Effect of Particle Size on Properties and Droplet Formation of Disperse Dye Multiphase Fluid

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Abstract

This research focus on investigating the effect of particle size on properties and droplet formation of disperse dye multiphase fluid. The results show that the stability, spreading area on the transfer paper and transfer rate increase with decreasing the particle size of disperse dye in multiphase fluid. The droplet formation process of multiphase fluid from a fine pinhole is composed of ejection, stretching, necking, pinch-off, recoil and recombination of primary drop and satellite. The larger particle size of the disperse dye, the shorter droplet pinch-off time is. And the larger disperse dye content leading to the smaller pinch-off time. A small droplet following the primary particles is formed when disperse dye content is high.

Introduction

Inkjet printing is one of the fastest growing textile printing technologies [1]. In addition to the other advantages, it is more eco-friendly, required low water and energy consumption, and has no or minimal residue dye in comparison with the conventional printing technologies [2,3]. Disperse dye inks with high performance in hue, brilliant, and color strength have become one of the main colorant for printing polyester textiles [4-6]. As can be known that disperse dye ink as multiphase fluid is consisted of disperse dye, polymeric dispersant, polyol and the other additives [7-9]. Many researches have been proved that apparent viscosity, pH value, the structure and amount of additives, particle and its content can greatly influence on the properties and droplet formation process of the multiphase fluid [10-15]. Among all of the above factors, particle and its content as the most important one should give more attentions.

However, although there are many reports about the disperse dye multiphase fluid, they are mainly focus on the modification of disperse dye and formulation of disperse dye ink, the effects of particle size and disperse dye content on properties and droplet formation of multiphase fluid was rarely discussed. In this paper, we investigated the effect of particle size on apparent viscosity, stability, spreading performance, transfer rate, K/S value of the printed textiles and the droplet formation process of disperse dye multiphase fluid. This research may provide a new guidance for formulation of disperse dye ink.

Experimental

Materials

C.I. disperse dye red 60 (its chemical structure was shown in Chart 1, press cake, water content 47%, Yabang Dyestuff, Changzhou, China) was dried before using. Poly(styrene-alt-maleic acid) (PSMA, molar ratio of styrene to maleic acid was 0.56, *M*n = 4700, Nanocolorants and Digital Printing R&D Centre of Jiangnan University, Wuxi, China). Glycerol, ethylene glycol mono-methyl ether, sodium solution and polysorbate 80 (analytical grade, Lingfeng Chemical Reagent, Shanghai, China). All the distilled water was used in the experimental.

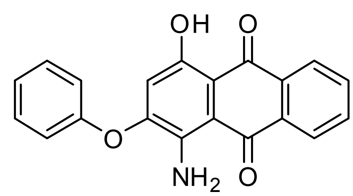

Chart 1. *Chemical structure of C.I. disperse dye red 60*

Preparation of disperse dye dispersion

6 g PSMA was dissolved into 184 g distilled water, and then 20 g C.I. disperse dye red 60 was added after pH of PSMA solution was adjusted to 7.5 by 0.1 mol/L NaOH. The mixture was transferred to a bead mill (Minizeta 03E, Netzsu, Germany), which ZrO_2 bead (0.8 mm, mass ratio of ZrO2 to disperse dye 5:1) was used as milling media. The mixture was dispersed for desired time to get the disperse dye dispersion with the particle size 150 nm, 200 nm, 250 nm and 300 nm respectively.

Preparation of multiphase fluid

The formulation of multiphase fluid in a weight basis was given as follows: disperse dye dispersion x%, glycerol 13%, ethylene glycol mono-methyl ether 12%, polysorbate 80 1%, and distilled water (74-x)%. The above components were mixed under stirring until a homogeneous dispersion was obtained. Multiphase fluid was prepared after filtered through 0.5 μm pore filtering sieve.

Characterization

Particle size and apparent viscosity

The samples were diluted to 1500 times by distilled water. The Particle size was measured by Nano-ZS90 (Malvern Instruments, England).The apparent viscosity (ηa) of multiphase fluid was measured using a spindle-type Brookfield viscometer (model DV-III, Stoughton, U.S.A.) at 25°C.

Stability

Centrifugal stability: The absorbance of multiphase fluid which was diluted 1500 times was recorded on a UNICO UV-2000 spectrophotometer. Wavelength of maximum absorbance multiphase fluid was found to be 530 nm and original absorbance was recorded as A_0. The dispersion was centrifuged at 3000 r/min for 15 min. 0.03 g super dispersion was diluted 1500 times with distilled water. The absorbance of the super dispersion (A_1) was also measured at 530 nm. Relative absorbance (R) was calculated according to Eq. (1):

$$R = \frac{A_1}{A_0} \times 100\% \qquad (1)$$

Freeze-thaw Stability: The multiphase fluid was sealed and stored at -5 °C for 24 h and then put into an oven at 60 °C for another 24 h. The particle size was measured before (d0) and after storage (dT). The freeze-thaw stability (D0) was evaluated by comparing the changes of particle size before and after treatment using eq. (2).

$$D_0 = \frac{|d_0 - d_T|}{d_0} \times 100\% \qquad (2)$$

Transfer rate and K/S value

Two printed transfer paper (4 cm × 4 cm) were prepared which uniformly distributed the same amount of multiphase fluid. One was extracted with 20 mL DMF for 30 min, and its absorbance of the extracted solution was measured and recorded as A0. The other one was stick to the polyester textiles and heated at 210 °C for 30 s, and then extracted with 20 mL DMF for 30 min, and the absorbance of the extracted solution was measured and recorded as A1. The transfer rate of disperse dye (TR) is calculated using eq. (3):

$$TR = (1 - \frac{A_1}{A_0}) \times 100\% \qquad (3)$$

The color strength (K/S values) was determined using the Kubelka-Munk equation. The color appearance of printed textile was specified using CIE Lab color space.

Droplet formation

The droplet formation process was observed and taken photos by Drop Shape Analysis System DSA100. The working process of drop shape analyzer DSA100 was shown in Fig. 1. The droplet formation from a pinhole (diameter 1.5 mm, flow rate 0.2 cm/s) was recorded by a high-speed camera, and then the screenshot in 16 ms time interval was analyzed frame by frame.

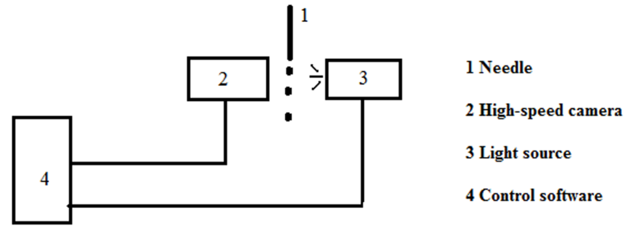

Fig. 1 *Schematic of drop shape analyzer DSA100*

Results and discussions

Effect of particle size and disperse dye content on apparent viscosity of multiphase fluid

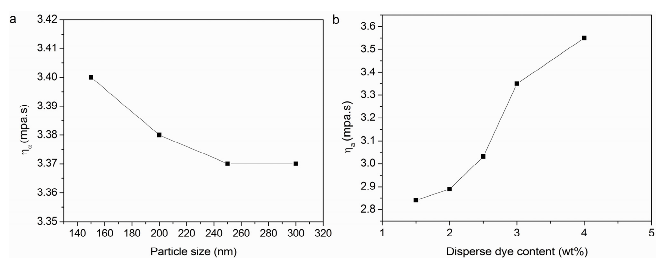

Fig. 2 *Effect of a) particle size (disperse dye content 3 wt%) and b) disperse dye content on apparent viscosity of disperse dye multiphase fluid (particle size 150 nm)*

Fig. 2a shows that the apparent viscosity of multiphase fluid decrease slowly when particle size of disperse dye increases from 150 nm to 300 nm. In the same weight, disperse dye with smaller particle size result in more amounts of particles in multiphase fluid, which may shorten the distance between the particles, and therefore causes a high apparent viscosity. Fig. 2b shows that the apparent viscosity increases with an increase of disperse dye content in the multiphase fluid. It is known that the distance between the particles will reduce with an increase of disperse dye content, which will reinforce the *van der waals* attractive forces among the particles, thus lead to an increase of the apparent viscosity.

Effect of particle size and disperse dye content on stability of multiphase fluid

The particle size of the disperse dye in the multiphase fluid can not only affect the printing performance, but also affect its stability. Fig. 3a and b indicates that the stability of multiphase fluid reduces with an increase of particle size of the disperse dye, these may be explained by Stokes law [16].

$$v = \frac{2d^2(\rho - \rho_0)g}{9\eta} \qquad (4)$$

Where ν is the particles' settling velocity; d is the particle size; ρ is the mass density of the particles; ρ_0 is the mass density of the fluid; η is the viscosity of the fluid; g is the gravitational acceleration. Eq. (4) indicates that the larger particles leading to the higher particles' settling velocity. Therefore, the centrifugal stability of the fluid decreases with an increase of the particle size. Moreover, the dispersant which absorbed onto the disperse dye may be desorbed under freeze-thaw treatment. Moreover, the disperse dye with large particle size will be more easily aggregated due to its weak Brownian motion, thus leading to large change rate of the particle size.

Fig. 3c indicates that the freeze-thaw stability of multiphase fluid decreases with an increase of disperse dye content. This is because the distance among the particles is shortening, and the effective collision among the particles is increasing with an increase of disperse dye content in multiphase fluid, which may be responsible for the large change rate of the particle size.

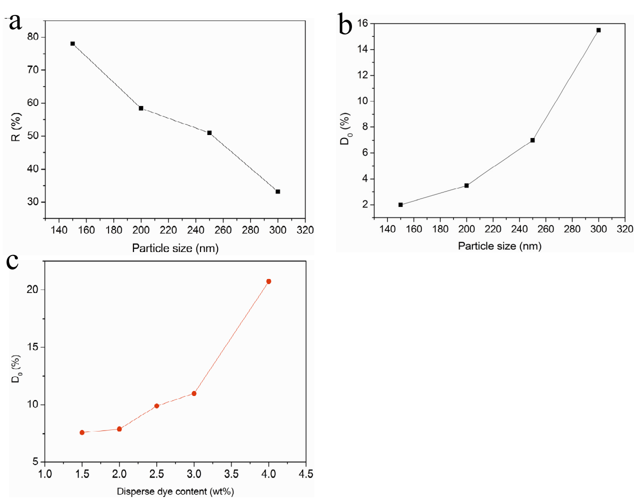

Fig. 3 *Effect of particle size on stability of disperse dye multiphase fluid, (a) centrifugal stability and (b) freeze-thaw stability; c) effect disperse dye content on multiphase fluid freeze-thaw stability*

Effect of particle size on spreading area and K/S value

Unlike the traditional printing, the disperse dye ink for inkjet printing can readily bleed and spread on the transfer paper for its low apparent viscosity, thus causing a poor printed quality. Therefore, it is important to investigate the relationship between the particle size and bleeding performance of the multiphase droplets on the transfer paper. Fig. 4a shows that the spreading area decreases with an increase of the particle size. This is because that the disperse dye with the small particle size can easily move in the capillary of the transfer paper following with the water, thus leading to a large bleeding and spreading area.

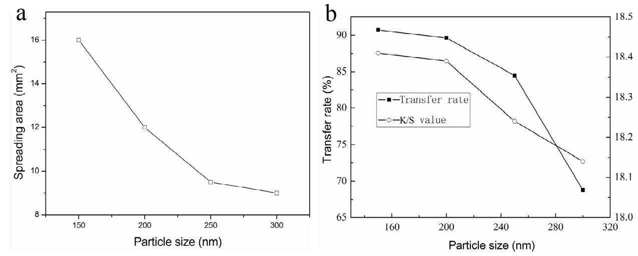

Fig. 4 *Effects of particle size of disperse dye particles on a) spreading area of the multiphase droplets and b) transfer rate and color strength*

Fig. 4b shows that the transfer rate of the disperse dye and the K/S value of the printed textiles decreases with an increase of particle size of disperse dye in multiphase fluid. The reason was that the smaller disperse dye particles, the lower sublimation energy of disperse dye required, and more amount of disperse dyes transferred into the textiles under the same conditions (180 °C for 30 s).

Effect of particle size and disperse dye content on droplet formation

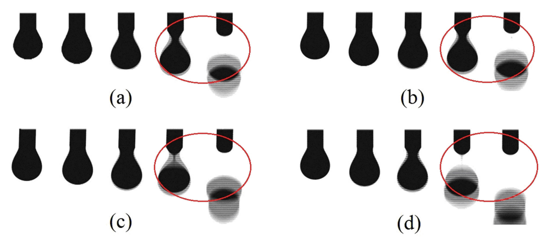

Fig. 5 *Effect of particle size on droplet formation of the multiphase fluid, (a) 150nm, (b) 200 nm, (c) 250 nm, (d) 300 nm, the mass ratio of disperse dye content in the dispersion 2.0%.*

Fig. 5 indicates that the droplet formation process of multiphase fluid from a fine pinhead is composed of ejection, stretching, necking, pinch-off, recoil and recombination of primary drop and satellite. Larger particle size of the disperse dye in dispersion, pinch-off time for forming the droplet is shorter. Due to that the flowing stability of the fluid was disturbed for the introduction some large particles in multiphase fluid, which may help to accelerate the droplet formation.

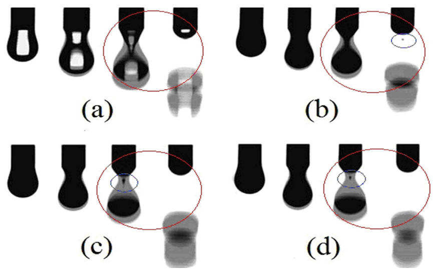

Fig. 6 *Effect of disperse dye content on droplet formation of multiphase fluid with particle size 150 nm, (a) 0, (b) 1.5%, (c) 2.0%, (d) 2.5%.*

Fig. 6 shows that the pinch-off time of multiphase fluid decreases with an increase of disperse dye content. Meanwhile, a small droplet was formed following the primary particles. During the printing, the flowing stability will be severely disturbed for introduction more amount of disperse dye particles, and moreover, the density of the fluid raised as an increase of disperses dye content, all of these are responsible for accelerating the falling speed of the droplet and thus reducing the pinch-off time. The reason for the formation of small droplet may be for the uniform particles distribution of the neck fluid.

Conclusions

The particle size of disperse dye multiphase fluid can greatly influence on the properties and droplet formation process. Disperse dye with small particle size leading to the higher stability and the larger spreading area on the transfer paper. The droplet formation process from a fine pinhole is composed of ejection, stretching, necking, pinch-off, recoil and recombination of primary drop and satellite. The larger particle size of the disperse dye in multiphase fluid, the shorter droplet pinch-off time is.

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