Ink-Water Emulsified State in Offset Printing

Toru Iwaki*, Kazuhiko Sato*, and Toyoo Nimoda*

Abstract: In offset printing, print quality depends on balance of the feeding amount of ink and fountain solution. It is well-known that ink/fountain solution on printing press co-exist in the form of W/O emulsion. In this report, the surface of ink films and water-droplet formation on them have been investigated by the observation through emulsion visualization apparatus developed in our research center. It was made clear that the surface of any ink film on a roller is not flat during rolling and that surface water-droplets appear on the emulsified ink film at a certain water content, which greatly effects the properties of emulsified ink.

The IPA-substituted reagent has been selected by examining the emulsifying characteristics on the ink tester and printing machine among several kinds of surfactant solutions in orderto come to close to the aqueous IPA solution as a standard solution, which exhibits the metastable emulsified state. Further, the role of fountain solution in image production on plates by emulsified ink film has been discussed.

1. Introduction

Offset printing is a printing system utilizing repellence of ink and water. Ink is mixed with dampening water on a group of ink rollers to be emulsified ink and is transferred from one roller to another until printed on a paper. Offset printing has a variety of print quality problems (ghost, greasing, poor inking, insufficient gradation reproducibility) resulting from emulsification.

When an emulsified ink film is transferred between rollers under high speed revolutions (roller speeds = 2 ~ 10 m/s), various changes such as adhesion or filamentation of ink films, ink/water emulsification, leveling and water vapor evaporation due to the nature of roller surface and physical properties of ink because of intermittent extended shearing (rate of shear $\fallingdotseq 10^{3\,1}$/s) at the nip of rollers.

* Mitsubishi Heavy Industries, Ltd.

To a chieve a high print quality in printing process what should we control from the view point of ink and water.

(1) In inking unit, emulsified ink must transfer from ink pan to plate through rollers, showing stable and uniform flow.

(2) On the plate emulsified ink must adhene to the image area uniformly and exactly according to the plate image. Further, the image-formed ink on the plate must be transtered to blanket and on the paper uniformly and stably.

(3) Emulsified ink on the paper must be subject to leveling and drying by the structural relaxation. These subject are considerd to be remarkably associated with the emulsion state of the ink and its rheological properties.

To prove such phenomena, we had previously developed the ink film thickness and water content meter (1) which can be use don a machine for continuous measurements. A newly developed emulsion visualization apparatus (2) has proved uneven film shape, existence of surface water-droplets and inner water.

In this study, we have also made an emulsion evaluation tester on an experimental basis for mixing ink/water on a plate surface. Emulsifying characteristics such as the rate of emulsification, equilibrium water content, and the distribution of W/O emulsion droplets as well as ink/water replacing velocity onthe plate have been investigated and the IPA characteristics as a fountain solution have been verified incomparison with demineralized water and additive solution. Also made clear was the role of a fountain solution in offset printing.(3,4) Based on these results, it has become possible to lead to development of substitute additives by establishing the selection criteria for IPA-substitute reagents and narrowing down its type.

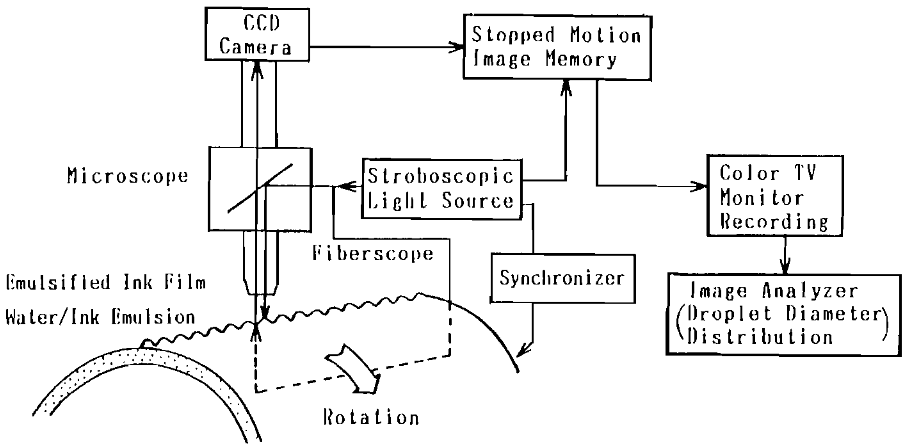

Fig. 1 Schematic diagram of emulsion visualization test apparatus

2. Emulsified ink condition on rollers

An observation method for distribution of water droplets in emulsified ink on roller has recently been developed and an attempt is being conducted to obtain the characteristics of emulsified ink from the distributing condition.(5,6,7) We,Mitsubishi, have also developed an emulsion visualization apparatus for investigation of ink film condition, water mixing behavior and emulsifying condition and studied effects on ink transfer and gloss of emulsified ink.

2.1 Emulsion visualization apparatus

Fig. 1 shows the schematic diagram of the visualization appratus. In combination with a microscope, stroboscopic light source (half breadth 0.5 ~ 4 μ s) CCD camera, image memory and picture processor, permeable and reflected images of ink films on the roller surface under rotation (roller speed ≒ 3m/s) were observed and analyzed. The resolution is 0.2 μ m.

2.2 Observation result of emulsified ink films

The generative form of emulsified ink by means of dampening water on the roller was observed with a transparent roller of acrylic resin (Fig.2). Raw ink films are not uniform and they present irregular surfaces (melon pattern) having

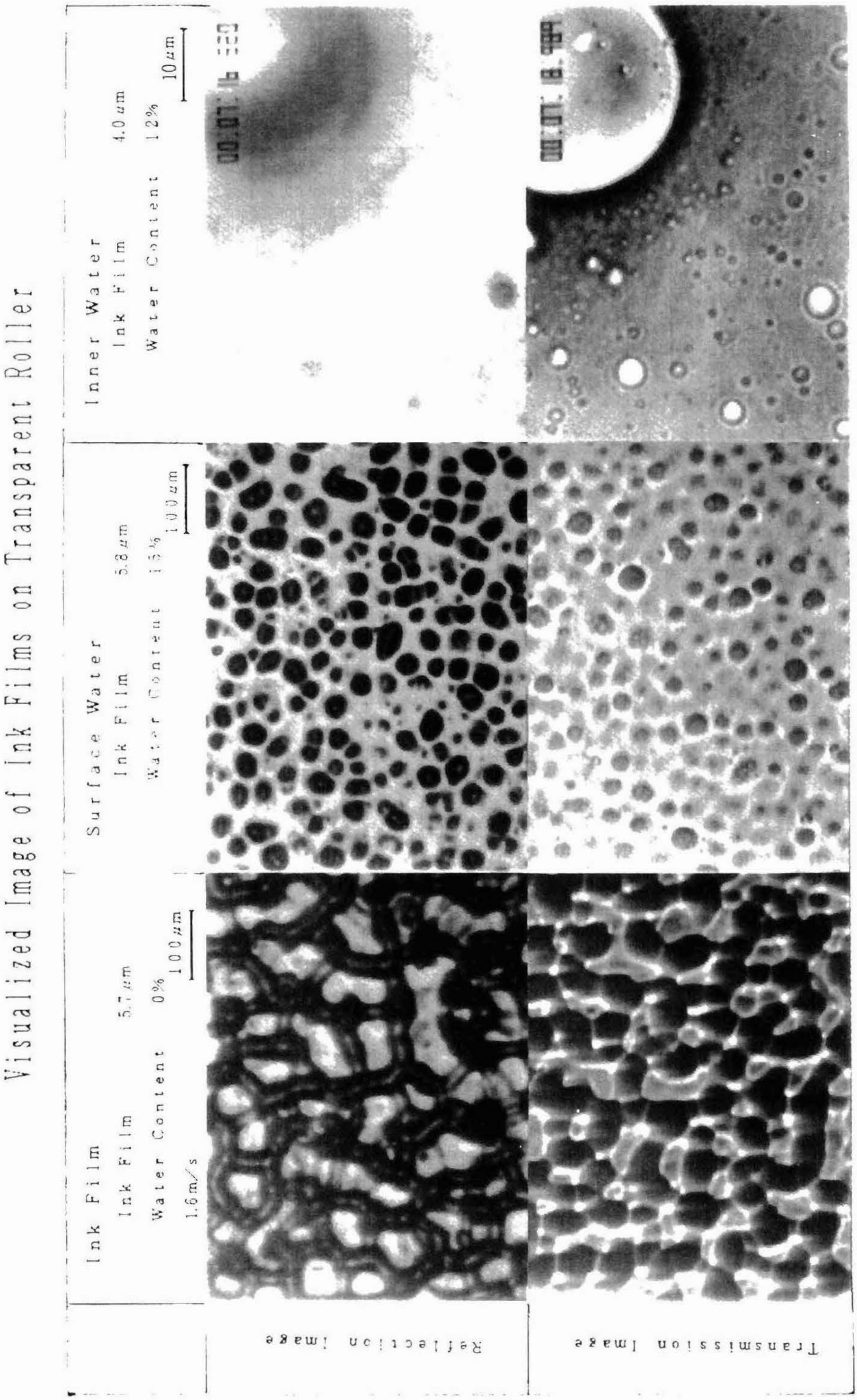

Fig. 2 Visualized Image of Ink Films on Transparent Roller

network structure like the pericarp of a melon. This configuration is resulted from the filamention of ink at an nip exit between rollers. As emulsification progresses by mixing with water, the network pattern is sphitted to fine pieces. When water droplets begin to appear on the surface, the network structure disappears. When the emulsifying limit is reached,ink surface is covered with droplets alone. From the fact that these droplets are quickly evaporated and that fine droplets existin the ink films, they are verified to be surface waterdroplets. The cross-section of ink films of different emulsification degree is assumed as in Fig. 2 by comparison of a permeable image with a reflected image. The network pitch P of melon pattern is represented in the following equation by dimensional analysis:

$$\frac{P}{t} = A\left[\frac{t}{R}\right]^{\chi}\left[\frac{tv\rho}{\mu}\right]^{y}\left[\frac{tv^2\rho}{\gamma}\right]^{z} \cdots\cdots\cdots\cdots (1)$$

Where, t, A, R, v, μ , ρ and γ represent film thickness, constant, roller diameter, peripheral speed, viscosity, density and surface tension respectively. The third term of right-side shows Reynold's number, and the fourth term shows Weber's number. Coefficients χ , y and z become χ ,z > 0, y < 0, and the network pitch decreases with the lowering of viscosity and decrease of speed and film thickness. The unevenness of ink films on the plate surface of a machine is very fine.

With the progress of emulsification, surface water droplets exist at the network pitch, when the water content isindependent of ink film thickness, but varies according to the type of ink. Offset ink is liable to cause surface water droplets. This is considered to be caused by small compatibility of resin in the ink with water. The tack of sheet ink suddenly decreases as surface water droplets appear.It is also considered that from the generative form of surface water droplets, emulsified water has a part in separation of emulsified ink films.

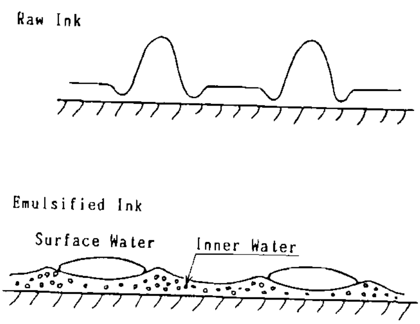

Fig.3 Cross-section of ink films (Assumed picture)

The droplet-size distribution of surface water observed by the emulsion visualization apparatus was obtained by means of image analysis and part of the result is shown in Fig. 8. When surface water begins to appear, the droplet size start sfrom 0.3~ 100μ m. As for maximum emulsification rate, sheet ink has the widest distribution. When ion-exchanged water is used as dampening water, the droplet size increases.

Inner water can be distinguished by comparison of a permeableimage wiht a reflected one. The droplet diameter ranges from 0.3 μ m to slveral micrmeters according to the film thicness. When inner water is saturated, excess water forms as surface water. The amount of inner water also depends on ink species and water species.

3. Evaluation of emulsifying characteristics

3.1 Emulsion evaluation tester

The emulsion evaluation tester fabricated for study of emulsifying behavior by mixing ink/water on the plate consists of a plate cylinder, dampening unit, ink mixing rollers anda transparent roller. This is a testing device for emulsion visualization on the roller although no printingis made. The ink film thickness and water content in emulsified ink by uptake of water were measured by the film thickness and water content measurement instrument installed on the oscillating roller (copper roller). The distribution of water droplets in emulsified ink was measured on the plate and the transparent roller above the ink form roller bymeans of the emulsion visualization apparatus. The feeding methods of fountain solution are a plate dampening method (AD method) to feed water on the plate by the dampening system and an emulsion feeding method (Diamatic G type dampening method) to feed water to the inking system, namely to the nip between the ink form roller and the copper roller.

3.2 Emulsion evaluation method on the roller

The rate of emulsification of thin film ink, equilibrium water content (emulsifying limit) and distribution of water droplets in W/O emulsion type emulsified ink can be investigated as follows:

3.2.1 The rate of emulsification

Water is supplied at a given velocity to the ink film adjustedby the inking system on the copper roller for examination of an increase rate of water content and the emulsifying rate immediately after a start of water uptake is regarded as an initial emulsifying rate. Emulsifying rate varies depending on the temperature and humidity.

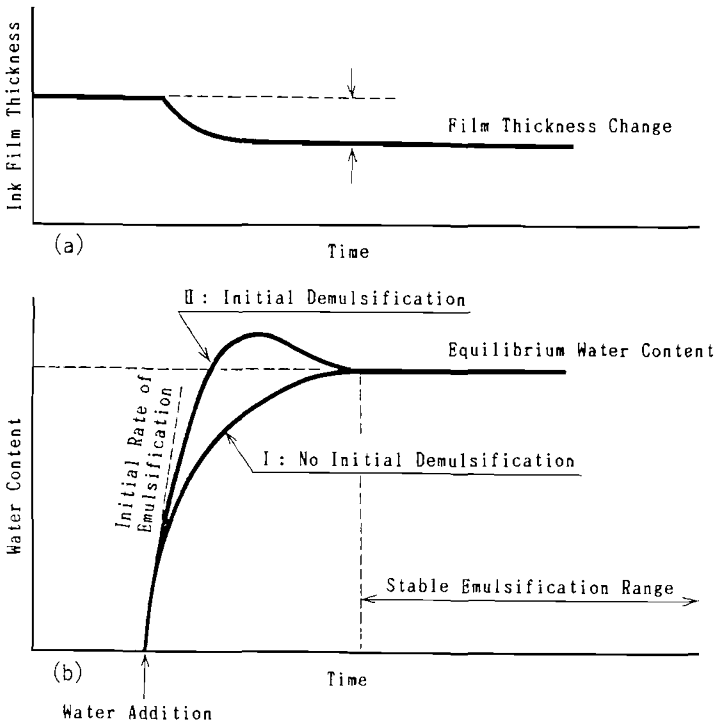

Fig.4 Representative profile of film thickness and water content of ink as a function of time

3.2.2 Equilibrium water content

A value at which water content is constant through a continuous supply of water to thin film ink is regarded as an equilibrium water content or emulsifying limit. As shown by the curve II in Fig. 4 (b), there are cases where water content decreases until an equilibrium water content is reached after starting water supply. This is an excess emulsification which occurs at an initial period of water uptake. The difference between maximum water content and equilibrium water content is regarded as a demulsified water content. As shown in Fig. 4 (a), there are cases where ink film thickness decreases at the time of water uptake. Ink is transferred from the copper roller to the ink form roller according to the degree of emulsified state.

3.2.3 Distribution of water droplets

The condition of emulsified ink on the plate or ink form roller is evaluated by the distribution of water droplets in ink transferred on the transparent roller. The surface water on emulsified ink films is identified by a reflection method and interfacial water in ink films by permeable & reflection methods. The minimum droplet size by an IR microscope is 0.3 μm. The droplet size distribution can be investigated by an image analysis system.

3.3 Evaluation of plate image formation

After applying ink films evenly on the PS plate having a dot pattern consisting of an image area (lipophilic) and a non-image area (hydrophilic), water is supplied to the plate cylinder. The ink on the non-image area is replaced by water and a dotted image is formed on the plate. This image formation speed (formation time) and dot profile are evaluated by the emulsion visualization apparatus.

3.3.1 Image formation speed

Water is supplied on the plate by the AD method to have the water form roller contact with the plate cylinder covered with ink films and by the Diamatic G type dampening method to have the ink form roller covered with emulsified ink contact with the plate cylinder and the time required for image formation by replacement of ink/water is measured by observation of an image with a microscope. Readiness of image formation is evaluated by the time for replacing part of ink films with water and the time until a dotted image is completed.

3.3.2 Image formation

Dynamic image formation by emulsified ink onto the plate is evaluated by checking the distinctness of boundary profile of ink/water films at a dot profile formed by replacement of ink/water on the plate or tinting of non-image area caused by partial ink sticking.

3.4 Evaluation of emulsifying characteristics of aqueous IPA solution

In order to make clear the IPA properties to see why aqueous IPA solution has so far been used as a fountain solution, pure water and commercially available additives for fountainsolution were used as the comparison substances for examination of emulsifying behaviors

3.4.1 Test conditions

Ink film thickness of 4～10 μ m, dotted area rate of 0～80 % for plate image, plate cylinder speed of 1～3 m/s, pan roller revolution of 20 rpm, plate temperature of 20～35℃, relativehumidity of 60%. IPA density of 1% or 15%. Ion exchange water and distilled water is used as ion-exchanged water.

3.4.2 Emulsifying behavior

Examples of emulsifying rate and equilibrium water content measured are shown in Fig. 5. The characteristic of aqueous IPA solution is that the emulsifying behavior ranks in the middle between water and additives for fountain solution. Ion-exchanged water has a small emulsifying rate and less water content and even resulted in demulsification. Emulsified ink formed at the image area of the plate was transferred on a transparent roller. The emulsified state of W/O emulsion and distribution of droplets are shown in Figs. 6 & 7 respectively. IPA is featured by its broad range of droplet size distribution. Ion-exchanged water is difficult to be emulsified and fine droplets alone exist. The greater part of water exists on the ink films as surface water. In case of additive A, a large quantity of interfacial water exist in stable and droplet distribution is excessive compared to that of IPA.

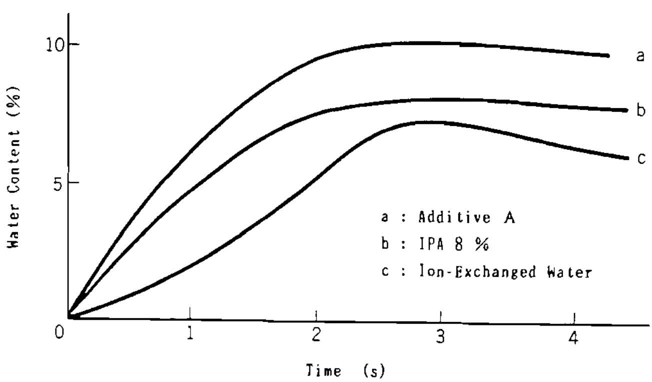

Fig.5 Rate of emulsification of water in ink film

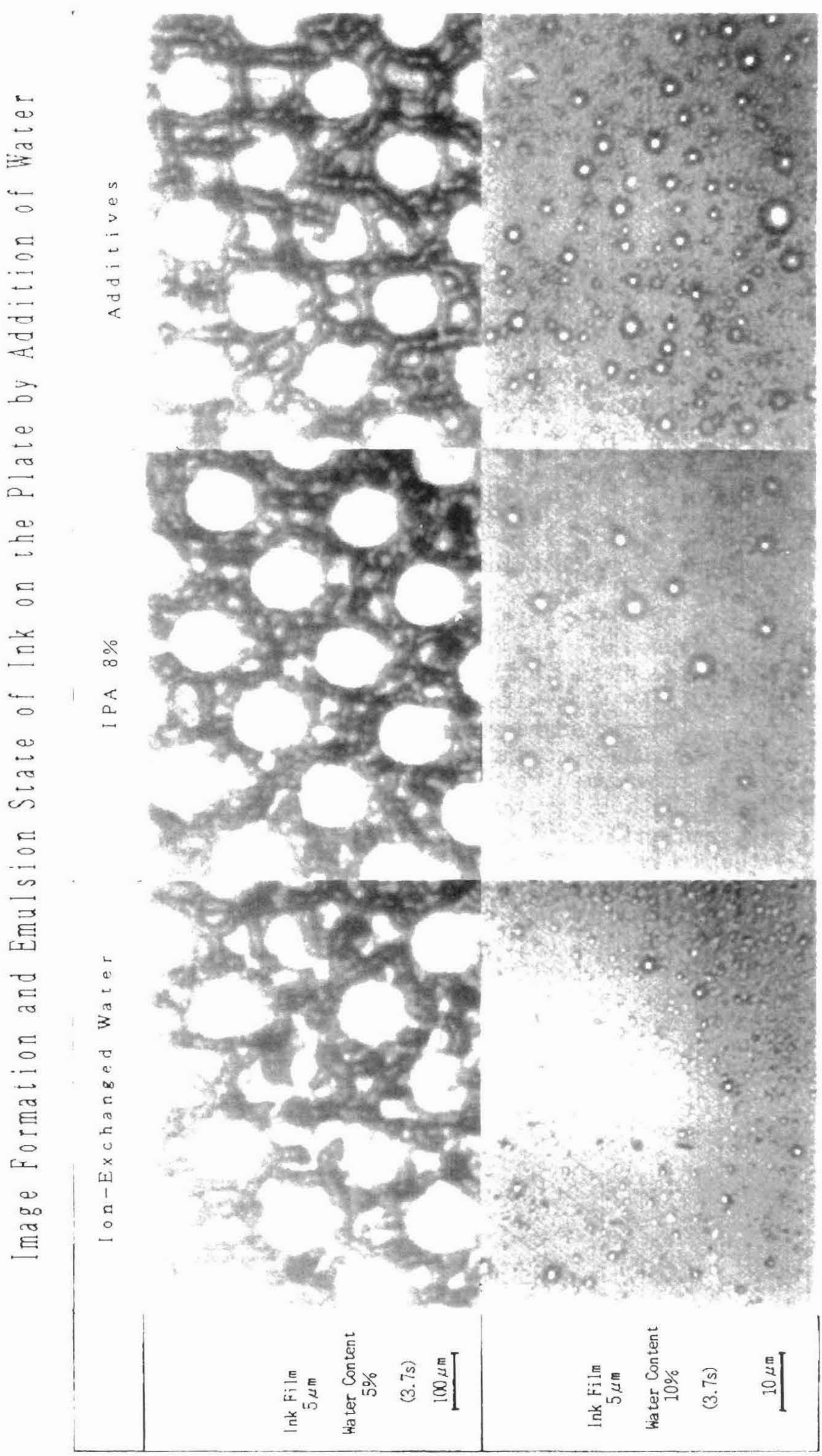

Fig. 6 Image Formation and Emulsion State of Ink on the Plate by Addition of Water

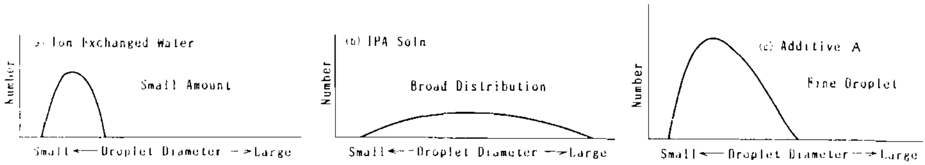

Fig.7 Histogram of water droplet formed in emulsified ink film

Fig. 6 shows an image formation on the plate by the addition of three kinds of water. A distinct dot image is notformed by demineralized water and a large quantity of surface water exist on the ink film in the image area.
There is no significant difference in image formation between IPA and additive A, but the additive A causes more surface water.

Fig. 8 shows an image formation speed by replacement of ink/water. The vertical axis stands for the time required for completion of image formation. An image formation speed is in the order of IPA > additives > demineralized water.
For feeding method of fountain solution, an image formation speed is in the order of Diamatic G method > AD method. Ink/water replacement starts in 2～3 seconds after water feeding and nosignificant difference is found among the types of water or water feeding methods.

In addition to ink/water replacing rate on the plate and droplet distribution of W/O emulsion, further investigation

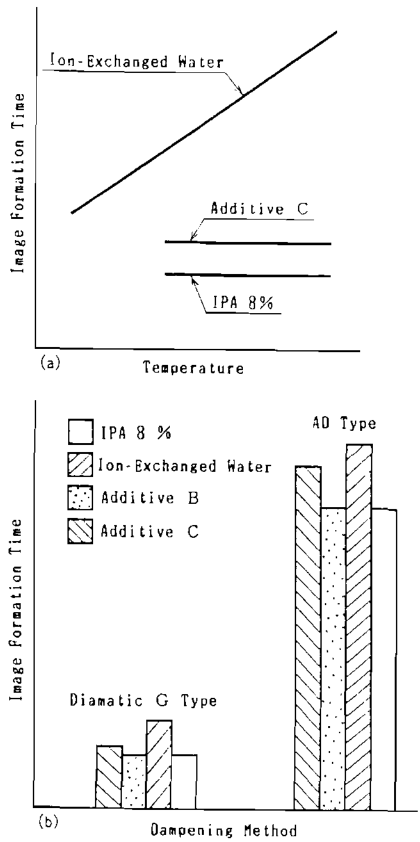

Fig. 8 Change of Image Formation Rate by Fountain Solution and Dampening Method

was made among these additives seeking for an IPA-substitute reagent which showed an emulsifying behavior close to that of IPA. As a result, it was found that some additives are effective for the purpose.

4. Emulsifyinh behavior on a machine

In order to confirm an actual applicability of IPA-substitute reagent, printing tests were carried out for additive solution using the Diamatic D typedampening system.

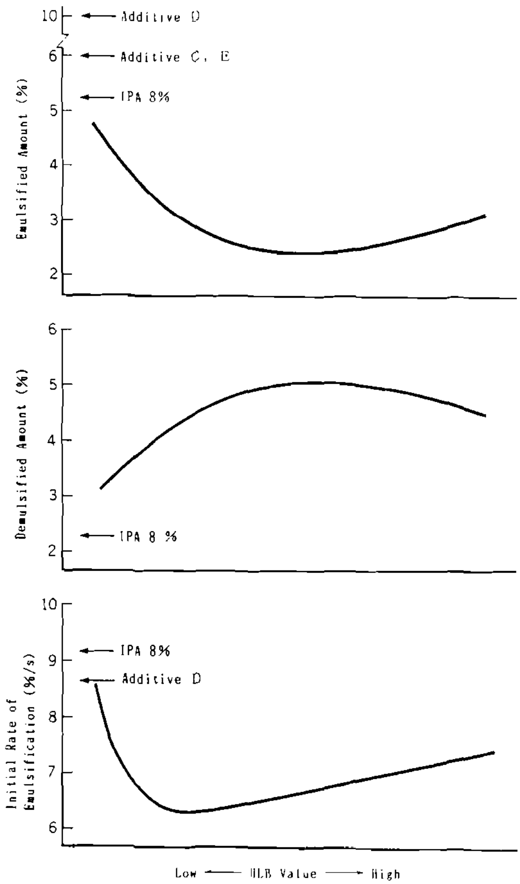

Fig. 9 Emulsifying behavior of dampening solution additives as a function of HLB value

Table 1 Print quality as a function of dampening water quality

Quality / Dampening water	Density in solid area	Relative contrast	Dot gain		Shape factor	
			20%	80%	20%	80%
IPA 10%	1.49	0.49	6.8	10.9	1.36	1.35
Additive B	1.57	0.48	5.2	12.5	1.27	1.48
Additive D	1.51	0.47	7.0	11.7	1.28	1.32

4.1 Test conditions

Printing machine: Dia 3F-4, Ink: Toyo Ink Mark V (Indigo), plate: Konicaimage rate of 50% & 80%, gradation scale (175 lines/in, dotted area rate0 ～100%, intervals at approx. 10%), printing paper: SK coated paper 62.5 kg, printing speed: 6000 ～10,000 sheets/hr, atmospheric temperature: 25℃, humidity: 60%. The water contents of water film on the plate and emulsified ink were measured on the machine.

4.2 Test result

The water content in emulsified ink on the roller by additive B is slightly higher than that by IPA (image area 7 %, non-image area 11%), but the print quality shows no drawbacks in comparison with IPA as shown in Table 2.
For additives B & D selected by investigation of emulsifying behavior using an emulsion evaluation tester, it was found that they can be used for actual printing. Further selection is required for more reasonable additive equivalent to IPA.

5. Emulsified state and role of fountain solution

In selection process of IPA-substitute additives, an emulsifying rate, droplet distribution and ink/water replacing rate on the plate of additive solutions were controlled with IPA solution as standard in order to bring the emulsifying behavior close to that of IPA. But further study is required for ink/water emulsification and behavior on the plate.

5.1 Ink/water interfacial tension and emulsifying stability

Ink/water emulsification is expressed as a function of ink/water interfacial energy and shearing rate for ink/water mixing at the roller nip.

$$\text{Ink/water emulsification} = f\,(\text{ink/water interfacial energy}, \text{shearing rate for ink/water mixing}) \quad \cdots (1)$$

After experimentally obtaining the three dimensional interfacial energy of ink and fountain solution by Fowkes plotting,(8) ink/water interfacial energy was obtained from a geometrical mean.

$$\gamma_{W/I} = (\gamma_W^{d\ 1/2} - \gamma_I^{d\ 1/2})^2 + (\gamma_W^{p\ 1/2} - \gamma_I^{p\ 1/2})^2 + (\gamma_W^{h\ 1/2} - \gamma_I^{h\ 1/2})^2 \quad \cdots\cdots\cdots (2)$$

Where, subscripts W & I stand for fountain solution and ink and d, p & h stand for variance component, polar component and hydrogen bonding component of total surface energy respectively. Each component of surface energy γ was obtained using standard fluid and standard solid which have the known values of d, p & h. Surface energy and interfacial energy of ink and fountain solution obtained are shown in Table 3.

The interfacial energy of IPA solution levels in the middle between demineralized water and additives. When the interfacial energy gets closer to zero (0), a stable W/O emulsion is readily formed, but if it increases, emulsion formation becomes difficult. This means that ion-exchanged water is difficult to get inclued in ink, while additive solution is easy to the contrary. When ink/water is mixed between to rollers, emulsification and demulsification occur simultaneously. In case of IPA solution, it is considered that both behaviors are making a metastable emulsified state well-balanced. This corresponds to the fact that emulsified IPA solution shows a broad droplet size distribution because of intermediate interfacial energy.

5.2 Emulsified state and emulsifying behavior on plate

It was made clear that excessive variations occur in image formation depending on the properties of fountain solution. It is explained here-under from an interfacial chemical viewpoint (on the plate) as to why emulsified state would affect the image formation. At the same time, demineralized water and additives are examined for

Table 2 Surface energy of several fountain solutions and ink-water interfacial energy

Surface Energy of Fountain Solution γw (mN/m)								
Fountain Solution	Dispersion Component γ^d	Polar Component γ^p	Hydrogen Bonding Component γ^h	Surface Tension γ^*	Critical Surface Tension γ^c	Surface Tension γ^{**}	Ink/Water Interfacial Energy $\gamma_{w/i}$ (mN/m) Calc. Value	Exp. Value ***
H_2O	29.1	1.3	42.4	72.8	73.5	—	38.7	24
IPA 8%	36.42	8.85	0.0	45.27	44.7	45.4	5.98	15
Additive B	32.30	0.83	0.0	33.13	43.2	39.1	0.33	15
Additive C	33.09	13.35	0.0	46.44	41.9	39.1	9.72	8
Additive D	34.00	1.98	0.0	35.98	40.7	39.7	0.87	13
Additive E	35.84	14.24	0.0	50.08	45.1	44.3	10.46	5
Ink	34.9	0.32	0.16	35.4	33.7	* Calculated Value	** Measured Value	

comparison in connection with a non-image area of plate, making IPA as a standard solution.

First of all, IPA has the greatest capability of water film formation when fountain solution is fed to the ink form roller or non-image area of plate. Demineralized water has less extended dampening capability and is difficult to form uniform water films compared to others due to its greater surface tension.

For an emulsified ink state on the ink form roller before it is touched on the plate, IPA has, as shown in Fig. 7,a wide distribution of water droplets in emulsified ink films and demineralized water has much surface water and less interfacial water. Additives have a quantity of fine droplets existing in stable.

When emulsified ink on the ink form roller contacts with non-image area, some water droplets dispersed in emulsified ink films are demukified by nip pressure onto a very hydrophilic plate. In order that a Weak Boundary Layer is formed on the plate, it is necessary to cause demulsification of W/O emulsion. Demineralized water results in less inner water, and additive solution has less water demulsification effect because of formation of stabilized W/O emulsion.

In case of imperfect water film formation, some ink sticks and causes scaming on the non-image area of the plate at theexit of roller nip. To prevent tinting, a large quantity of emulsifying water is further required or a large quantity of water film is required in advance on the plate. An excess emulsificaton lowers ink density for non-image area, which results in poor dot formation. Existence of excess surface water also causes poor ink transfer onto an image area.

To obtain the print quality with excellent inking and dot reproducibility and no tinting, it is considered important to achieve an optimum water content and an optimum water droplet distribution in emulsified ink. Whichever feeding method of fountain solution (AD method or Diamatic G type dampening method) may be applied, it is important to form emulsified ink films having a minimal water content and an optimum droplet distribution on the ink form roller for obtaining a minimum Weak Boundary Layer on the non-image area of the plate.

6. Conclusion

For an optimum printing by IPA-substitute solution, emulsifying behaviors such as the rate of emulsification, droplet distribution and ink/water replacing rate on the plate were investigated by bench tests for clarification of emulsifying characteristics of IPA. An IPA-substitute reagent was selected with IPA as a standard solution and tested on a machine for the feasibility of application. The rate of emulsification, droplet distribution and ink/water replacing rate of IPA depend on the balance in surface tension of ink/fountain solution. Since IPA forms a metastable emulsified state in ink, it is considered that an image formation is readily done on the plate. In other words, the primary role of fountain solution in offset printing is to form a metastable emulsified ink films so that ink on the plate can be replaced by water droplets dispersed in emulsified ink to form water films on the plate. It can be said that fountain solution is necessary to obtain an optimum water content and an optimum emulsified state.

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