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The Effect of Weber Number on the Dynamic Contact Angle During the Impacting of Single Droplet onto a Hot Oblique Surface

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Abstract. The effect of Weber number on the dynamic contact angle of single impacting droplet onto inclined hot surface has been studied experimentally. The Weber number variations are 10, 30 and 60. To adjust the Weber number variations, the droplet injector is modified at various height. In the present study, stainless steel is placed as heated material while the surface temperature is adjusted at the desired temperature, they are 100°C - 220°C controlled by the data logger. The droplet phenomena was recorded by high-speed video camera with frame rate 4000 fps and attached with the macro lens. The objectives of this studied are to understand the regime phenomenon, the time variations, and other important parameters of a droplet impacting onto an inclined surface. It was found that (1) the regime of droplet phenomena has specific models for each range of temperature, (2) The increase of Weber number decreases of contact time at temperature 200°C and 220°C, (3) The increase of Weber number increases the spreading ratio significantly at 200°C and 220°C, (4) The increase of Weber number will have significantly affected to result of advancing and receding contact angle are presented.

Keyword: droplet, single droplet, weber number, contact angle, image processing

INTRODUCTION

The spray-cooling method, or releasing particles of water with micrometric droplet sizes is very common for the cooling of mechanical tools. Impacting droplet dynamics with heated surface is a phenomenon that became a matter of interest for certain groups of researchers. The structure and the dynamics of liquids that were visible after the droplet contacted the heated solid surface are fundamental point for the case of impacting droplet. There are some droplet phenomena, such as spreading, splashing, and bouncing [1].

Investigated a droplet impacts on a heated surface with the temperature variations of 200°C, 250°C, 300°C, 400°C, 450°C, 500°C with the inclination angle of 15°, the impact velocity is 4.5 m/s, delivered with 4 regions, which are initial impact to maximum spreading, maximum spreading to receding, receding to evaporation and receding to bouncing [2].

Investigated the dynamics of water contact angle during droplet impact on different surface coating at various Weber numbers, they concluded that value of advancing contact angle are different compared to the values of static or quasi-static measurements. Also the increase of Weber number results of an increase in the gap between contact angle in advancing and receding [3].

Studied the effect of Weber number with impacting droplet on heated flat surface with the temperature range between 70°C and 400°C, Weber numbers were varied between 50 and 700. They reported that the velocity of bubble growth is independent of the Weber number and depends on the wall temperature [4].

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Studied the static contact angle on the droplet dynamics during impacting on heated surfaces. The increase value of static contact angle will decrease the wetting diameter value of a droplet while droplet is at wetting limit temperature of each coating material variation. This studied was conducted onto flat surfaces [5].

Observed the effect of Weber number and temperature towards the spreading characteristics of the droplet impaction resulted with some informations of droplet phenomenon, a) levitation after bouncing, b) levitation after the initial bounce, c) droplet disintegration after bouncing, d) droplet disintegration when impacting. They also informed that the disintegration phenomena occured when higher Weber number at the lower temperature, and otherwise when Weber number at lower number with higher temperature, different phenomena would occur, which are levitations [6].

Investigated the droplet impacting onto oblique surface. This studied was conducted on weber number 50, 90, 391 and under the room temperature. Their results indicated that the increase of Weber number increases the spreading in all directions also the rebound only occurred on a dry smooth glass and wetted surfaces [7].

Investigated the droplet impacting on a non-heated inclined area and found the increase of Weber Number can raise the spreading factor value. This research was conducted on dry inclined surface at temperature 25°C. They presented a theoritical formula to predict the maximum spreading area when we<1000 [8].

There are several experiments about droplet impacting onto oblique hot surfaces however the studied on the effect of Weber number on the dynamic contact angle onto hot oblique surface is rarely found. The aim of this study was to obtain the essential information of the droplet phenomenon onto hot oblique surfaces at Weber number variations then classifies the dependance on specific parameters reveal to the present study.

EXPERIMENTAL APPARATUS & PROCEDURE

The experimental apparatus used in the present study is shown as Fig. 1. It consists of droplet injector, heating surface, high speed video camera, LED light source, data logger and laptop or PC for data acquisition of surface temperature and record the visualizations. The heated surface is adjusted into 45 degree inclined and heated speciments of stainless steel at the temperature of 100°C to 220°C.

For the purpose of Weber number variations, the height of droplet injector is modified at 3 positions, (1) We = 10, (2) We = 30, (3) We = 60. The data visualizations recorded by high speed video camera that require bigger data space and high transfer rate, the harddisk SSD have been used at current study. A macro lens attached to the camera so the droplet phenomenon can be clearly recorded. In the present study, the video images were taken at 4000 frame per second while the output resolution of the camera was set on 1024 pixel x 768 pixel. The high speed camera was set on manual focus to minimize any defocusing while capturing the object.

The experimental set up described in Table 1, the heated surface material made of stainless steel (S304) placed on variations of Weber number of 10, 30 and 60 as generally described in Table 1. The diameter size of stainless steel material about 50 mm. The droplet size diameter was measured on actual condition while impacting on heated surface by image processing technique. The room temperature on this study maintained at 25°C.

TABLE 1. Experimental conditions

Weber Number	Height of droplet injector (cm)	Inclination angle (°)
10	2,6	45
30	7,7	45
60	15,4	45

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In the present study, A heater controls the temperatur gradually from 100°C to 220°C. The data logger is used as warning sign of the temperatur. The droplet injector has been calibrated to produce a single droplet consistently at range of droplet diameter 3.2 mm. Next, liquid droplet were injected on droplet injector with follow all the experimental parameters and conditions. The time variations of liquid impacting droplets are observed visually at each temperature on Weber number variations.

To obtain the droplet dynamics during impacting on oblique hot surface, three output parameters are produced: the wetted diameter area d, the droplet height h, the contact angle of droplet θ, however some adjusments have been applied to this study to assure the quality result of image processing. In summary, the leading method of this process divided into several steps. First, the videos were extracted into several image sequences, then the images were converted from JPEG to binary image with adding some filters based on threshold adjustment. The value of threshold may be different for each images to minimize noise pattern of outter droplet boundary. Afterwards, an additional algorithm of image rotation was applied into 45° of inclination angle. All of the the programming data calculations were introduced by[9]. As inclined surface used on this study, the contact angle will be divided into two categories: advancing contact angle of the front side (θ_a), and receding contact angle of the rear side (θ_r) as described in Fig. 2. In the present study, the additional program has been developed to calculate the change of front (X_{front}) and rear (X_{rear}) distances to produce droplet velocities per actual frame rate as shown in Fig. 2 & Fig. 3.

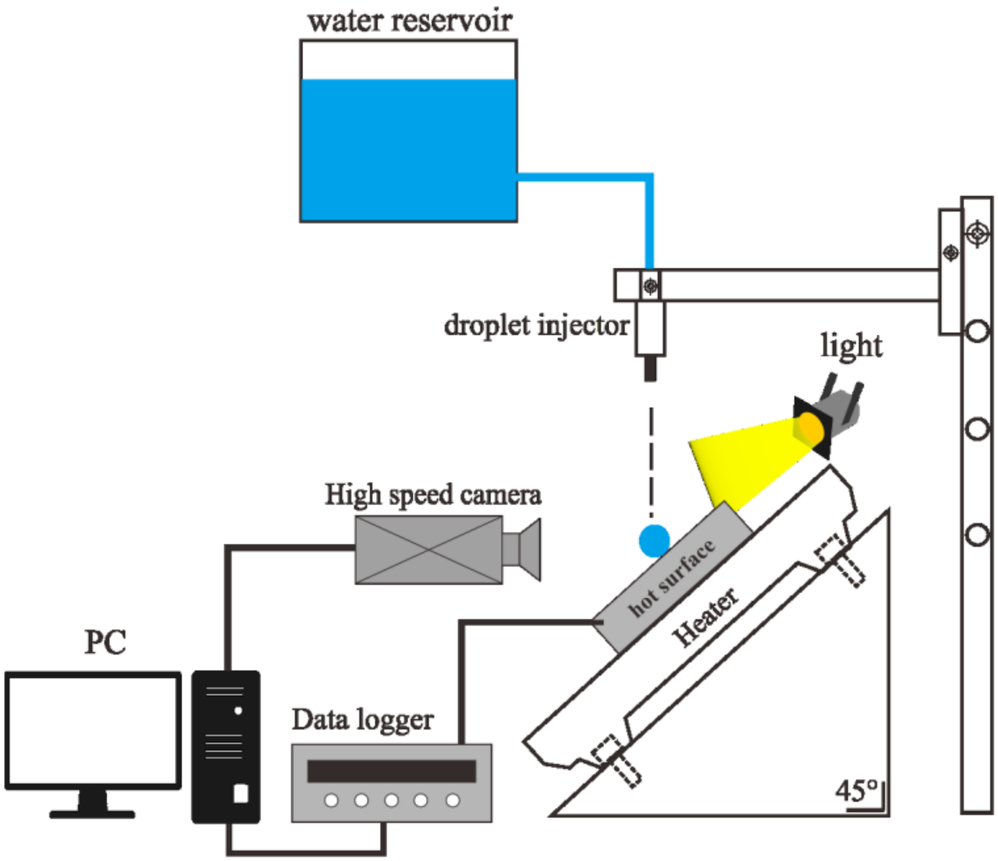


FIGURE 1. Experimental apparatus

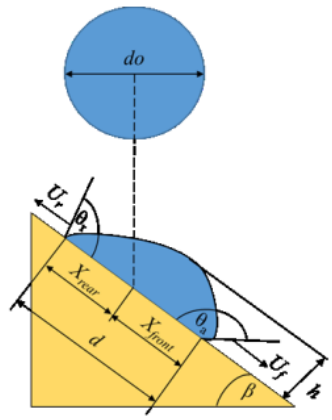


FIGURE 2. Characterizations of spreading ratio (d/d_o), apex height (h/d_o), sliding distance (X), droplet velocities, contact angle impacting onto inclined hot surface

RESULT AND DISCUSSION

Fig. 4 shows the dynamics behaviour of droplets impacting onto oblique hot surface. The inclination angle of 45° from horizontal axis, the surface temperature of 220°C, droplet diameter 3.2 mm and Weber number variations were 10, 30, 60. The visual observation of that figure reveals that increase of Weber number does not reflect to increase the time to achieve maximum spreading and receding. The increase of Weber number of 10 to 30 significantly increases the time to achieve maximum phases of spreading and receding. The maximum spreading time achieve at t = 6.5 ms of We = 10 when compared to We = 30, the time would take longer at t = 14.0 ms. Whereas, the increase of Weber number of 30 to 60 decreases the time to achieve maximum of droplet phases. The fact can be shown at t = 10.5 ms of We = 60 at spreading phase.

Fig. 5 indicated that the increase of Weber number accelerates the time to achieve spreading maximum. Spreading maximum at t = 26.5 ms of We 10. Then compared to We = 30, the spreading maximum at t = 12.75 ms. Afterwards, for higher Weber number, the time to achieve spreading maximum is at t = 10.25 ms of We 60. Fig. 5 reveals also that the Weber numbers has significant effect with contact time after droplet impact onto hot surface. The higher Weber number, the shorter the contact time, also accelerates the time of droplet to bounce and detached from surface. The fact can be shown in Fig. 4, at t = 20 ms, the droplet bounced from surface at We = 60 while the other Weber numbers of 10 and 30 take longer time to detach from surface.

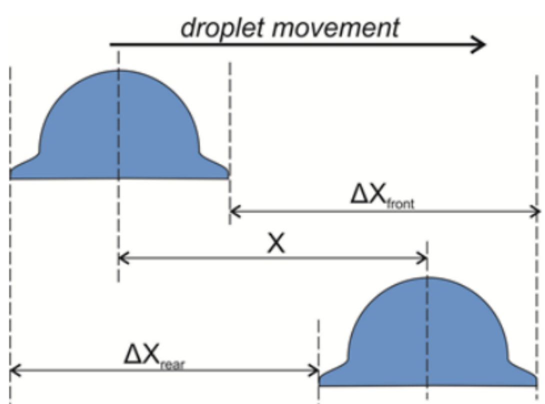


FIGURE 3. Definitions of sliding distance of droplet impacting onto hot surface.

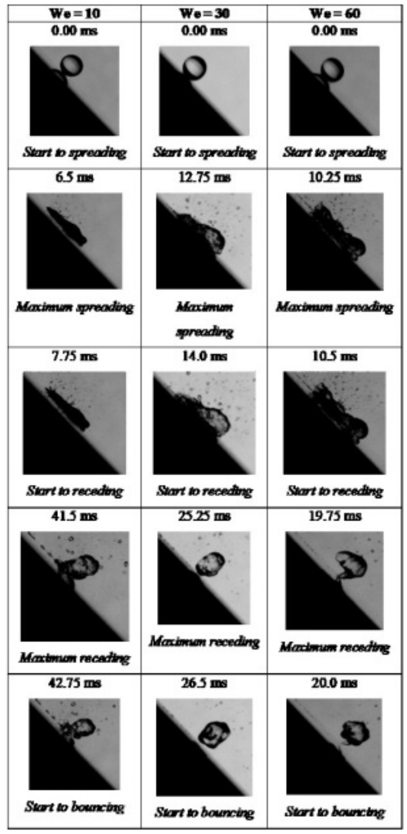


FIGURE 4. Time variations of dynamics droplet behaviour during impacting onto hot oblique surface (inclination angle of 45° from horizontal, surface material temperature of 220°C, initial droplet diameter 3.2 mm)

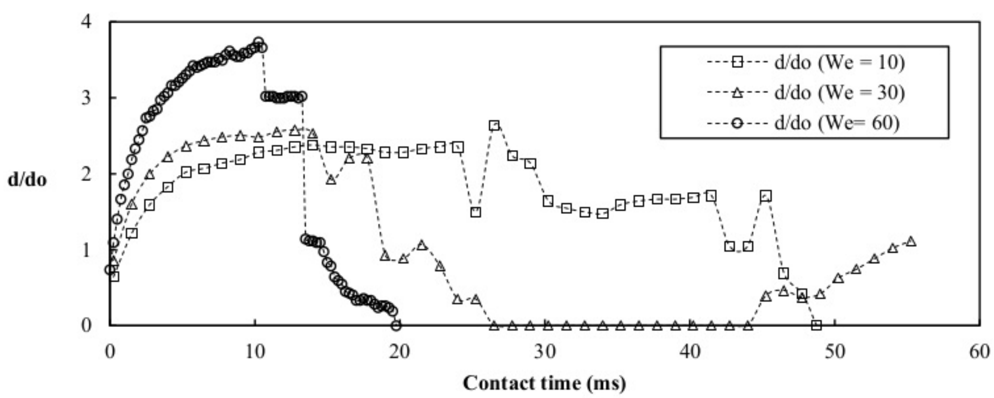


FIGURE 5. The evolution of spreading ratio at various Weber number (inclination angle of 45° from horizontal, surface material temperature of 220°C, initial droplet diameter 3.2 mm)

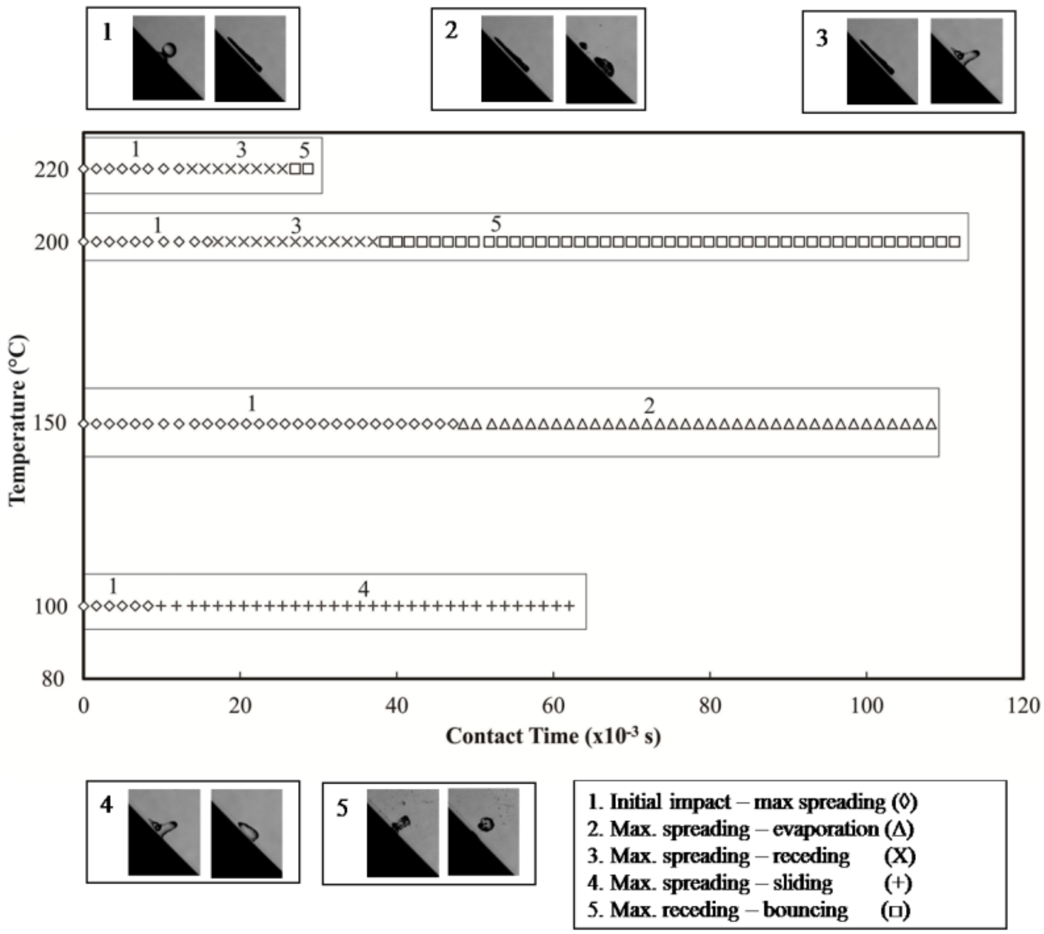


FIGURE 6. Regime history of impacting droplet dynamics at various temperatures (inclination angle of 45°, Weber number 60)

Fig. 6 shows the result of regime history at Weber number of 60, the inclination of angle 45°. At various temperatures, the different numbers were given for each phenomena during impactions. The result indicated 5 different phenomena as shown in Fig. 6, categorized into number 1, 2, 3, 4, 5. The spreading phenomena occurred in all various temperature as shown in Fig. 6. The evaporation phenomena occurred when the temperature was 150°C, marked by the appearance of the secondary droplets in box number 2. Next, the sliding phenomena generally occurred at the low temperature of 100°C. In the present study, the sliding phenomena only occured at temperature of 100°C. It shows a droplet move downward after spreading phenomena already achieved with no physical appearance changed such as secondary droplet.

Next, the increase of temperature decreases the contact time at specific temperatures, exactly above leidenfrost point 200°C, 220°C which has spreading, receding and bouncing phenomenon as shown in Fig. 6. However the increase of temperature from 100°C to 150°C takes longer the contact time. This is likely happened due to the evaporation phenomena holds a droplet to recede and rebounce. The bouncing phenomena occurrs when the temperature is at 200°C and 220°C. It is possible to conclude that the increase of temperature holds the main factor on the effect of the dynamic droplet impacting at time variations. [2]was experimentally the droplet impacting onto inclined surfaces at temperature 250°C, 300°C, 400°C, 450°C, and 500°C. They categorized the droplet phenomena in three regions, region I is initial impact to maximum spreading, region II is maximum spreading to maximum receding, then region III is maximum receding to maximum bouncing.

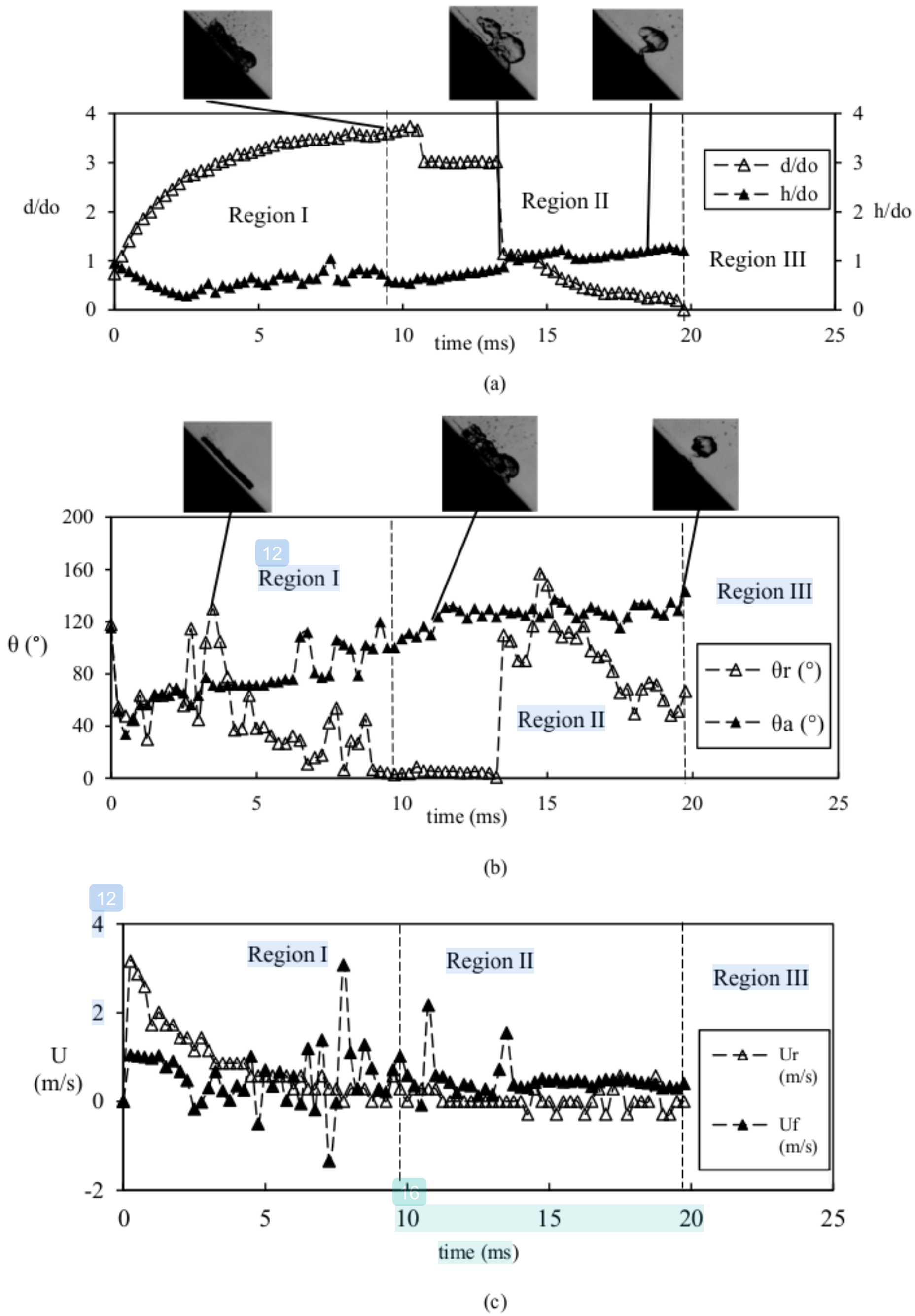
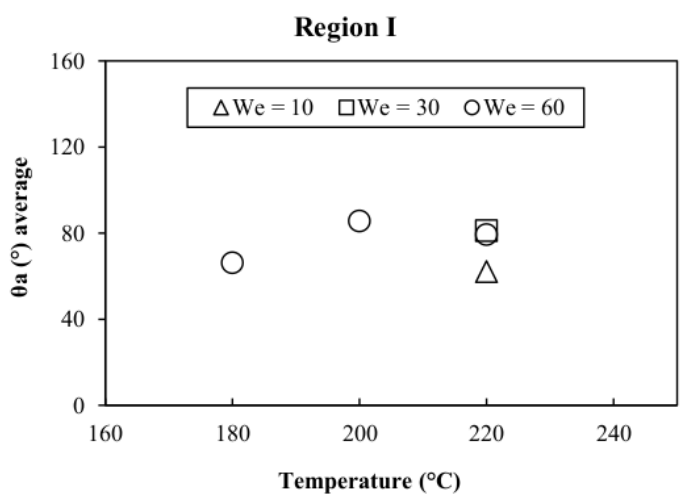


FIGURE 7. Time variations of (a) d/d_o and h/d_o, (b) receding and advancing contact angle, (c) rear and front velocity during the impacting of single droplet onto inclined hot surfaces (We = 60, θ = 45°, surface temperature of 220°C)

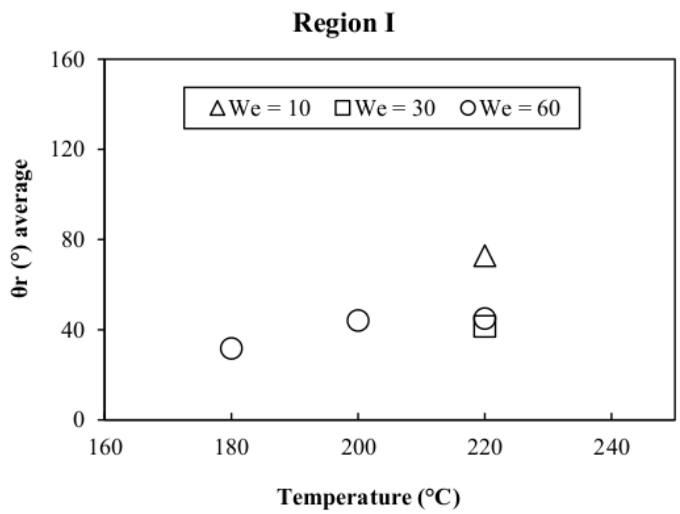
The values of spreading ratio (d/d_o), apex height (h/d_o), advancing contact angle (θ_a), receding contact angle (θ_r), droplet front velocity (U_f), droplet rear velocity (U_r) are plotted in Fig. 7 (We = 60, $\theta = 45°$, surface temperature of 220°C), the result of observations are as follows:

- From the visual observation of regime history, it shows the droplet phenomenon categorize in three regions, they are region I as spreading, region II as receding, and region III as bouncing.
- In region I shows the value of d/d_o increases to spreading maximum and decreases until the minimum value of height droplet. In this region, the contact angle resulted on small oscillation value of advancing and receding contact angle caused by the evaporation already occurred. It shows the secondary droplets at t = 3.5 ms. Moreover, the different value of U_f and U_r in the region I indicates the spreading process. At the initial of droplet impacting, the front side of droplet move faster than rear side. Next, the rear side comes to overtake the value by producing small oscillated pattern.
- In region II, the receding phase occurred when the apex height starts to increase and spreading ratio starts to decrease, it shows unity value at t = 13.75 ms. In this region, the receding contact angle reachs minimum value while advancing contact angle achieve maximum value. The bigger oscillation pattern of dynamic contact angle values in this region indicated the evaporation occurred on the receding phase. The results of U_f & U_r come to stable result of U_f higher than U_r.
- In region III, the droplet starts to leave from the surface called as bouncing phenomena. The maximum contact time indicated the value of bouncing phenomena occurred in this region. The value of d/d_o reaches to 0 as minimum value; otherwise the h/d_o comes to maximum value as a droplet enlarges vertically to jump from hot surface.

In addition to dynamic contact angle investigations at region I of spreading phase resulted the average value of dynamic contact angle of advancing and receding on droplet impacting onto oblique surface as shown in Fig. 8. In the Fig. 8 (a) displays the increase of Weber number increases the value of advancing contact angle respectively at temperature of 220°C. In Fig. 8 (b) indicated the increase of Weber number decreases the value of receding contact angle. It caused by gravity effect tends a droplet to move downward. It confirms that all the result of θ_a and θ_r correspond to high wettability as average contact angle <<90°.



(a)



(b)

FIGURE 8. Average value of (a) advancing contact angle at region I, (b) receding contact angle at region I

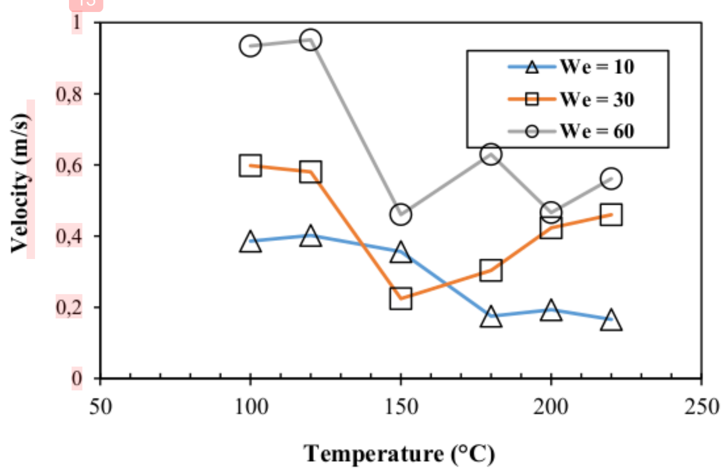


FIGURE 9. Droplet velocity at spreading phase

The sliding velocity value of a droplet is measured based on the sliding distance with the contact time as described in Fig. 3. In Fig. 9 shows that the increase of Weber Number significantly affects the value of droplet velocity towards the various temperatures. The increase of Weber number from 100°C to 120°C increases the droplet velocity. However, the velocity value tends to oscillated pattern while entering the temperature of 150°C. It causes by the evaporation occurred at this temperature. Next, the higher Weber number at higher temperature of 180°C to 220°C increases the droplet velocity respectively.

Fig. 10 shows the effect of Weber number to the result of maximum spreading ratio. It shows that the highest of Weber number on this study does not reflect the highest spreading maximum at various temperatures. Afterwards, it is possible to conclude that the increase Weber number from 10 to 30 will increase the value of spreading maximum, instead of the increase of Weber number from 30 to 60 will build smaller.

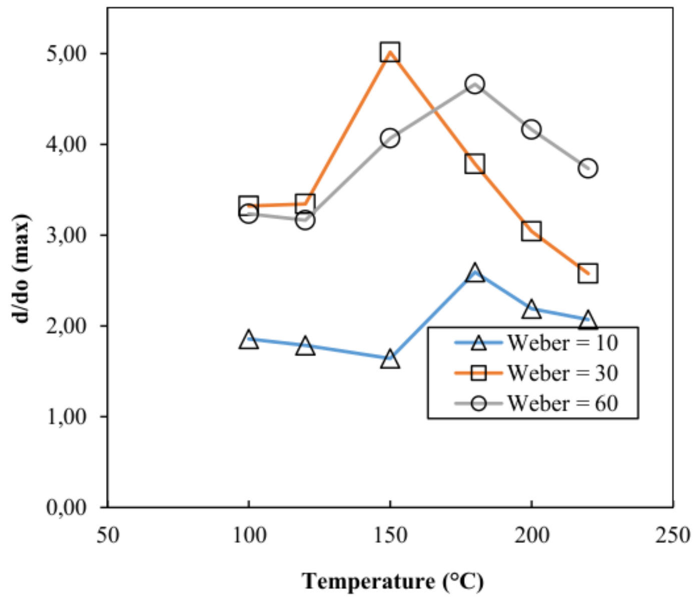


FIGURE 10. The effect of surface temperature and weber number variations on the spreading ratio maximum d/d_o (max)

CONCLUSION

The effect of Weber number on the dynamic contact angle of a single impacting droplet onto inclined hot surface has been studied experimentally. Weber number varies from 10, 30, 60. Dynamic behaviour phenomenon were captured by high speed video camera which analyzed by image processing technique with some additional adjustments. Several outputs such as spreding ratio (d/d_o), apex height (h/d_o), advancing contact angle (θ_a), receding contact angle (θ_r), droplet velocity (U) are summarized as follows:

1. In the visualization overview, droplet has several types of droplet phenomenon such as spreading, evaporation, sliding, receding and bouncing.
2. The increase of Weber number increases the spreading ratio of droplet impacting
3. The increase of Weber number accelerates the time to achieve spreading maximum
4. At above leidenfrost temperature, the regime phenomena will definitely occured in three regions, they are spreading, receding and bouncing.
5. The result of dynamic contact angle such as receding and advancing contact angle, weber number 10, 30, 60 corresponds to high wettability <<90°.
6. The increase of Weber number increases of droplet velocity at all various temperatures except at 150°C.

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REFERENCES

1. S. Chandra and C.T. Avedisian, Proc. R. Soc. *A Math. Phys. Eng. Sci*. **432**, 13 (1991).
2. Deendarlianto, Y. Takata, A. Widyatama, A.I. Majid, A. Wiranata, A. Widyaparaga, M. Kohno, S. Hidaka, and Indarto, *Int. J. Heat Mass Transf.* **126**, 39 (2018).
3. M. Remer, M. Psarski, K. Gumowski, J. Rokicki, G. Sobieraj, M. Kaliush, D. Pawlak, and G. Celichowski, *Colloids Surfaces A Physicochem. Eng. Asp*. **508**, 57 (2016).
4. H. Chaves, A.M. Kubitzek, and F. Obermeier, Int. J. Heat Fluid Flow **20**, 470 (1999).
5. Deendarlianto, Y. Takata, S. Hidaka, Indarto, A. Widyaparaga, S. Kamal, Purnomo, and M. Kohno, *Int. J. Heat Mass Transf.* **71**, 691 (2014).
6. S.G. Kandlikar, M.E. Steinke, and A. Singh, Proc. Natl. Heat Transf. Conf. **2**, 1035 (2001).
7. Š. Šikalo, C. Tropea, and E.N. Ganić, *J. Colloid Interface Sci*. **286**, 661 (2005).
8. K. Konakom, P. Kittisupakorn, and I.M. Mujtaba, 2011 Int. Symp. Adv. Control Ind. Process. 361 (2011).
9. R.R. Windy Hermawan Mitrakusuma, Deendarlianto, S. Kamal, M. Nuryadi, Proceeding Semin. Nas. Thermofluid VI 186 (2014).

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