Reduction of friction in high-viscosity ink tubes using ultrafine bubbles

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This study explores the use of ultrafine bubbles (UFBs) to tackle a major challenge in inkjet printing technology: reducing friction in pipes that carry high-viscosity ink. Inkjet printing, known for its 100% coating efficiency, has substantial potential to contribute to global carbon neutrality, especially in industries like automotive manufacturing. However, the narrow and complex flow channels in inkjet systems create high-pressure resistance, impeding the stable dispensing of high-viscosity ink. UFBs—bubbles smaller than 1 µm—help reduce this friction. This research measured ink flow rates with and without UFBs, revealing that UFBs significantly increase flow rates over time, indicating reduced friction and improved stability in ink discharge. Furthermore, ink with UFBs exhibited a smaller contact angle compared to ink without UFBs, enhancing wettability. These findings suggest that incorporating UFBs into inkjet printing could improve the reliability and efficiency of industrial applications, fostering future technological advancements.

1. Introduction

Inkjet printing technology has the potential to significantly advance global carbon neutrality, particularly in industries such as automotive manufacturing, due to its 100% coating efficiency and digital printing capabilities. Digital inkjet printing has been shown to reduce CO_2 emissions and volatile organic compounds (VOCs) compared to conventional analog printing[1]. However, the technology's widespread adoption is limited by challenges associated with high-viscosity inks used in certain applications. Specifically, the narrow and complex flow channels in inkjet printers create high-pressure resistance, complicating the maintenance of stable and efficient ink flow. To address this issue, this study explores the use of ultrafine bubbles (UFBs) as a novel solution. UFBs—invisible bubbles smaller than 1 µm—have unique properties that allow them to remain suspended in liquids for extended periods. Previous studies have confirmed through molecular dynamics simulations that UFBs reduce the frictional resistance of fluids and act as friction modifiers[2][3]. This research investigates the potential of UFBs to improve the flow characteristics of high-viscosity ink in inkjet printing, aiming to enhance the technology's reliability and broaden its industrial applicability.

2. Flow Rate Measurement

2.1 Experimental method

The experiment aimed to investigate the effect of UFBs on reducing friction in pipes carrying high-viscosity ink. The setup included a UFB generation device and a flow meter installed in the flow channel, as shown in **Fig. 1**. Three ink configurations were tested: (1) UFB-generation, where UFBs were introduced into the ink flow; (2) Unit, where the ink flowed without UFB generation; and (3) Tube, where the UFB device was replaced with a simple tube. Flow rates were measured at 15 min intervals over a 60 min period.

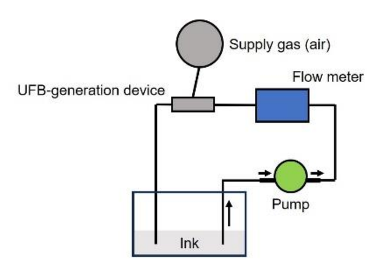

Fig. 1 Schematic of the ultrafine bubble injection setup

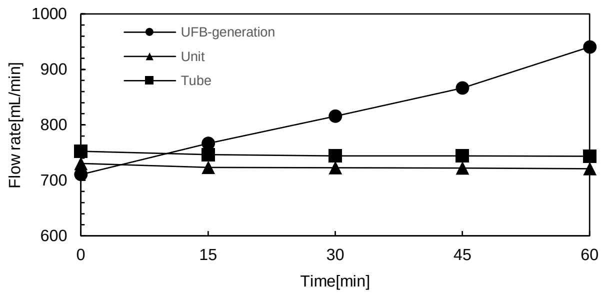

Fig. 2 Flow measurement results

2.2 Result and discussion

The flow measurement results are shown in **Fig. 2**. Data indicated that the flow rate was highest in the UFB-generation configuration, followed by the Tube, and then the Unit. The flow rate of the UFB-generation ink increased over time, while the other configurations remained constant. Although the installation of the UFB-generation device complicated the flow path and initially reduced the flow rate, the generation of UFBs ultimately compensate for this disadvantage, resulting in a higher flow rate compared to tubing alone. These findings suggest that UFBs reduce friction in the pipes, thereby improving the flow of high-viscosity ink and potentially enhancing inkjet printing efficiency.

3. Contact angle measurement

3.1 Experimental method

Contact angle measurement experiments were conducted to evaluate the effect of UFBs on ink behavior. The contact angle is commonly used to assess the wettability of solid surfaces. **Fig. 3** illustrates the contact angle, θ. In this experiment, UFBs were generated in the ink for 60 min using the equipment described in Chapter 2. After this period, the contact angle of the ink was measured and compared to the contact angle of ink without UFBs. The aim was to assess the impact of UFBs on the wetting properties of ink by analyzing the differences between the contact angles of UFB-treated and untreated ink.

3.2 Result and discussion

The contact angle measurement results are shown in Fig. 4. The data indicate that ink with UFBs has a smaller contact angle compared to ink without UFBs, suggesting that UFBs enhances the wettability of liquids. Improved wettability may reduce friction, as the liquid becomes a more effective lubricant and the interface between the liquid and solid surface becomes smoother.

4. Conclusion

In this study, UFBs were generated in ink, and the flow rate and contact angle were measured to assess their effect on reducing friction in high-viscosity ink for inkjet printing. The following conclusions were drawn:

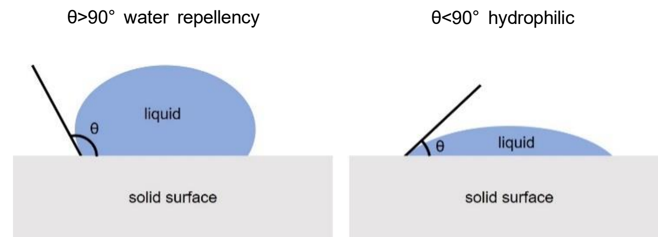

Fig. 3 Definition of contact angle

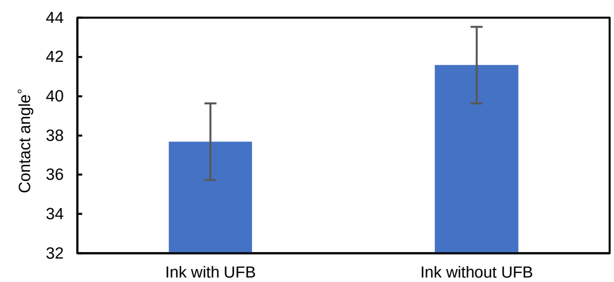

Fig. 4 Contact angle measurement results

(1) The flow rate increased when the ink was circulated through the channel with UFB generation.

(2) Ink with UFBs exhibited a smaller contact angle and better wettability compared to ink without UFBs.

These findings suggest that UFBs effectively reduce friction in high-viscosity ink pipes. Further research is needed to examine the long-term effects of UFBs on ink properties and to optimize the technology for broader industrial applications.

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