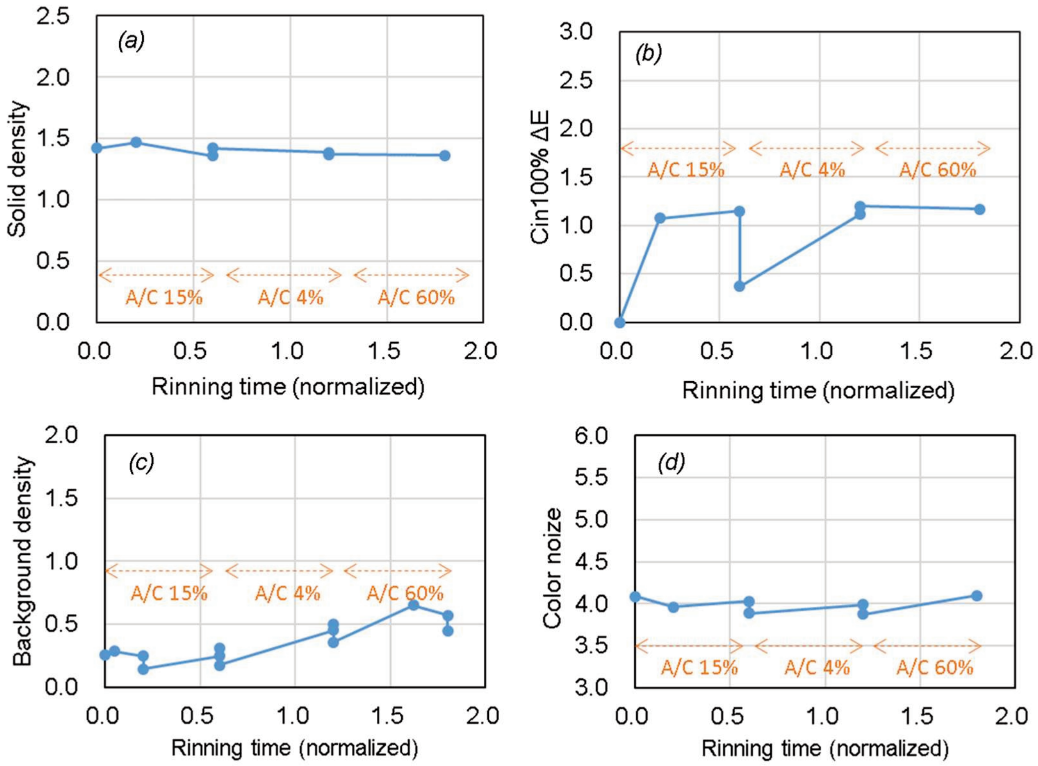

Figure 16. *Image quality evaluation results. (a) Solid density. (b) Color deference (ΔE) of input coverage 100% image. (c) Background density. (d) Color noise score.*

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Author Biography

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