Present Status of Liquid Toner Development Technology and the Problems to be Solved

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Abstract

The present technical status of liquid toner development and a view of possible improvements are discussed. Liquid toner development is an ideal process for getting a precise image in high quality continuous tone printing. This process has also several weak points that currently prevent its universal use. In this paper, the variations in system configuration and materials are reviewed. The merits and demerits of liquid toner development are summarized, and then an overview about how to eliminate these barriers and emphasize its merits is shown. The discussion includes optical density, development speed, stability, handling, and the potential problem of pollution. In the discussion on optical density, it is indicated that the roughness of developed toner image surface should be improved because the scattering of light from this rough surface is considered to be one of the key reasons for its low optical density. The point is made that new materials should be tried as solvents and new structures of development station should be proposed to strongly advance liquid toner development.

1. Introduction

The historical trends of the liquid toner development are shown in table 1. The liquid development system has had a long history since it was invented in Australia by Metcalfe[1)] in 1955[2)]. It was once very popular for various applications including copying machines for office use[3)]. Its popularity started decreasing with the more rapid improvement in powder type development toner. However, this trend has started to reverse with the creation of new liquid toners and advanced liquid toner development systems.

The biggest advantage of the liquid toner development system is the small size of the individual toner particles. While the particle size of dry toner is being continually reduced, it will never match the particle size of liquid toner, which can be of sub-micron order. The viable application area for liquid toner development now appears to be extremely high quality imaging.

This paper first reviews the variations in liquid toner development in terms of both system configuration and toner material. It then focus on the merits and demerits of liquid toner development, and reviews current progress in liquid toner development. A perspective of future progress is introduced toward the end of the paper.

Table 1. Historical Trends of the Liquid Toner Development

Events and Trends	Period
Invention by Metcalfe.	1955
Popular, especially for copying.	1970--1980
Drop off with the advancement of dry toner.	1980--1990
Revival for high quality development system.	1995--

2. Variation in Toners and Development Systems

2.1 Development Systems

There is a wide variation in development systems and toner materials. Table 2 shows typical liquid toner development system configurations. The merits and demerits of each system are summarized in Table 1. The development system in table 2-(1), a pan with a development electrode, is the most primitive and simple approach. The surface of a photoconductor drum can be used to hold the latent image with the same kind of liquid pan system. The merit of this system is its simplicity and potential for high image quality. The development zone shows very small liquid disturbance; the ideal condition for precise image development. The demerits of the system include relative slow development speed, requirement for a solvent removal system, and evaporation of the solvent.

Table 2-(2) shows the vacuum slit development system. Rapid streams of toner liquid are circulated by toner pumps in the sealed areas formed by metal gutters and the paperÕs surface. The paper surface is almost dry just after exiting the development zone; this is the most remarkable merit of this type of system. This is achieved by establishing a low-pressure region at the final slit. This system has another merit of compactness; the width of the development station can be reduced to a few centimeters. The sensitivity of development performance to paper surface roughness is a demerit of this system. The other demerit is the increase in drag force caused by the paper sticking to the slits.

Table 2. Variation in Liquid Toner Development System

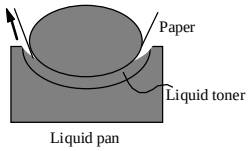
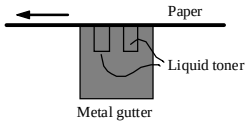
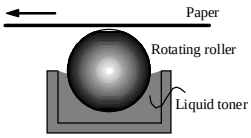
Development method	SYTEM CONFIGURATION	Merit	Demerit
(1)Liquid Pan		Simple apparatus Least distubance to image	Evaporation of liquid Wet output
(2)Vacuum Slit		Dry output Compact station	Sensitivity to paper surface roughness High drag force
(3)Rotating Roller		High speed	Mechanical configuration Necessity for drying method

Table 3. Variations in Production Methods for Liquid Toner

Production method	Essential Part of Production	Merit	Demerit
(A) Milling	(A1)Dispersion of pigment, soluble resin, and other additives in carrier liquid[4)]	Broad range of materials	Broad distribution of toner diameter Easy precipitation
	(A2)Milling of mixed bulk of toner contents		Long processing time for milling.
(B)Particle Synthesis	(B1)Particle nucleation and growth by polymerization of monomers[6)]	Sharp distribution of toner diameter.	Fewer materials
	(B2)Forming toner particles by cooling polymer solution[7)]	Better homogeneity	

Table 2-(3) shows the configuration of the roller development system. This system has the advantage of high development speed due to the high efficiency with which fresh toner is supplied to the development area. One demerit is that it requires a solvent removal system. Moreover, the system configuration is rather mechanically complicated.

2.2 Toner Production Methods and Materials

There are large variations in toner materials and production methods as is listed in table 3. There are two production method types. One is the conventional process in which toner particles are formed by mechanical milling. The other forms toner particles from a solution.

Conventional milling can handle a wide range of toner materials. However, the distribution of toner particle diameter tends to be broad, and the time required for milling is generally long. Forming particles from a solution can achieve uniform toner particle size, which offers more precise development and higher toner stability. However, the range in toner material is rather small, especially in terms of the colorants. Figure 1 shows a SEM image[5)] of the toner particles made with the particle synthesis method. (B1 type) The spherical shape of the particles is remarkable in this figure.

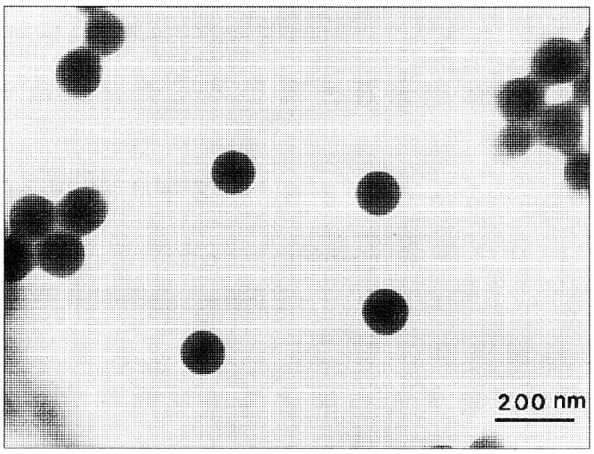


Figure 2. SEM Image of the toner particles made with particle synthesis method.[5)]

3. Comparison Between Wet and Dry Process

Table 4 shows a comparison of wet and dry systems. The most remarkable merit of the liquid toner development system is its high resolution and precise reproduction of continuous-tones made possible by the small size of the toner particles. Insufficient optical density is sometimes a problem depending on the toner material. Process speed is also sometimes a problem depending on the development system configuration. Other problems are toner stability, liquid handling, and environmental problem including the smell of the solvent. The current dominance of dry toner is due in part to its solution of these problems. Accordingly, these problems must be overcome if the liquid system is to become popular.

Table 4. Comparison of Wet and Dry Processes

Item	dry	wet
Resolution	Δ	◎
Continuous Tone	Δ	◎
Optical Density	❍	Δ ~❍
Process Speed	❍	Δ ~❍
Stability	❍	Δ ~◎
Handling	❍	Δ
Smell	❍	Δ
Environmental Problem	❍?	Δ?

4. Current Trend and Topics

The technology and marketing of the E-print system[8] are most remarkable. The liquid toner development system and material used in the E-print system were very skillfully designed. The large toner particles used in this system, still smaller than those of dry toner, enables constant toner particle dispersion with toner liquid stirring. It also enables rapid development owing to the large mobility of toner particles. The toner particles have a special tentacular shape and this enables easy and high efficiency toner image transfer owing to the filming effect of the toner layer. A lot of systems have been sold for short-run printing.

Recycling of toner materials is a current trend in this field. A carrier liquid recycle system consisting of a cooler and a filter to separate solvent from water has been tested in a prototype machine[9]. A system to recycle residual toner has already achieved in the commercial E-print system; residual toner particles are skillfully separated from the solvent.

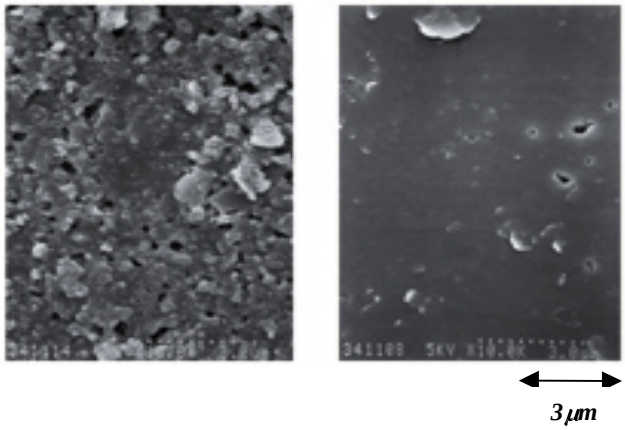
A new liquid toner development concept was suggested recently[10]. Called Impression development, it doesn't use the electrophoretic phenomenon for development.

Studies on non-hydrocarbon liquid toners have been carried out. The candidates include water, silicon oil, and ester. This direction of study is very important in securing the future of liquid toner development.

5. Perspectives on Future Progress

Liquid toner development is currently experiencing a revival. It has already secured an important position in short run printing applications. The E-print system is a typical product. However, liquid toner development has many problems that must be solved to increase its popularity. The challenges are listed in table 5.

The latest toner particle synthesis schemes are promising for achieving more homogeneous and stable toners. Increasing the range of colorants available is an important goal.



(a)Without finishing *(b) With rubbing*

Figure 2. SEM view of developed toner surface.

Table 5. Items to be Solved for Progress of Liquid Development

ITEM	CURRENT STATUS	BREAK THROUGH NEEDED
Smell of solvent	Still true	New solvent without smell
Print density	Sometimes lower than dry process	Finishing of developed surface
System configuration	Roller or slit	New configuration
Image quality management	Control parameters or measurement method are not adequately fixed	Fixed control parameters and measurement method
Manufacturing process	Synthesized toner starting to be used in printer applications	Synthesis method with wider range of materials

The optical density of liquid toner development is sometimes too low to reproduce photographic images. Figure 2 shows the SEM results of images developed by liquid toner. It is seen that without fixing [fig.2(a)] the surface is very rough and granular. The scattering of light from this rough surface is considered to be one of the important reasons for the low optical density. Figure 2(b) shows the SEM results of an image developed after simply rubbing the surface. The surface is dramatically smoother after rubbing and the optical density is much higher. These results confirm the impact of surface finishing on optical density. Appropriate finishing methods must be created to realize higher optical density.

The development system configuration is an important research topic. There are too few variations; new configurations that offer better performance and simplicity should be created to realize the maximum potential of the liquid toner development system.

One challenge is to establish a liquid toner not based on hydrocarbon solvents. Liquid toner development will be accepted in the office again if non-hydrocarbon liquids can be made suitable. Studies on non-hydrocarbon liquid development should be accelerated.

The problem of the toner liquid handling is considered to be a relatively easy problem to solve. Users will be unaware of the development system approach if easy operation is possible using sealed toner bottles and maintenance free development systems. Liquid toner development has the essential benefit that the toner particles are not released into the air.

The negative impression of liquid toner development was created by the primitive development systems initially available. People disliked the solvent smell, wet paper output, and the dirty toner bottle. The liquid toner development system has already overcome some of these disadvantages. Non-hydrocarbon liquid development will yield a drastic break-through in terms of widening the application range.

6. Summary

The present status of liquid toner development and perspectives on its future were discussed in this paper. This paper is summarized as follows.

1) Characteristics of various development systems and toner manufacturing method were reviewed.
2) Current topics were introduced; development system for short-run printing, toner recycling, research on new solvents, and the effect of surface finishing on optical density.
3) Perspectives on future progress were introduced, and the problems to be solved were indicated.

A revival in liquid toner development is seen in short-run printing applications. The future of liquid toner development is promising considering its potential for high-resolution image development.

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Biography

Makoto Omodani received his B.S. and M.S. in Mechanical Engineering from Tohoku University in 1978 and 1980, respectively, and his Ph.D. from Tokyo University in 1987. He joined NTT in 1980 working on printing technologies at Yokosuka Electrical Communication Laboratories. He has moved to Tokai University in 1997. He has now engaged in digital imaging technologies including digital paper technologies.

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