Application Report

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How waveform, surface tension, and viscosity affect the jetting behavior in inkjet printing

An illustration of basic relationships with the Drop Shape Analyzer – DSA Inkjet

The generation of drops at a piezo-based inkjet nozzle is an interaction between the geometry of the print head, the parameters of the liquid, such as surface tension and viscosity, and the waveform with which the piezo element is actuated. Here we present, by way of example, using the Drop Shape Analyzer – DSA Inkjet, how these quantities determine the jetting behavior based on a trapezoidal waveform and simple model liquids.

When measuring with the DSA Inkjet, the desired print parameters can first be defined, and then the trigger function of the measuring instrument synchronizes the generation of the drops with their image acquisition and analysis. For such image analyses, the DSA Inkjet is equipped with innovative optical technology. Relevant parameters such as volume and velocity of the drops, ligament length, and number of drop parts are available within a very short time, which simplifies the performance of studies such as this one or makes it possible in the first place. For some supported print head models, it is also possible to directly control the print head with integrated print electronics and an easy-to-use waveform editor. This option was used in this study.

Background

When generating drops using the DOD method (Drop-on-Demand), the waveform for actuating the piezo element is decisive for how the liquid is jetted from the nozzle. Furthermore, surface tension (SFT) and viscosity together with the nozzle diameter determine whether a liquid can be jetted at all and without the excessive formation of satellites [1]. The SFT and viscosity of the ink formulation as well as the waveform can be adapted in order to optimize the drops with regard to volume, velocity, and satellite formation for a given print head. In this study, we illustrate this relationship using water-based, simple model liquids.

Experimental

Liquids investigated

Table 1 summarizes the main properties of the model liquids investigated. The SFT was varied by means of two surfactants (designated A and B) from BYK Chemie (Wesel, Germany) which are frequently used for ink formulations. Liquids of different viscosities were produced by mixing water with glycerol, which is likewise a typical component of inks.

Tab. 1: Test liquids used. The percentages and mixture ratios are based on mass.

Test liquid	SFT [mN/m]	Viscosity [mPas]
Water	72	0.9
Water / Glycerol (9:1)	67	1.0
Water / Glycerol (1:1)	65	4.0
0.125% BYK-A/H_2O	21.4	0.9
0.5% BYK-A/H_2O	18	0.9
2% BYK-B/H_2O	28.5	0.9
1.8% BYK-B in H_2O/Glycerol (9:1)	28.8	1.0

Measuring instrument used

All measurements were carried out with the KRÜSS Drop Shape Analyzer – DSA Inkjet. The instrument features its own printer electronics which can communicate with a compatible commercial print heads (see Fig. 1).

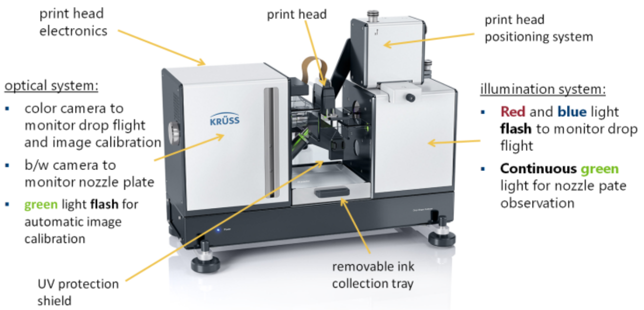

Fig. 1: Construction of the DSA Inkjet with fitted print head

For this purpose, the electronic control is carried out via a waveform editor in the ADVANCE software. This allows the construction of any waveform simply by drag-and-drop, limited only by the technical characteristics of the print head. A compatible, commercially available print head was used for the results presented here. If the print head is not directly compatible, droplet generation takes place via a trigger function which works synchronously with the droplet detection in the video image.

The drop generation and the drop flight were analyzed using the so-called double-strobe method. With this method, the drops, which move at up to 40 m/s, are illuminated by two successive flashes in order to create a double exposure of a single camera frame. In this way, two images of the drop are produced at very short time intervals.

The double-strobe method has been revolutionized for the DSA Inkjet. While a color camera is used, red and blue flashes are generated instead of white flashes. By splitting up the color channels, the two drop images can be separated from one another without overlap.

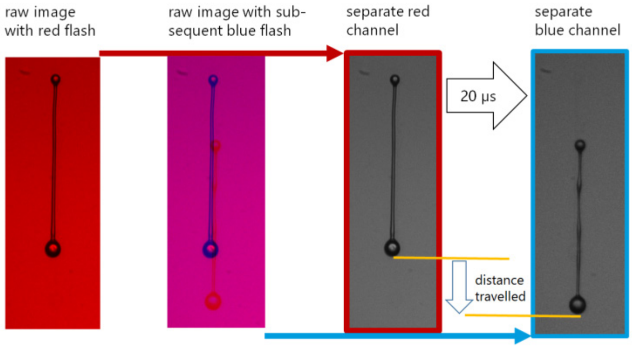

Fig. 2: Image generation in the DSA Inkjet. A red flash is produced at a specified delay time after the piezo pulse. After a further time (here 20 µs) the same image is illuminated in blue. The color channels are then separated, which enables the drop velocity, for example, to be determined.

In contrast with the conventional white-light method, this two-color technology always enables the drop image to be unambiguously associated with the respective flash.

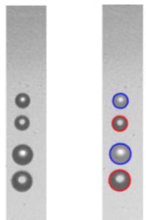

Fig. 3: Double-exposed image of a flying drop; right with contour detection. The software automatically and unambiguously associates the images with the red and blue flashes and therefore with the respective points in time, and outlines the drops in the appropriate colors.

Elaborate analyses of the development with respect to time in order to associate satellite drops with the parent drops for example are a thing of the past. In addition, information, which would otherwise remain hidden, becomes available, for instance when satellite drops in the second image overlap parts of a drop in the first image.

Results

Water with different pulse heights

Fig. 4 shows the flight of water drops jetted with a pulse of length 8 µs and a height of 9 to 21 V. The times of the red and blue light flashes are shown under the drop images.

With the images for 15, 17 and 19 V, which show the occurrence of satellite drops, this association would be difficult or even impossible using conventional white-light methods.

At 21 V, no drops can be jetted; the drop merely oscillates at the nozzle outlet.

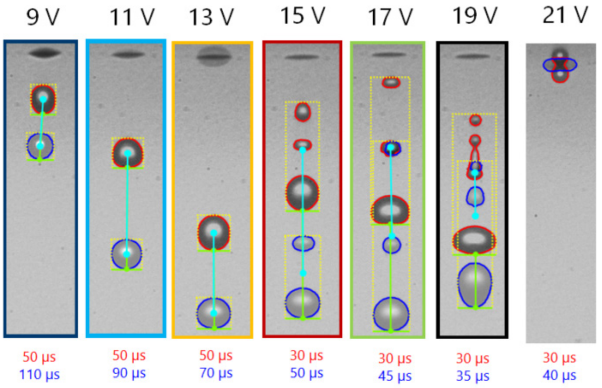

Fig. 4: Images of water drops dosed with a pulse length of 8 µs at different pulse heights

The analysis of the image encompasses a large number of result parameters, wherein the respective data on which they are based can be visualized by layers on the image. The yellow outlines show the height and width of the drops or ligaments and also the drop cluster in the case of satellite drops. The bottom peak of the (lowest) drop is marked with a green dot as the leading edge. The green connecting line represents the course and direction (trajectory) of the leading edge. The volume of the drop or the combined drop parts is likewise calculated. The software also determines the center of mass, shown in the image by light blue dots. The light blue connecting line indicates course and direction referred to the center of mass.

The drop images in Fig. 4 show that as the height increases the drops have covered a comparable distance in a shorter time, in other words the drops have become faster. This approximately linear relationship, which is to be expected, can be clearly seen from a plot of the results (Fig. 5):

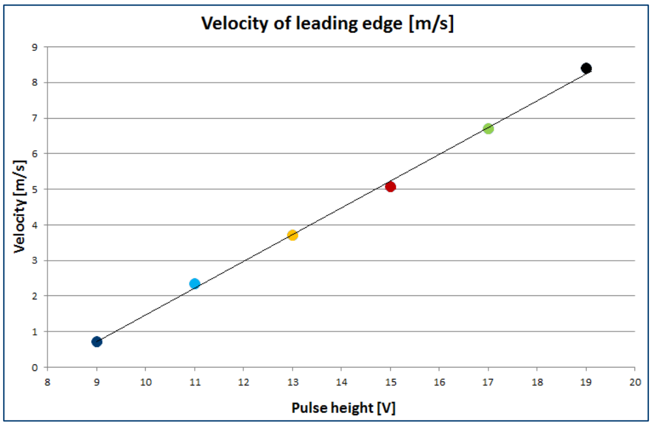

Fig. 5: Velocity of the leading edge as a function of pulse height determined with ADVANCE. The colors of the data points correspond to the outlines of the corresponding drop images in Fig. 4.

Effect of SFT and viscosity on jettability and satellite formation

Fig. 6 shows the drop generation and drop flight for five liquids with a constant waveform of 8 µs and 21 V.

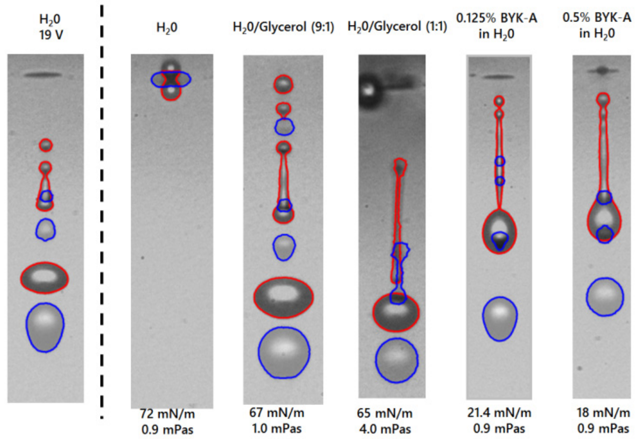

Fig. 6: Drops of different liquids each jetted with 21 V and 8 µs. The drop generation for water with a pulse height of 19 V can be seen on the far left.

As water cannot be jetted at 21 V, Fig. 6 also shows the drop generation with the highest possible pulse of 19 V. From the example of the two water/glycerol mixtures, it can be seen how an increase in viscosity at approximately constant SFT reduces the number of satellites generated. A similar effect is observed using the surfactant solutions as an example. A reduction in SFT at constant viscosity inhibits satellite formation.

Effect of pulse height, SFT, and viscosity on drop volume and velocity

Figs. 7 (top and bottom) show the drop velocity and drop volume, respectively, for the different test liquids as a function of pulse height at constant pulse width.

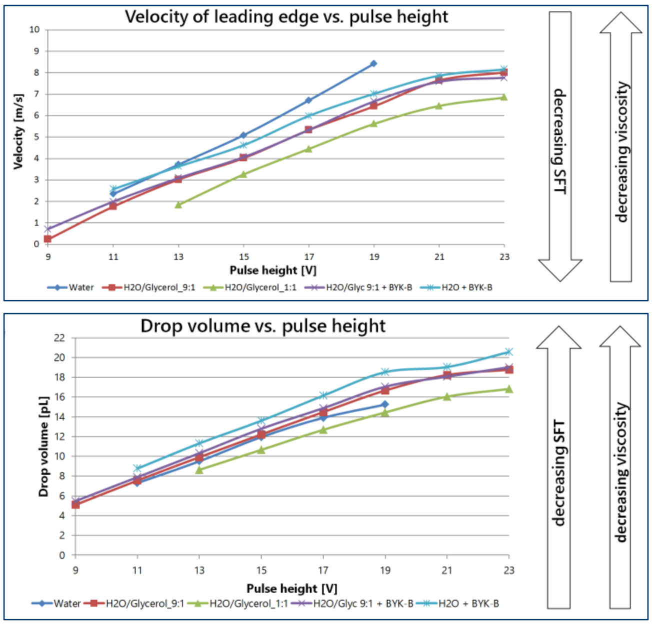

Fig. 7: Velocity of leading edge (top) and drop volume (bottom) for liquids of different SFT and viscosity at different pulse heights

From the diagrams, it can be seen that both drop volume and drop velocity increase approximately linearly with the pulse height for all liquids tested. It can also be seen that the drop velocity increases with increasing SFT or reducing viscosity. The drop volume increases with reducing SFT and with reducing viscosity of the liquid.

Effect of pulse width on drop velocity

Finally, by way of example, we determine a quantity which is characteristic for a given print head ink system, the measurement of which is expediently part of standard testing. The quantity in question is the pulse width at which the maximum drop velocity is achieved. Fig. 8 shows the drop velocity as a function of pulse width at a pulse height of 9 V for a solution of 2% BYK-B in water. The typical doubling of drop velocity at a relatively sharply defined pulse width can be seen.

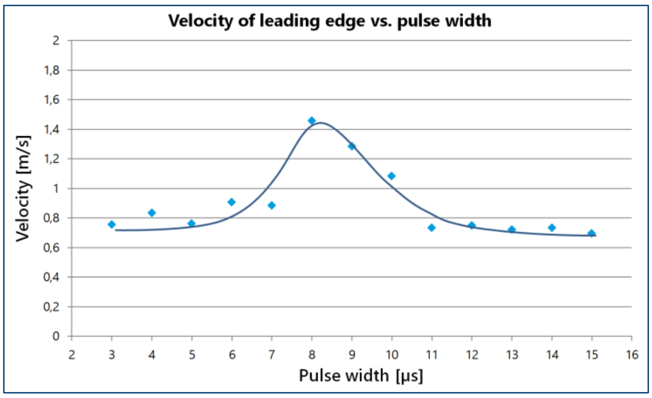

Fig. 8: Velocity of the leading edge as a function of pulse width at a pulse height of 9 V for a solution of 2% BYK-B in water

This maximum is determined by the geometry of the print head and the velocity of sound in the liquid. If the pulse width resonates with the running time of the acoustic pressure wave in the print head, primary and reflected wave constructively overlap, which causes the drop velocity to double.

Summary

The DSA Inkjet enables fast and precise analysis of ink drops immediately after jetting. We controlled the print head used for this study with a trapezoidal piezo pulse and jetted water-based test fluids with varied surface tension (SFT) and viscosity. This has enabled us to illustrate the following, basic relationships for drop generation:

- The volume and velocity of the drop increase approximately linearly with the pulse height.
- A reduction in SFT inhibits satellite formation.
- An increase in viscosity inhibits satellite formation.
- A reduction in SFT reduces the drop velocity.
- A reduction in SFT increases the drop volume.
- A reduction in viscosity increases the drop velocity and the drop volume.
- If the pulse width resonates with the running time of the acoustic pressure wave in the print head, the drop velocity can be doubled.

Bibliography

[1] Brian Derby, Inkjet Printing of Functional and Structural Materials: Fluid Property Requirements, Feature Stability, and Resolution Annu. Rev. Mater. Res. 2010. 40: 395–414

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