

Article

Enhancing Droplet Quality of Edible Ink in Single and Multi-Drop Methods by Optimization the Waveform Design of DoD Inkjet Printer

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Abstract: The multi-drop method with a good droplet quality is a big challenge in inkjet technology. In this study, optimization of Drop on Demand (DoD) inkjet printer waveform design was conducted. The effectiveness of the waveform design, so-called W waveform, from previous study as a preliminary vibration for the multi-drop ejection method was investigated. The unmodified W waveform was proven not to be an effective waveform for lower viscosity of liquid, especially when compared by the standard waveform obtained from a print-head manufacturer. Edible ink with a viscosity below the optimum range for print-head specifications was employed as the operating liquid. The preliminary vibration W waveform was modified to improve the droplet quality of the edible ink. It was proven that a 40% adjusted voltage of the rear wave of the W waveform was effective as the optimum waveform design for edible ink. The droplet quality of the multi-drop ejection method for grey-scale technology was improved by optimizing the W waveform design.

Keywords: waveform design; edible ink; inkjet printer; multi-drop



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1. Introduction

There are three fundamental components of an inkjet printer, namely the printhead, actuation waveform, and inks. The waveform is needed to actuate the piezo-electric for droplet ejection. A current requirement in inkjet printing technology is the establishment of printheads that have higher flexibility with fluid properties. A more flexible printhead versus fluid formulation can be achieved by the design of the printhead itself, or that of the operating parameters for actuating the printhead. Hence, using the same printhead for different liquid properties becomes a significant challenge for printer manufacturers [1]. It would be very beneficial for the printer company to use a few types of printheads for various types of ink or operating liquid. A printer company in Japan has different types of customers, such as medicine companies and food companies. The customers have different requirements. The flexibility of the printer capability is necessary for the printer manufacturer. Recently, they have had difficulty controlling the printing result for liquids with low viscosity, such as edible ink. Edible printing refers to the process of printing onto various food products using edible ink [2]. Edible ink is a liquid with edible food colours used for creating pre-printed images on various confectionery products, such as cakes or cookies. Designs made with edible ink can either be pre-printed or created with an edible printer, which is a specialty device that transfers an image onto thin, edible paper. The edible paper is made from starches and sugars, onto which edible food colours are printed. An unsuitable printhead for specific fluid properties will generate droplets of inferior quality. Instead of changing the printhead, which will be costly under certain conditions, the waveform design can be adjusted to use another fluid property. An optimum waveform design will generate superior droplet quality [3–8]. This liquid has a lower viscosity and is therefore more difficult to control.

One printer manufacturer in Japan got their printhead from a supplier which is a printhead manufacturer. The printhead they bought included the standard waveform design from the supplier. Figure 1 presents a droplet shape with poor performance when employing the standard/basic waveform. The standard/basic waveform is a waveform standard obtained from the printhead manufacturer. Even at low voltages, the actuating waveform could not generate a clear droplet. At 14 V for a single drop, the droplet was separated into two drops, while the others produced a droplet with a clearly visible tail. For the multi-drop concept, it was also found that a satellite would be generated at a low voltage, while a higher applied voltage would cause weeping.

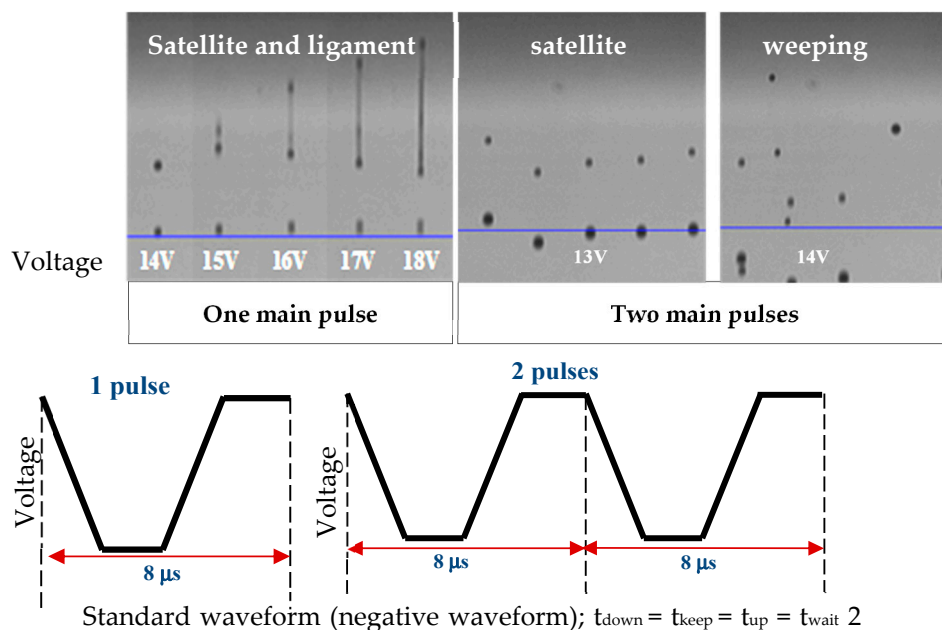


Figure 1. Droplet shape for edible ink using standard/basic waveform.

A study on waveform design using the preliminary waveform, namely the W waveform, proved effective for solving the problem of the satellite and ligament for both the single and multi-drop ejection methods [9]. The waveform parameters of the W preliminary vibration are illustrated in Figure 2. However, this waveform design is only effective in the optimum range of viscosity of the printhead specification, which is 10 to 12 mpa.s. In this study, the researcher faced the challenge of using the edible ink which has a viscosity of 7.6 mpa.s, which means that it was below the optimum viscosity range. Therefore, an optimized waveform design should be employed in the printhead to improve the droplet's quality.

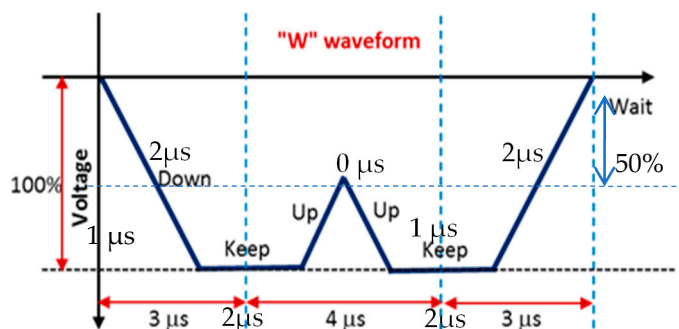


Figure 2. W preliminary vibration.

2. Research Method

The experiment was conducted using a droplet observation system GEN 5 which is connected to a computer. The ejection signal was sent to the printhead to generate the droplet and release it from the nozzle. The printhead used was the piezoelectric type D33. The droplet image was taken by a Charge-Couple Device (CCD) camera that was equipped with an iDS CMOS sensor and strobe lights from Japan manufacturer that were synchronized to the firing signal. We can see the droplet shape image on the computer's observation system. The delay time from nozzle until 1 mm from the nozzle is also displayed in the PC to obtain the droplet velocity. The experimental scheme is shown in Figure 3. The experiment was carried out using edible ink as the operating liquid at a temperature of 25 °C, frequency 1 kHz, and applied voltage range from 14 V to 18 V. The waveform design can be seen on the experimental device settings shown in Figure 4. The example droplets generated from the input pulse can be seen in Figure 5.

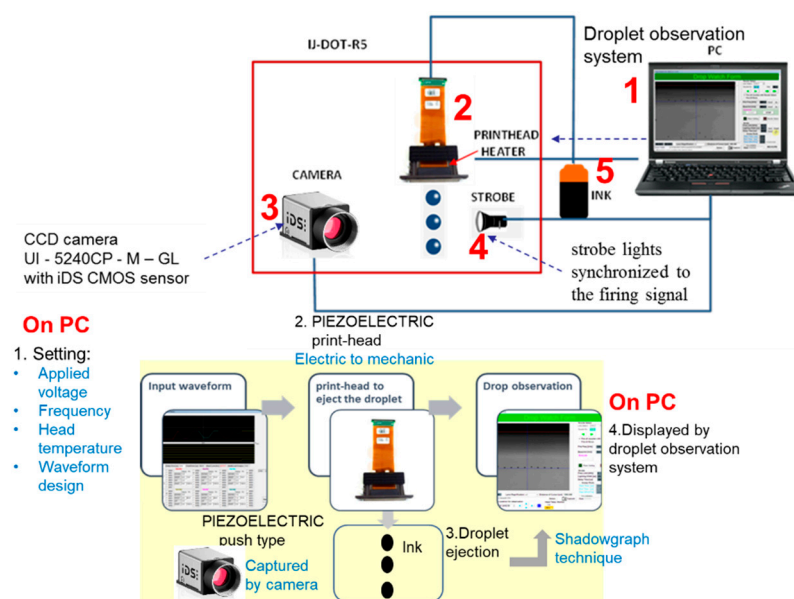


Figure 3. The experimental scheme.

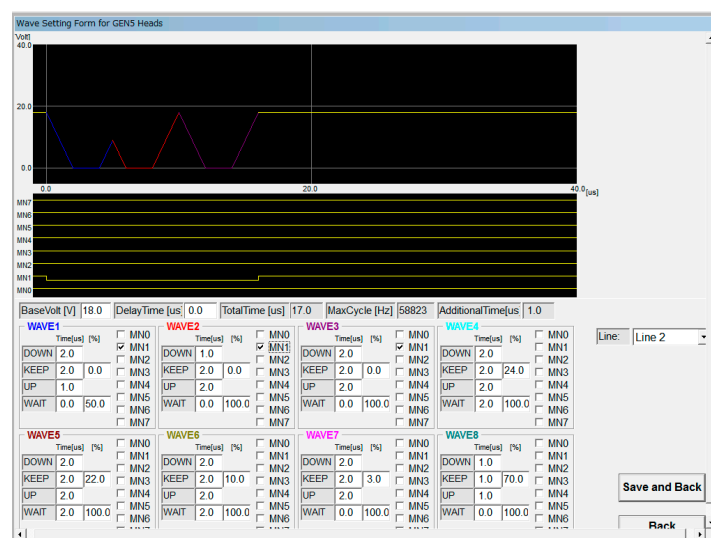


Figure 4. Waveform setting.

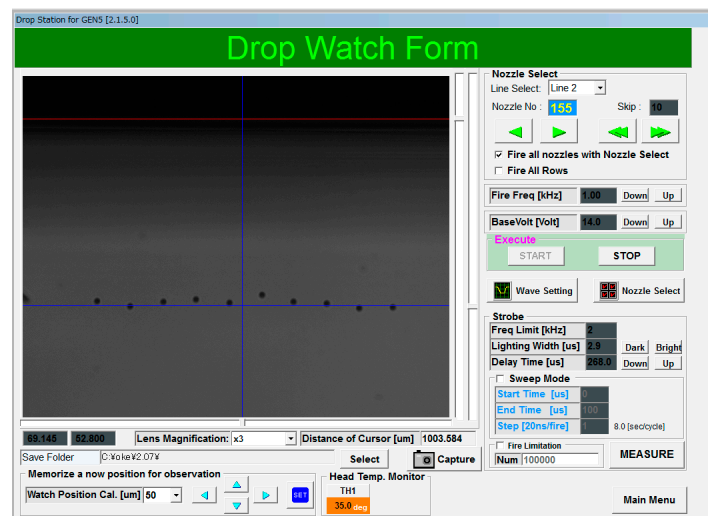


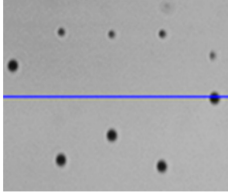
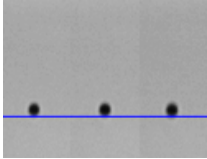


Figure 5. Drop watch from input waveform.

3. Evaluation of Unmodified W Waveform as Preliminary Vibration on Multi-Drop Method

The evaluation of the unmodified W waveform using edible ink as an operating liquid is presented in Table 1. It was demonstrated that the unmodified W waveform could control the droplet behaviour in a single drop by means of additional suppressing vibration at the last pulse. This could produce a clear droplet up to 14 V by using a 30% voltage from an additional suppressing vibration.

Table 1. Examination results of unmodified W waveform on edible ink.

Voltage	Preliminary Vibration W Waveform	Main Pulse	Suppressing Vibration	Droplet
13	✓	1	30% t_{wait} from main pulse = 0 μs $t_{\text{down}} = t_{\text{keep}} = t_{\text{up}} = 1 \mu\text{s}$	 Good (no satellite, no ligament)
14	✓	1	30% t_{wait} from main pulse = 0 μs $t_{\text{down}} = t_{\text{keep}} = t_{\text{up}} = 1 \mu\text{s}$	 Good (no satellite, no ligament)
15	✓	1	30% t_{wait} from main pulse = 0 μs $t_{\text{down}} = t_{\text{keep}} = t_{\text{up}} = 1 \mu\text{s}$	
14	✓	2	30% t_{wait} from main pulse = 0 μs $t_{\text{down}} = t_{\text{keep}} = t_{\text{up}} = 1 \mu\text{s}$	Poor (weeping)
14–16	✓	2	50% t_{wait} from main pulse = 0 μs $t_{\text{down}} = t_{\text{keep}} = t_{\text{up}} = 1 \mu\text{s}$	
17	✓	2	50% t_{wait} from main pulse = 0 μs $t_{\text{down}} = t_{\text{keep}} = t_{\text{up}} = 1 \mu\text{s}$	Poor (weeping)

For two main pulses, the unmodified W waveform was effective up to 16 V of the base voltage when using 50% additional suppression. These results are in strong agreement with the results from previous research [10]. The unmodified W waveform is only effective in producing a clear droplet without any satellite and weeping occurrences until three main pulses. Therefore, to gain a wider droplet size range the concept of the W waveform as the preliminary vibration must be improved.

4. Concept Improvement of W Waveform

One of the major issues affecting the droplet performance is residual vibration [11–13]. The fluid mechanics in the liquid chamber are not at rest immediately after the droplet is ejected; vibration remains owing to residual vibration. The residual vibration should be damped to control the droplet behaviour [14,15]. Optimization of the waveform design is therefore necessary to reduce the residual vibration and control the meniscus [16].

The preliminary study was conducted to simulate the meniscus behaviour by changing the waveform design [17]. The simulation used open-source software, namely Modelica. The study about the preliminary waveform called the W waveform revealed that the waveform was generated from two overlapped pulses with input parameter $t_{\text{down}}-t_{\text{keep}}-t_{\text{up}}$, respectively, 2 μs , 2 μs , 1 μs (50% adjusted voltage), then t_{wait} 0 μs , followed by the next pulse with $t_{\text{down}}-t_{\text{keep}}-t_{\text{up}}$, respectively 2 μs , for each parameter. W waveform consists of two ramps, namely the front ramp and rear ramp. An illustration of this concept is presented in Figure 6. This is the wave response from the front and rear ramp of the W waveform. The liquid viscosity will cause residual vibration, which is generated from both the front ramp and the rear ramp. The residual vibration from the front ramp will be damped by the rear ramp, as shown in the composite response. Nevertheless, the first peak from the rear ramp will still generate residual vibration in the total composite response of the front-rear ramp. Therefore, for damping the first “peak” from the rear ramp, the W waveform was modified by deducting the applied voltage in the rear ramp. This would reduce the residual vibration, which was hypothesized to prevent the occurrence of the satellite and weeping. The concept improvement with the “modified W” waveform is illustrated in Figure 7.

A comparison of the conceptual model between the “unmodified W” and “modified W” waveform is presented in Figure 5. It can be observed that the residual vibration from the W waveform could be reduced by the rear-ramp adjustment. Hence, an experimental study was conducted to verify the waveform design effectiveness.

In this study, optimization of the waveform design was conducted by using the adjusted rear ramp of the W waveform. This was employed as the preliminary vibration both for the single and multi-drop ejection methods. The optimization of the waveform design concept is illustrated in Figure 8.

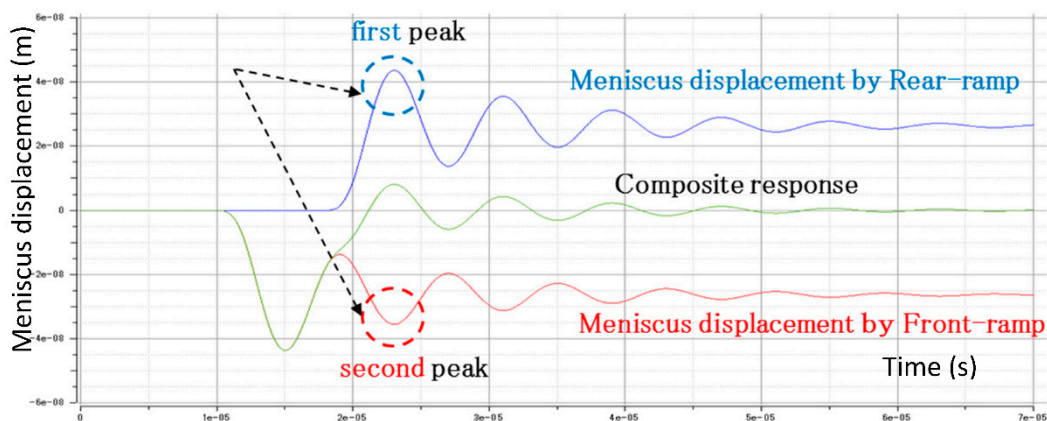


Figure 6. Front ramp and rear ramp in W waveform.

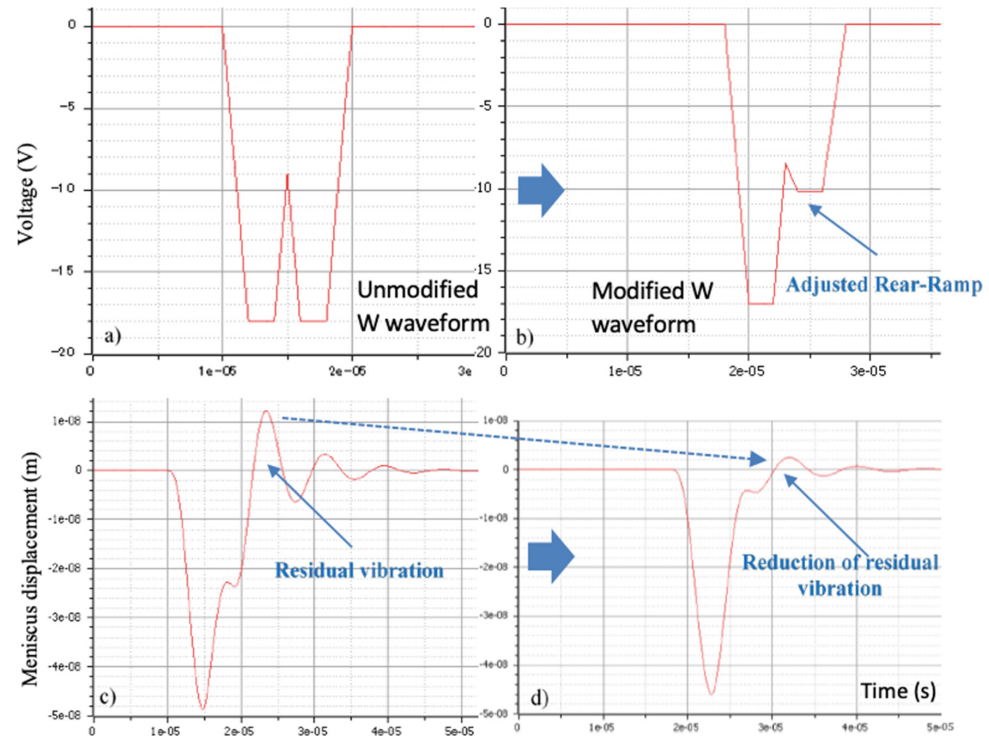


Figure 7. Comparison of and modified W waveform. (a) Input of unmodified W waveform, (b) input of modified W waveform with adjusted rear ramp, (c) response of unmodified W waveform, (d) response of modified W waveform with adjusted rear ramp.

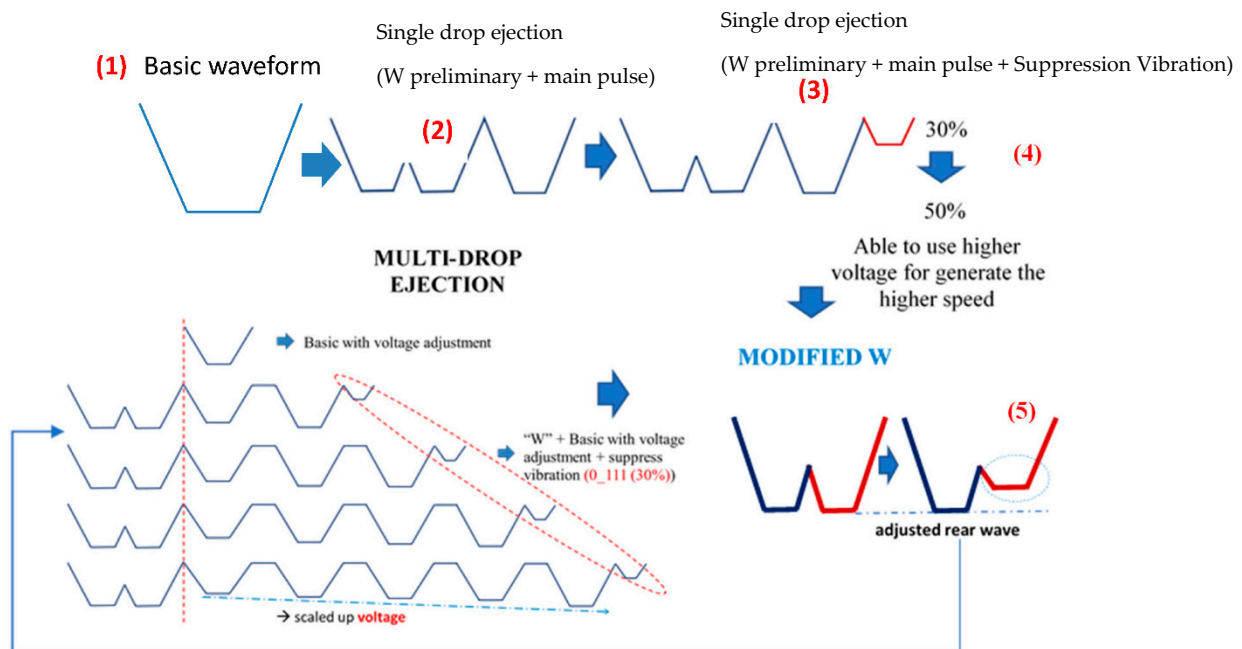


Figure 8. Concept of waveform design optimization.

5. Results and Analysis

The modified W waveform was employed in the experimental study by using the IJ-DOT-R5 apparatus, which was used to observe the droplet shape. The main objective of this study was to obtain a clear droplet with no satellite, ligament, or weeping occurrences. Different voltages were applied to determine the maximum voltage obtain the highest velocity and volume. It has been stated that a higher voltage results in a higher velocity and

a larger volume of the droplet [18–21]. The optimum voltage adjustment percentage for acquiring an effective droplet was obtained from an experimental study. The experimental results using different input parameters are presented in Table 2. The scale-up applied voltage was 20%, 30%, and 40% from full voltage with two conditions. The first condition was without suppression vibration and the other was with 30% suppression vibration on the final pulse. This table shows that the additional 30% small pulse with parameters $t_{\text{down}}-t_{\text{keep}}-t_{\text{up}}$, respectively 1 μs , was effective in generating a clear droplet in a higher applied voltage.

Table 2. Experimental results with different input parameters (modified W waveform with and without 30% suppression vibration).

Edible Ink	Main Pulse Number							
	1		2		3		4	5
	Full Voltage		Full Voltage		Scale-Up Voltage		Scale-Up Voltage	Scale-Up Voltage
Rear-Ramp Adjustment	No	30%	30%	30%	30%	30%	30%	
Voltage	Suppression Vibration	Suppression Vibration	Suppression Vibration	Suppression Vibration	Suppression Vibration	Suppression Vibration	Suppression Vibration	
13	●	●	●	●	●	●	●	
14	●	●	●	●	●	S	●	
15	S	●	W	●	●	W	S	
16	-	●	-	●	W	-	-	
17	-	S	-	●	-	-	-	
18	-	S	-	S	-	-	-	

●: Clear droplet; S: Satellite; W: Weeping.

It was determined that a 40% deduction of the rear ramp was required to generate a clear spherical droplet. This is shown in Table 3. This table shows the comparison of droplet generated from a modified W waveform with additional 30% suppression vibration with the standard waveform and an unmodified one. The modified W waveform design could generate a clear droplet until a 17 V applied a voltage for a faster droplet with a larger volume. Hence, we used a 40% deduction for the next design of the modified W waveform.

Table 3. Comparison of the generated droplet with different waveform designs (standard/basic waveform, unmodified W, and modified W).

Method	Single Drop						Multi-Drop								
	1			2			3			4			5		
Main Pulse	Waveform														
Voltage (V)	B	UW	MW	B	UW	MW	B	UW	MW	B	UW	MW	B	UW	MW
	13	S	●	●	S	●	●	W	●	●	W	S	●	W	S
14	S	●	●	W	●	●	W	●	●	W	S	S	W	W	●
15	L	●	●	W	W	●	W	W	●	W	W	W	W	W	S
16	L	S	S	W	W	●	W	W	W	W	W	W	W	W	W
17	L	S	S	W	W	●	W	W	W	W	W	W	W	W	W
18	L	S	S	W	W	S	W	W	W	W	W	W	W	W	W
Notes:	B: Basic waveform			UW: Unmodified W waveform			MW: Modified W waveform								
	S: Satellite			L: Ligament			W: Weeping			●: Clear droplet					

The experimental results using edible ink at an applied voltage of 14 V (one to five main pulses) are presented in Figure 9, which illustrates the expected performance of the droplet shape with no satellite, ligament, or weeping occurrence.

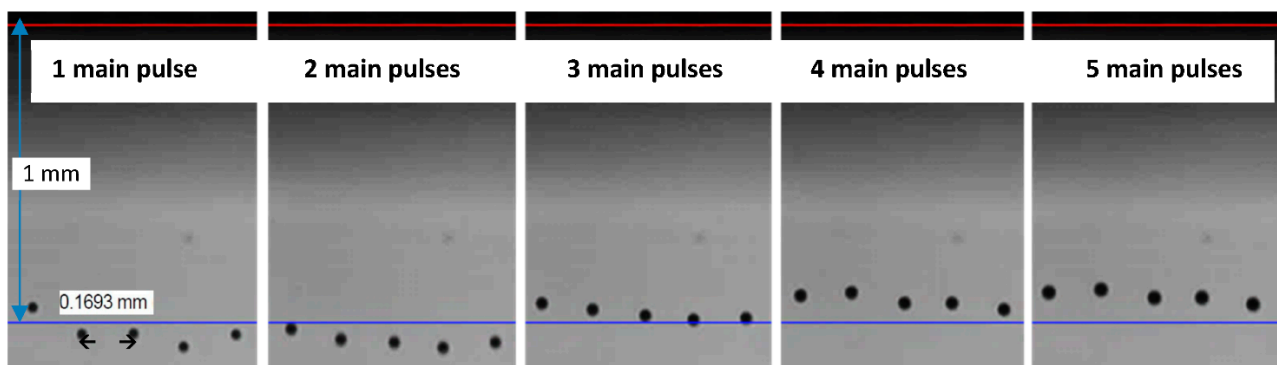


Figure 9. Droplet shape for edible ink using modified W waveform.

A comparison of the generated droplet with different waveform designs (basic, unmodified W, and modified W) is presented in Table 3. It demonstrates the effectiveness of the modified W in controlling the droplet behaviour after five pulses for obtaining a wider droplet size range in the multi-drop concept (greyscale technique). It is possible to improve the performance of four main pulses with an applied voltage of 14 V by adjusting the percentage of each pulse to obtain the optimum condition for reducing the residual vibration and eliminating the satellite.

6. Conclusions

The influence of the fluid properties on the droplet performance from an inkjet printer are inevitable. Hence, it is necessary to establish a flexible waveform design for different fluid formulations. In this study, edible ink with a lower viscosity than the optimum viscosity of the printhead specifications was used for verifying the effectiveness of the W waveform design. From the experimental study it was found that the unmodified W waveform (without an adjusted rear wave) is effective in generating a clear spherical droplet up to three main pulses. As an improvement of the W waveform design, we proposed the modified W by means of rear-ramp adjustment. It was proven that the modified W waveform is effective until five main pulses in the multi-drop ejection method. Therefore, the modified W waveform is suitable for edible ink or other liquids with a low viscosity.

The rear-ramp adjustment was performed by voltage deduction. This method was found to generate more suitable wave superposition in reducing the residual vibration. The optimum adjustment of the rear ramp was a 40% deduction from the base voltage for edible ink. The rear-ramp adjustment can reduce the residual vibration, as demonstrated by the simple conceptual simulation model established using Modelica.

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