The dynamics behavior of successive multiple droplets impacting onto hot surface under high concentration of ethylene glycol aquades solution

by Teguh Wibowo

The dynamics behavior of successive multiple droplets impacting onto hot surface under high concentration of ethylene glycol aquades solution

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Abstract. The aim of this research is to reveal the dynamic behavior of the successive multiple 20% ethylene glycol aquades droplet impacting on the hot surface. An experiment has been conducted by utilizing the stainless steel as the hot surface. The diameter of droplet and the impact velocity are 2.8 and 1.1 m/s, respectively. Then, the Weber number is approximately 55. In the present study, an induction heater is utilized to achieve the desired temperature of hot surface. It is set at 110 - 230°C. In addition, image processing technique is applied in order to obtain essential quantitative information from the multiple droplets. Based on the result, it is found that the secondary droplet starts to present at temperature 150°C. While at the temperature 230°C, the bouncing phenomena occurs several times. Finally, the present study has been able to reveal spreading characteristics of the droplet comprehensively and can be used as a starting point to develop further research.

Keyword: ethylene glycol, multiple droplets, image processing, spray cooling

INTRODUCTION

The research on the field of spray cooling has been focused on the improvement of the heat transfer between the fluid and the hot surface. For instance, Deendarlianto et al [1] have found that the combination of TiO_2 coating and ultraviolet irradiation are applied on stainless steel surface in order to enhance the adhesive force between the water and the surface. Moreover, the importance of surface roughness on the spray cooling ability has been investigated in detail by Deendarlianto et.al [2].

Furthermore, the heat transfer coefficient can be increased either by using more efficient heat transfer methods or by improving the thermophysical properties of the heat transfer material i.e. coolant [3]. The use of some binary mixtures has demonstrated good potential. Moreno et al [4], who investigate the pool boiling phenomena using water-ethylene glycol nanofluids, pointed that the use of some binary mixtures has demonstrated good potential. Hence, it is important to develop the use of water-ethylene glycol or other water based solution on the various type of cooling system.

There are some studies [4] [5] [6] [10] which were discussed the use of the ethylene glycol water solution as a coolant in heat exchanger process. As stated by Kandlikar [9], the heat transfer coefficient increases slightly with the

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addition of small amount of ethylene glycol to water. Also, the presence of ethylene glycol leads the change of coolant properties, such as surface tension. The reduction of surface tension will increase the ability of the droplet to spread on the hot surface. However, Zhang and Basaran [8], has revealed that the addition of the surfactant, which basically reduces the surface tension, can also rise the Marangoni stresses and inhibit the drop spreading due to the non-uniform distribution of surfactant along the fluid interface.

Although the application of ethylene glycol has widely spread in the field industry cooling system, the research which is focused on the droplet phenomena is rarely found. For example, Li et al [7] have studied the interaction between a single ethylene glycol-water droplet with a stationary sessile droplet. However, to the best of author knowledge, the phenomena of successive ethylene glycol aquades droplet impacting on the hot surface has not been investigated yet. Therefore, this research is conducted to obtain essential information regarding the phenomena of the successive multiple 20% ethylene glycol aquades droplet impinging the hot surface. The experiments are carried out by utilizing the visual observation through high speed camera supported with image processing technique. Two droplets are generated from the droplet controller so the interaction between them can be captured. Also, a wide range of surface temperature is used to study the behavior of the multiple droplets in different region.

METHODOLOGY

The experimental apparatus is schematically presented in Figure 1. It is placed in Laboratory of Fluid Mechanics of the Department of Mechanical and Industrial Engineering, Universitas Gadjah Mada. In general, the set up consists of the hot surface, droplet generator, a high-speed video camera, and lighting system.

The multiple droplets were injected to the hot surface through droplet generator which consists of a fluid tank and droplet injector. The liquid tank is placed at specific height as a liquid storage. Furthermore, the droplet injector, which is controlled by an automatic valve, is set on 70 mm above the hot surface. It produces the droplet which has diameter 2.8 mm. To capture the phenomena of multiple successive droplets in detail, a high speed camera Miro M310 is utilized. It offers advantage due to the ability to adjust the frame rate and image size so the optimal result can be achieved. In the present work, the frame rate and the resolution are set at 4000 fps and 1024x768, respectively. A set of LED lamp added with the diffusive layer is placed behind the hot surface as a lightning source. As a result, the visualization study can be conducted accurately.

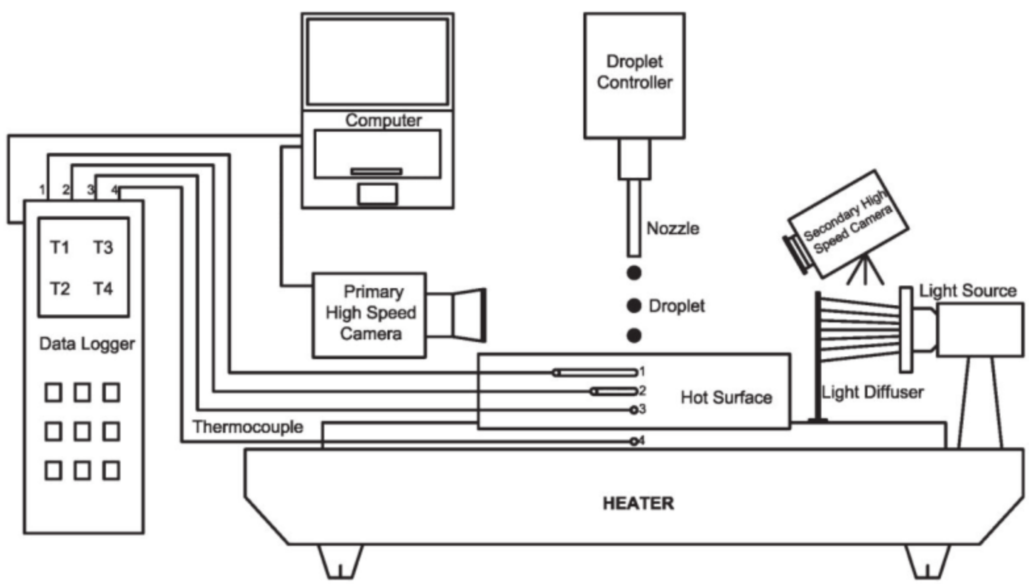


FIGURE 1. The schematic drawing of experimental apparatus.

In the present study, the mixture of aquades plus 20 % Ethylene glycol is used as cooling fluid. While the stainless steel is used as the hot surface which is placed on the induction heat heater. On the hot surface, three thermocouples is installed in the particular positions to ensure the desired temperature is achieved. The temperature of the hot surface is set on the range between 110°C and 230°C. Overall, the fluid properties and the temperature condition is summarized in the Table 1.

Table 1. the experiment condition properties of droplet at room temperature

Fluids	ρ (kg/m^3)	σ (N/m)	*We*	Temperatur (°C)
Water + 20% Ethylene glycol	1,019	0.048	55	110-230°C

As the temperature reaches the desired condition, the droplet is injected to the hot surface. The behavior of successive multiple droplets are recorded by high speed video camera then transferred to the personal computer. Here, an image processing technique is utilized to obtain the quantitative data from the image. The general steps of image processing technique applied in the present work are presented in the Figure 2. The raw image is processed through sequence function which produces binary image. Therefore the boundary of each droplet can be determined. It is used for measuring the spreading ratio of the droplet. Each temperature will be observed and analyzed in time series diagram.

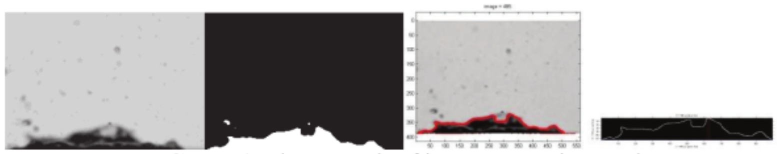


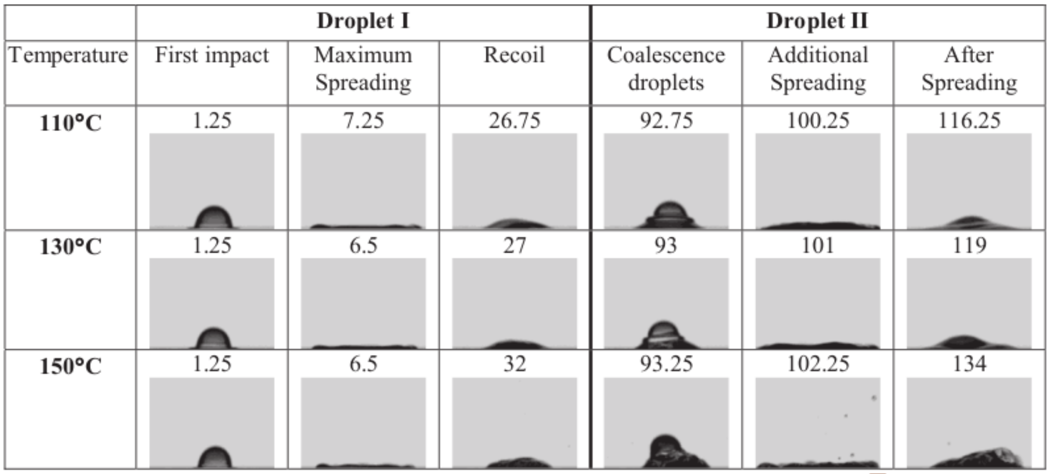
FIGURE 2. The Example of image processing result

RESULT AND DISCUSSIONS

The present work discusses the behavior of successive multiple 20 % ethylene glycol aquades droplets on to the hot surface. The observation using high speed video camera and image processing technique is able to reveal the droplet dynamics in detail. In general, the phenomenon can be explained as follows. After the first droplet impacts the hot surface, it will spread until reaches the maximum spreading value and then recoils. Therefore the spreading ratio decreases followed by some fluctuations. The presence of the second droplet affects the value of maximum spreading. Those phenomena which occur at various temperatures is discussed in this section and divided into three regions depending on the surface temperature.

Figure 3 shows the dynamic behavior of successive multiple 20 % ethylene glycol aquades droplets at temperature 110°C, 130°C, and 150°C. It is observed that as the first droplet achieve its maximum spreading, it starts to decrease. Since the surface temperature of this region is still considered low, the recoil process tends to be stable. The first droplet stays in its initial position so the second droplet impacts it completely. As a result, the droplet spreading, which strongly affects cooling performance can be improved. At the 110°C and 130°C, the spreading phenomena after the second droplet impacting the first droplet are similar to the previous one. On the other hand, at 150°C, there is tiny droplet which is separated from the main droplet. These phenomena, called the presence of secondary droplets, are affected by various factors including the impact energy and the heat transfer process inside the droplet.

To confirm the visual observation, the evolution of spreading ratio of successive single droplets at 110°C, 130°C, and 150°C obtained by image processing technique is depicted in Figure 4. On the first droplet maximum spreading, the spreading ratio achieves around 3.3 for all cases. However, at 150° C, it is found that the spreading ratio on the first maximum spreading is slightly lower than the others. This phenomenon occurred since at this temperature, the cooling process has produced tiny bubbles at the droplet body and surface. As a result, it slows down the spreading process. After 20 ms, the droplets recoils and Figure 4 reveal that the droplet spreading ratio tend to be constant before the second droplet impacts the first one and improves the spreading ratio significantly.



	Droplet I			Droplet II		
Temperature	First impact	Maximum Spreading	Recoil	Coalescence droplets	Additional Spreading	After Spreading
110°C	1.25	7.25	26.75	92.75	100.25	116.25
130°C	1.25	6.5	27	93	101	119
150°C	1.25	6.5	32	93.25	102.25	134

FIGURE 3. The visualization of the dynamics of successive single droplets at temperature 110°C, 130°C, and 150°C

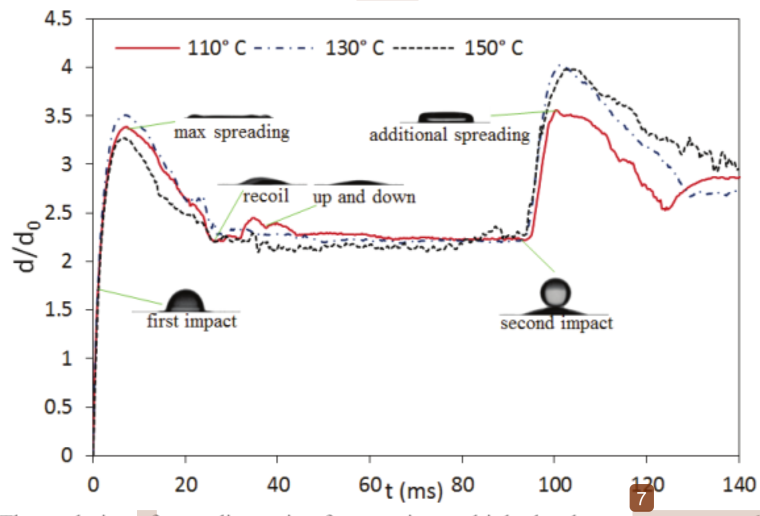
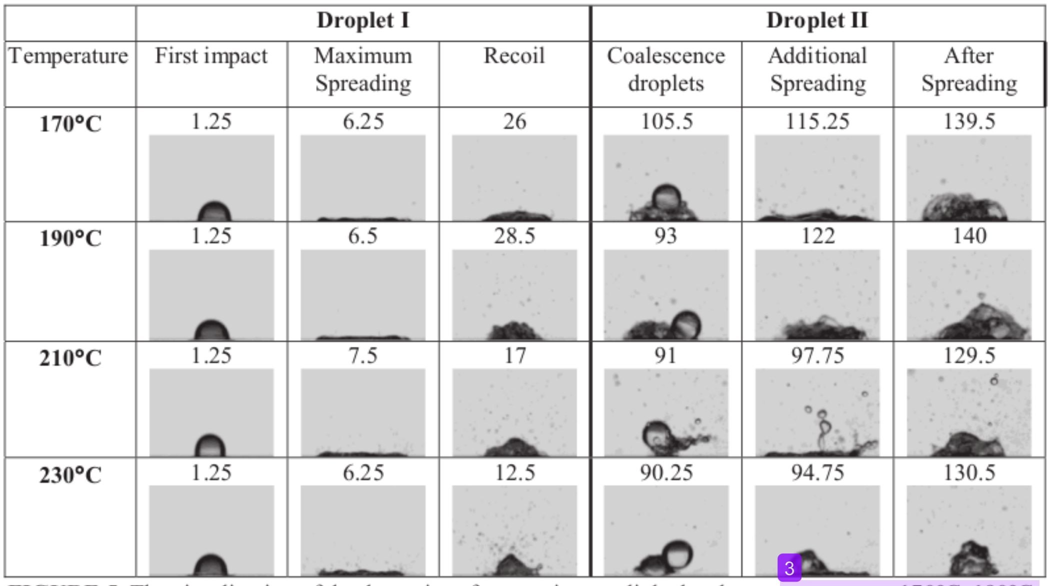


FIGURE 4. The evolution of spreading ratio of successive multiple droplets at temperature 110°C, 130°C, and 150°C

The increase of surface temperature causes the change of droplet behavior. Figure 5 shows the dynamics of single successive droplets at a higher temperature. Here, the temperature 170°C, 190°C, 210°C and 230°C are chosen as the example. Based on the figure, the presence of secondary droplet can be observed in the first droplet spreading process at 170° C - 210° C. Due to the number energy absorbed by the droplet, the number of secondary droplets even increases on the transition from spreading to recoil process. Consequently, the droplet volume decreases. Furthermore, it is also observed that after the second droplet impinges the first one, the bubble generation and break up inside the droplet affects the droplet interface. It looks relatively bigger and produces wavy interface.

Figure 6 shows the evolution of spreading ratio of successive single droplets at temperature 170°C, 190°C, and 210°C. In comparison with the previous region (110°C, 130°C, and 150°C), the maximum spreading of droplet in this region is slightly lower, around 3. Moreover, it is apparent that on the spreading ratio fluctuates during the recoil process. At 210°C, the spreading ratio on that stage is lower than the others. The decrease of the main droplet size is caused by the increase in the number and the size of the secondary droplet. Generally, the presence of second droplet in this region is still able to improve the spreading ratio as well as the wettability.



	Droplet I			Droplet II		
Temperature	First impact	Maximum Spreading	Recoil	Coalescence droplets	Additional Spreading	After Spreading
170°C	1.25	6.25	26	105.5	115.25	139.5
190°C	1.25	6.5	28.5	93	122	140
210°C	1.25	7.5	17	91	97.75	129.5
230°C	1.25	6.25	12.5	90.25	94.75	130.5

FIGURE 5. The visualization of the dynamics of successive mutliple droplets at temperature 170°C, 190°C, 210°C and 230°C

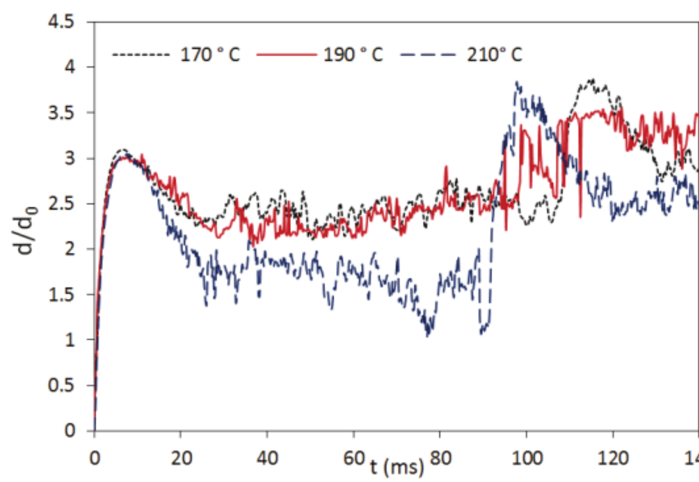


FIGURE 6. The evolution of spreading ratio of successive single droplets at temperature 170°C, 190°C, and 210°C

At 210° C, secondary droplet appears clearly even in the beginning phase of spreading as shown in Figure 6. Then the droplet interface changes continuously because of the internal flows inside the droplet. The detail phenomena of the droplet behavior at temperature 230°C is shown in Figure 7. It is noted that the droplet interfaces behavior in this region leads the droplet to bounce off the surface as soon as it recoils. The zero value at 20 – 50 ms indicates that there is no contact between the droplet and the hot surfaces. In addition, the droplet tends to not stay in initial impact position. It is because the significant difference between the temperatures of the liquid inside the droplet makes the instability of droplet surface tension occurs. As a result, the droplet rotates and slightly moves from the initial position. These phenomena are called Marangoni effect. Due to the movement of the first droplet, the second droplet is unable to impact the first one and directly impinge with the hot surfaces. Under those circumstances, the spreading ratio will not significantly improve.

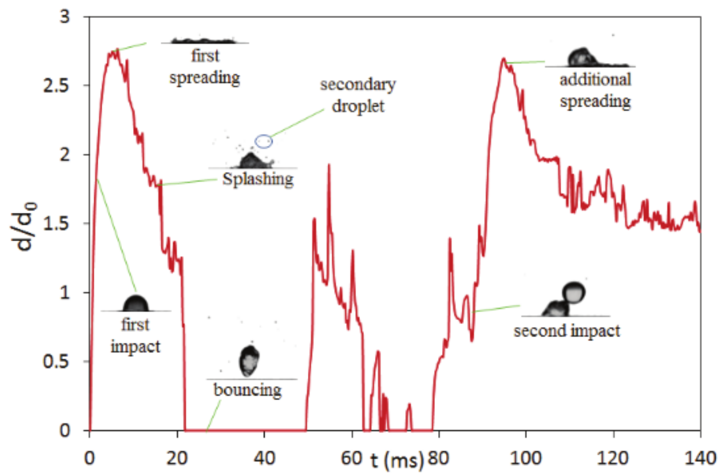


FIGURE 7. The evolution of spreading ratio of successive single droplets at temperature 230°C.

Figure 8 depicts the comparison of maximum spreading ratio after the presence of 1st droplet and 2nd at various temperature. In general, as the surface temperature increase, the maximum spreading ration after the first droplet impacting the hot surfaces decreases. It is because the liquid inside the droplet tends to be stable at the low temperature so the spreading process affecting by impact velocity occurs smoothly. Furthermore, under 230° C, the presence of droplet can improve the value of the maximum spreading ratio. On the other hand, at 230° C, the presence of thin gas layer and the influence of Marangoni effect cause the droplet cannot accurately impact the first one so the spreading ratio is not significantly affected.

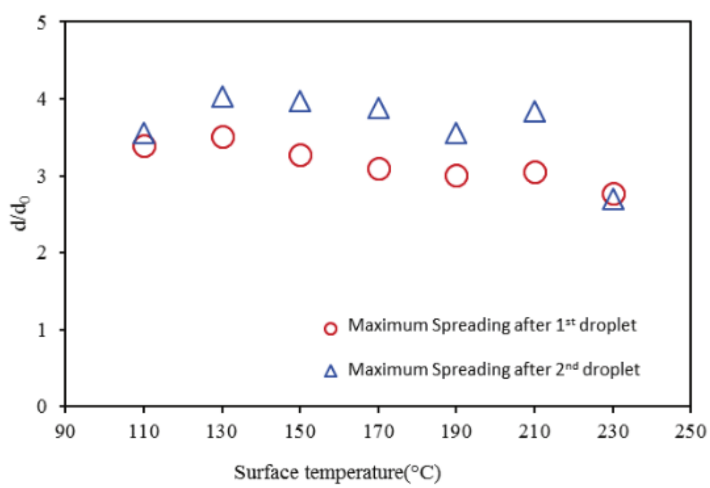


FIGURE 8. The comparison of maximum spreading ratio after the presence of 1st droplet and 2nd at various temperature.

CONCLUSIONS

The effect of 20% ethylene glycol aquades solution on the dynamics behavior of successive multiple droplets is investigated experimentally. It is found that the change of surface temperature produces the different behavior of the collision of the droplet. The highest spreading ration can be found at the temperature 130°C. While at the temperature 150°C, the secondary droplet starts to present and released itself from the main droplet. When the temperature reaches 230°C the droplet to bounce off the surface as soon as it recoils. It is clear that the present study has been able to reveal the behavior of the droplet in detail and can be used as a `starting point to develop further research in term of spray cooling utilizing different type of coolant.

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