Spreading Liquid on Moving Textured Surface

Abstract

After the impact of a liquid drop either on a stationary or a moving surface, the lamella can bounce back, spread or splash. The dynamics of its motion depends on some of the factors such as size of drop, drop impact velocity, surface characteristics like surface tension, surface roughness etc. Our review focuses on the experimental arrangements and numerical simulations studies of the dynamics of drop on moving surface with varying the different surface roughness with covering the range of hydrophilic and hydrophobic surfaces. We will also discuss the numerical modeling. Attention is also paid on the study of drop behaviour when changing the impact velocity and surface velocity, which will be relevant to many industrial applications.

Keywords: lamella, splashing, spreading, hydrophilic and hydrophobic surface

1. Introduction

In various technological applications include the impact of the liquid droplets on moving surfaces. Some of the examples are in printing, bed reactors and also cooling of hot electronic chips, hot metal alloys, rolling mills is done with the help of spraying the liquid on their surfaces in steel industries according to a review done by Yarin **[1]**. The study of a drop dynamics on a moving solid substrate is also essential for understanding the behaviour of different types of fluid, having different surface tensions. Inkjet printers are the best example of this as the ink sprayed over onto a moving sheet. The technique is also used in agriculture for spraying pesticides. Other examples of this phenomenon are automobile sectors, railway industries, and turbine blades manufacturing industries where spray coatings paint the parts. Also, the vehicle body passed through a spray zone one by one for mass production in automobile industries.

We emphasize our review based on the liquid drop impacting on a moving plate and a stationary plate and the change in the lamella shape when the key factors like surface roughness, droplet impact velocity, drop size, solid plate velocity etc. is changed. Here, lamella refers to the liquid bulk. Recently, Li et al. **[2]** investigated the dynamic behaviour of water drop changing the impact velocity and they studied the phenomenon of rebounding of the drop after impacting on the superhydrophobic surface. It should be noted that most of the studies and experiments were carried out for a smooth surface and with a stationary plate or inclined surface. Still, the detailed research to find the dependency of drop shape after impacting on a moving surface with varying surface roughness remains undiscovered.

We also modified the governing equations for our case, and non-dimensionalised it which will be used for the numerical simulation. We also studied the different experimental techniques used to generate a drop. We used Volume of Fluid model for our simulation, and then the simulation results will be validated with the experimental observations.

2. Discussions

2.1 Drop Impact Dynamics

The drop impact dynamics depends on the velocity of its impact, diameter of drop, surface tension values, surface roughness of surface. It also depends on the liquid properties like viscosity and density. Yarin **[1]** worked on the development of CFD models to simulate drop impact having low Weber number and provided experimental data to validate the CFD model results.

Studies performed by Gunjal et al. **[3]** at various impact velocities and at different contact angles. They used two types of surfaces glass (hydrophilic) and Teflon (hydrophobic) and two liquids- water and mercury and found three different regimes. The different regimes are-

(a) *Oscillations*: the drop starts to spread and recoils many times, and finally, it will come to rest minimizing its energy.

(b) *Rebounding*: the drop bounces back in an upward direction after striking with the surface.

(c) *Splashing*: the drop breaks into smaller droplets after its impact with the surface.

Oscillations include the term spreading which means the drop will minimize its kinetic energy and move in a radial direction reducing the height. The drop impact phenomenon is simulated using a VOF-based model. They also included the surface tension phenomena and wall adhesion phenomena in their model and experimental and numerical study has been done by changing the diameter of drop, value of surface tension and the properties of surfaces. Static contact angles and dynamics contact angles value were validated from obtained experimental and simulations results. The following are the key findings of this study:

When the value of contact angle is less than 90°, the DCA model should be used because it includes the dynamic variation of the contact angle. Microscopic factors such as surface tension and surface roughness can significantly affect the dynamic behaviour of drop. These properties have different spatial components and therefore they didn't include in their model. But even without using these phenomena, the simulation results were able to find the details of the behaviour of drop motion.

Almohammadi et al. **[4]** experimentally studied the spreading of drop over a moving surface. In this case of moving surface, drop has vertical and the tangential components of velocities with respect to the solid surface. They proposed a model which could predict the evolution of the asymmetric nature of the lamella during spreading with time. It was also found that the wetting properties can change the rebounding behaviour of the drop after the process of retraction.

Through this study, it was found that as the drop impact velocity increases, the spreading width of lamella will be more, whereas surface velocity increases the stretching of lamella length. The viscosity of the liquid does not affect the shape of lamella significantly. Comparison between the observations for hydrophobic and hydrophilic area was also done.

Bukush et al. **[5]** also studied the droplet impact on moving surfaces and observed that for inclined surfaces or moving surfaces, the drop has in-plane velocity also apart from the normal velocity. Therefore, there are changes in spreading of the lamella for different types of liquid having different surface tension values.

Initially, the kinetic energy of drop is high and it decreases due to viscous flow of drop spreading radially in outward direction. A similar spreading is observed for both the liquids of low and high surface tension values.

As time increases, the lamella with maximum diameter now contracts in radially inward direction. When the surface is in motion, the lamella width is less as compared to that of when the surface has zero velocity. The drop vertical impact velocity affects the stretching and maximum spreading of the lamella.

2.2 Experimental studies and methods

In 2005, experiments were performed by Gunjal et al. **[3]** with using a high-speed camera at different velocities of impact at different contact angles. They considered the surface to be remained smooth, i.e., neglecting the surface roughness. To see the different types of regimes, they took two types of surfaces and liquids which were Teflon and glass and mercury and water respectively.

Almohammadi et al. **[6]** also performed a systematic study to recognize the impact of drop on a moving hydrophilic and a moving hydrophobic surface in horizontal direction. Drops with a diameter of 2.5 mm was used in the experiments and they kept changing the type of liquid. The drop vertical velocities and surface velocities were also varied from the range 0.5 ms^{-1} to 3.4 ms^{-1} and 0 ms^{-1} to 17 ms^{-1}, respectively.

In the expansion and retraction processes, the drop behaviour is completely different on moving and stationary surfaces. It was observed that the drop expands in an asymmetrical nature if the surface is in motion. Due to surface velocity, stretching occurs in the downstream region. The lamella rebounds when a hydrophobic surface was used and the lamella sticks with the moving surface when the hydrophilic surface was used. In case of hydrophobic surface, the phenomena of rebounding and stretching occurs simultaneously.

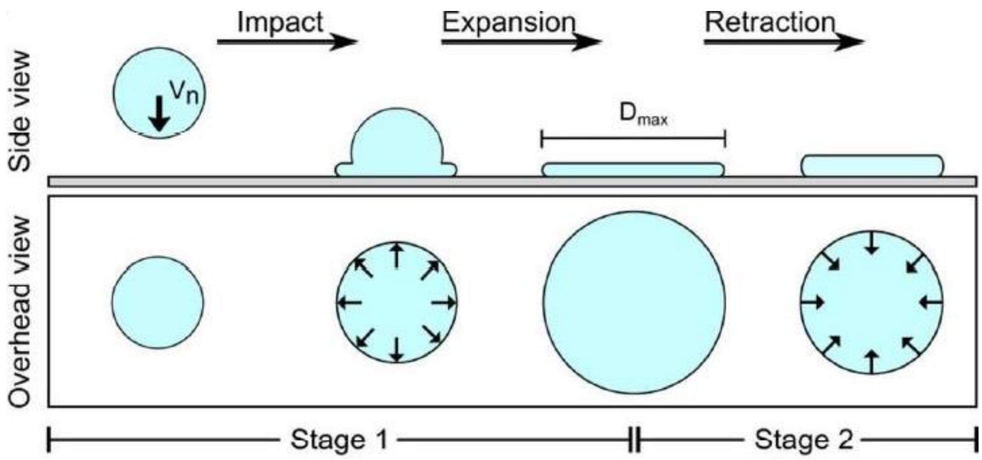


Fig. 1. Diagram of the lamella shape for two stages for a stationary surface. See Ref. **[6]**

For a stationary horizontal surface, the following are the two types of stages:

(a) Stage 1: During the impact of the drop with the surface, it spreads radially and attains a maximum diameter of D_{max} (shown in Figure 1).

(b) Stage 2: After its maximum spreading, the lamella can retract or sticks with the surface (shown in Figure 1).

In the first stage, when the droplet has high kinetic energy, there are mainly three types of regimes which can occur depending upon the velocities of impact. The termed them as spreading and splashing. There are mainly two types of splashing: prompt and corona splashing. When very tiny drop particles generated after the striking of the drop lamella with the surface, it is called as prompt splashing. Whereas, when some of the portion of lamella rebounds above the surface and then the tiny droplets are generated which is called corona splashing. Sometimes the drop bounces back in upward direction depending upon the hydrophobicity of the surface. Thus, the surface properties, volume of liquid drop and the operating conditions can give different results when changed slightly.

Kinetic energy now decreases to zero and spreading is stopped at the end of stage 1 and this energy is transferred into expansion of liquid opposing the viscous forces inside the drop and friction force between drop bottom surface and plate.

If the drop splashes on a stationary surface, the same drop if released on a moving surface shows decreased splash in the downstream region and increased spread in upstream region. The region which is in the same direction of the surface movement is called downstream region and opposite of that is called upstream region. When the drop spreads on a stationary surface, then it will show splashing in upstream region instead of spreading when the surface is in motion. In addition, it was also observed that the whole lamella which is stretched already is rebounding off to the surface for a hydrophobic surface.

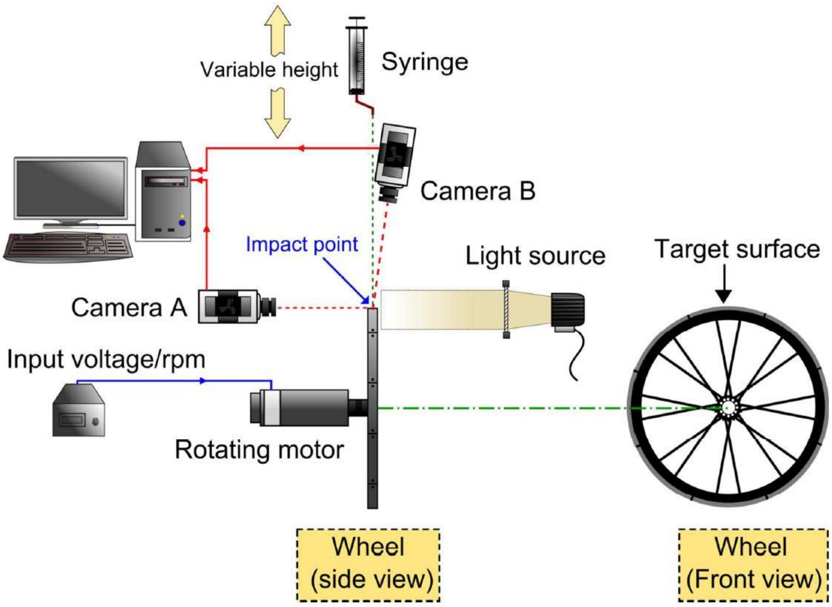


Fig. 2: View of experimental arrangement. Ref. **[6]**

Above Figure 2 shows the complete diagram of experimental arrangement which have some important functional parts. The primary requirement is to produce a drop, then the set up for moving the bottom surface using a wheel and a high-speed camera was used to detect the drop shape continuously.

For producing a drop, a needle was used. By varying the height of release of drop, the impact velocity can be varied. They kept the range of velocities 0.5 ms^{-1} to 3.4 ms^{-1} with a diameter of drop, D= 2.5 mm.

Moving surface: There were two types of surface used. A surface which was made up of stainless-steel used as hydrophilic and a stainless steel coated by Teflon was used as the hydrophobic surface.

The Phantom high-speed cameras with a resolution of images 1024x504 and 1088x552 for side view and the top view was used for recordings. ImageJ software was used for measuring the contact angle, the velocity of drop and the surface velocity.

In their experiments, they used a big wheel as a moving surface. And the drop size is much smaller as compared to the when so that the when can be assumed a flat moving surface.

The reason for using a wheel is to get the constant velocity which can give better experimental results.

Below Figure 3 shows the expansion of drop in the same direction as of surface. In this case, the bottom surface is moving in leftward direction. The region where the lamella expands can be referred to as downstream and the region opposite to that is called upstream. In the upstream region, there is less spreading of lamella.

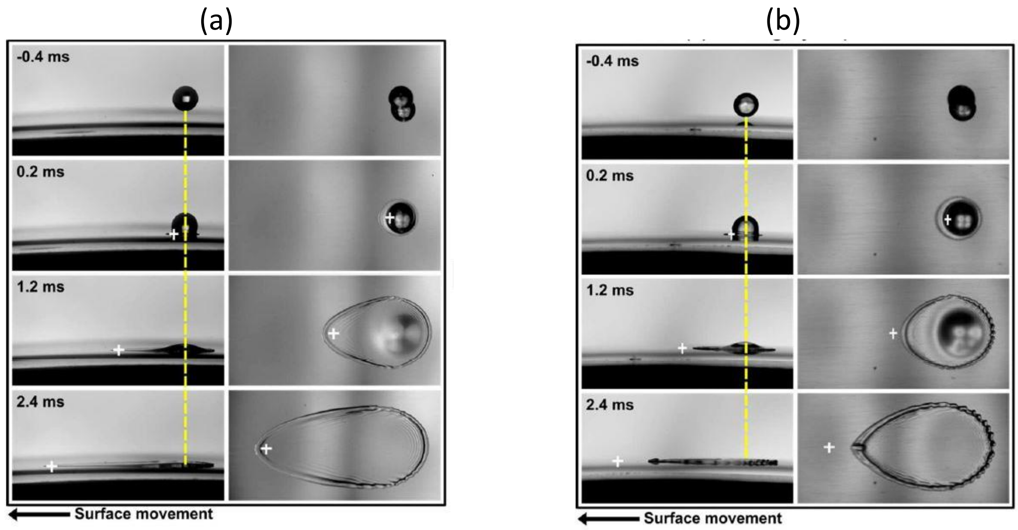


Fig. 3: Side view and top view of a drop on (a) Hydrophilic moving surface (b) Hydrophobic moving surface. Ref. **[6]**

In Figure 3(a), a hydrophilic surface was used with impact velocity as 2.01 ms^{-1} and the bottom surface velocity was 5.75 ms^{-1}. The white cross sign represents the point where the drop strike with the surface and the yellow line represents the apex of drop. The surface velocity of 5.65 m/s was used for hydrophobic surface in Figure 3 (b).

Zen et al. **[7]** used ethanol droplet on an inclined as well as horizontal moving surfaces at different angles of inclination and surface velocities for their experiments. The surface velocity for the horizontal moving surface increases the probability to splash in the region of opposite direction of the motion, but it decreases the splashing in down the plane direction on surface with increasing the spreading. Šikalo et al. **[8]** studied the rebounding and deposition phenomena. They used a hydrophobic surface in the experiments. A rolling cylinder was used as a moving surface. The effect of surface roughness on the drop was neglected in the calculation.

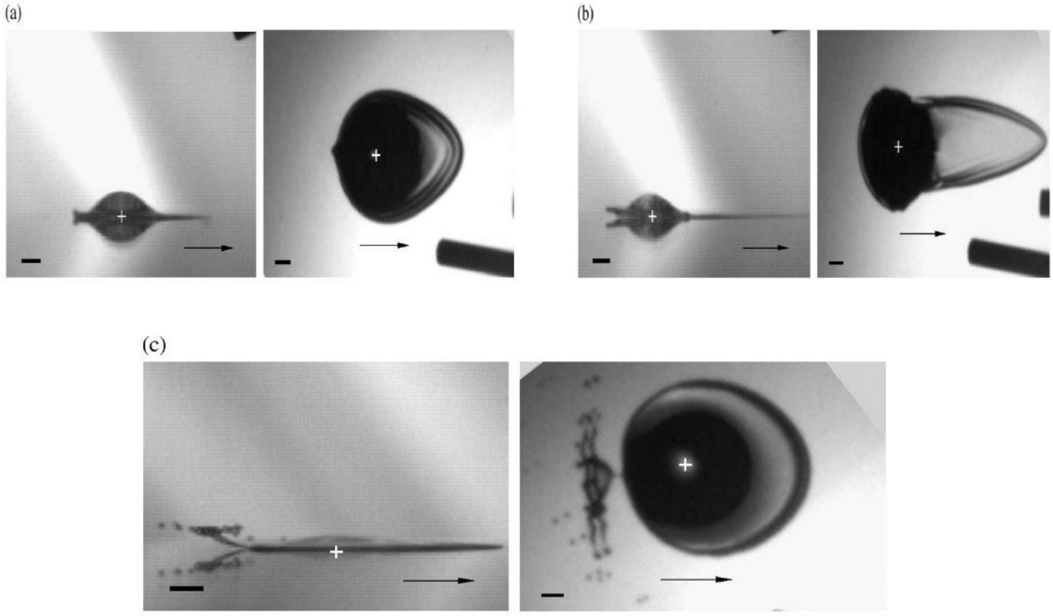


Fig. 4: Images of drop on moving surface with (a) weber number = 76 and surface velocity = 2.8 ms^{-1}, (b) weber number = 74 and surface velocity = 5.6 ms^{-1} (c) weber number = 277 and surface velocity = 2.8 ms^{-1}. Ref. **[7]**

Figure 4 (a) shows the image of the droplet when the weber number is 76 and the velocity of the surface of 2.8 ms^{-1}. The black arrow representing the direction of motion and the white cross is the initial point of impact. At low weber number means when the velocity of impact is low, the drop does not splash, but it is spreading more in the same direction as of surface velocity. Figure 4 (b) shows that when the surface velocity is increased, there is more stretching but if we increase the weber number, the drop starts to splash as shown in Figure 4 (c).

Ethanol has very low value of surface tension which gives us an advantage of easily producing the splashing phenomena asymmetrically. Sometimes, side splashing may occur in a particular direction.

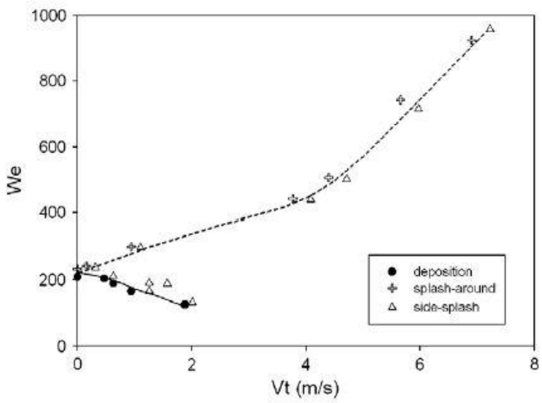


Fig. 5: Plot between weber number and surface velocity for a horizontal surface. Ref. **[7]**

From Figure 5, it can be seen that there is limiting value of weber number which differentiate the phenomena of splashing and deposition. For an inclined surface, if the inclination angle is high, then the splashing in downward direction will be more. The increase in weber number gives an additional enhancement of splashing. The splashing in upward direction becomes lesser as we increase the angle of inclination due to the effect of force of gravity.

There are following reasons which can explain the reason of side splashing at rear end of moving surface:

(1) When the energy is low during impact, the back-end edge of the fluid moves with fast speed and the lamella of the liquid jumps in air and splits up in tiny drops resulting in splashing phenomena.

(2) When the velocity of impact is high, the forepart of lamella moves with the surface resulting in low splashing. Now this splashing turned into deposition in the down plane region.

Bird et al. **[9]** investigated about the drop behaviour on a moving substrate and they also observed that spreading with stretching in the direction of substrate motion increased and splashing occurs in another direction.

Jiguang et al. **[10]** designed a system to study about the drop impact velocity changing the ambient air pressure. The tank filled with the liquid is kept at a height. Droplets are generated with the help of a needle and dropped on the surface using gravity force. They used three different diameters of drop 'D' which are 2 mm, 2.4 mm, and 3.1 mm. The drops are nearly spherical in shape during impact. The impact velocity is changed from $1ms^{-1}$ - $2.4\ ms^{-1}$ at different height of release of the drop. The moving surface is given a velocity of $5.1\ ms^{-1}$ with a help of a belt. Before each experiment, the belt is properly cleaned. The absolute pressure is changed ranging 10 KPa to 101 KPa.

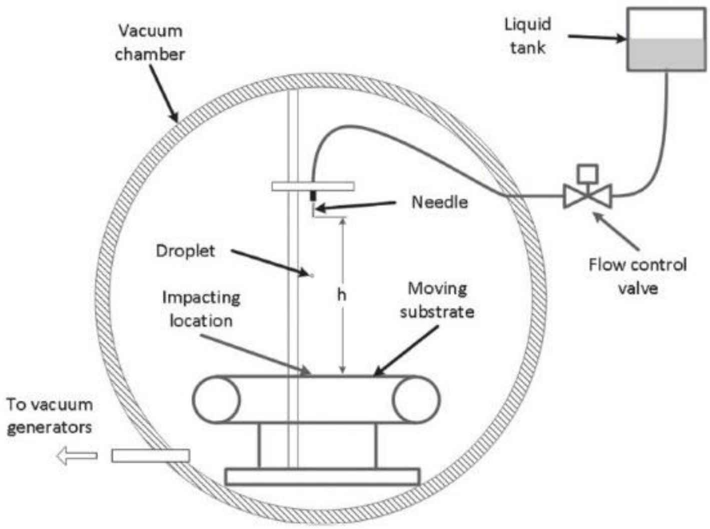


Fig. 6: A schematic diagram of experiment setup. Ref. **[10]**

In Figure 6 shown above, a belt was used as a moving surface which is driven by two rotating cylinders. In this way, the velocity does not vary too frequently. The liquid tank is at some elevation which is used for maintaining the pressure. This is a simple setup which we are also planning to set up for our experiments.

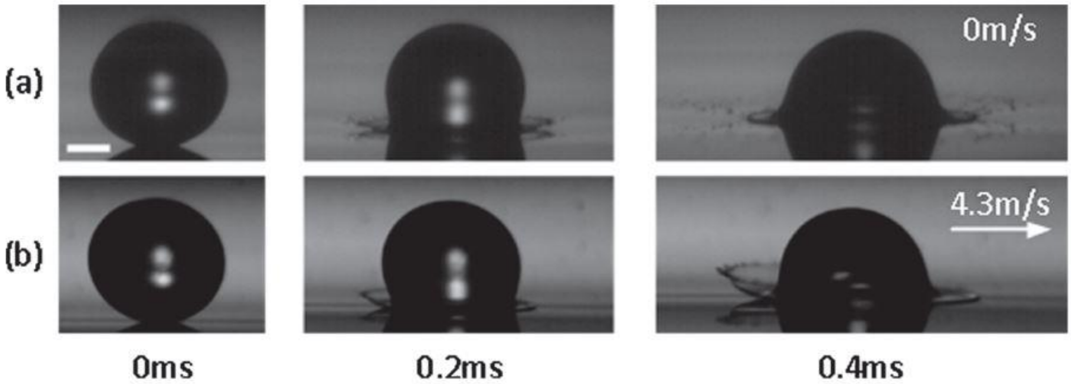


Fig. 7: Drop images for (a) stationary surface (b) moving surface.

Figure 7 shows a comparison of drop shape after its impact on a stationary and a moving surface under identical conditions. The diameter of drop used was 3.1 mm in both the cases. The surface is moving in rightward direction. We can see in Figure 7(a) there is prompt splashing in all the directions but in (b) after 0.4 millisecond time, spreading is observed in front side of drop movement and splashing occurs at rear end. The impact velocity and the ambient pressure is kept same for both the experiments. Ref. **[10]**

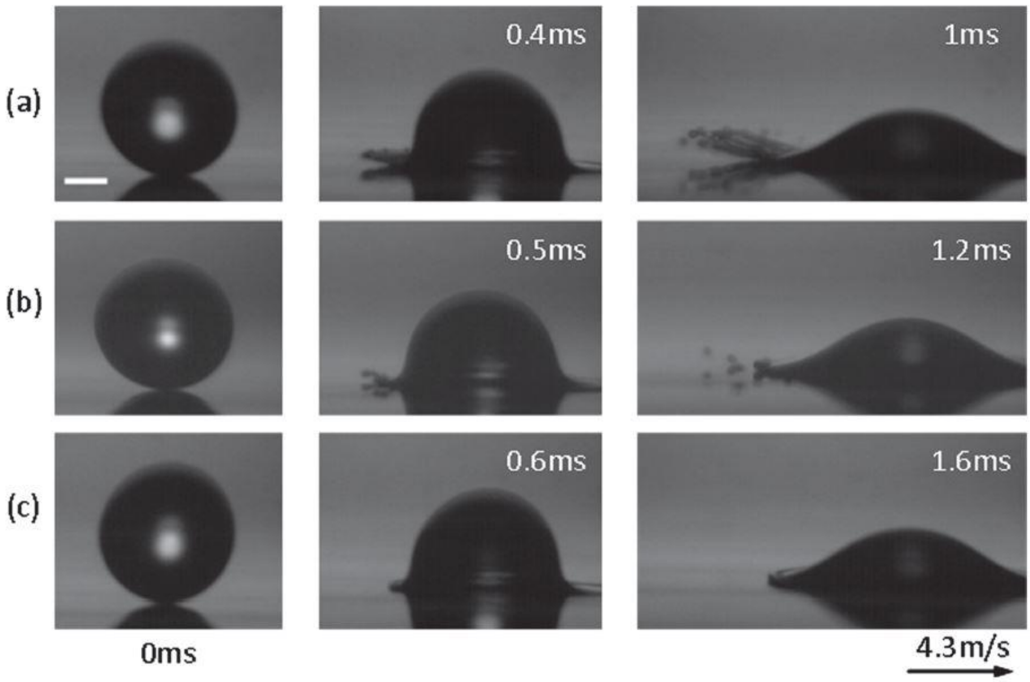


Fig. 8: Drop images with varying impact velocity (a) 2.2 ms^{-1} (b) 1.8 ms^{-1} (c) 1.4 ms^{-1}

There are different regimes in Figure 8 which was caused due to different impact velocity. The ethanol drop shows more splashing when the impact velocity is increased as in case shown in Figure 8(a) compared to Figure 8(b) after 1.2 millisecond. The surface velocity of 4.3 ms^{-1} was used and other operating conditions are kept same for all experiments. We can clearly distinguish that there is corona splashing in figure 8(a), prompt splashing in Figure 8(b) and only spreading or deposition in figure 8(c) in which low velocity is provided. Ref. **[10]**

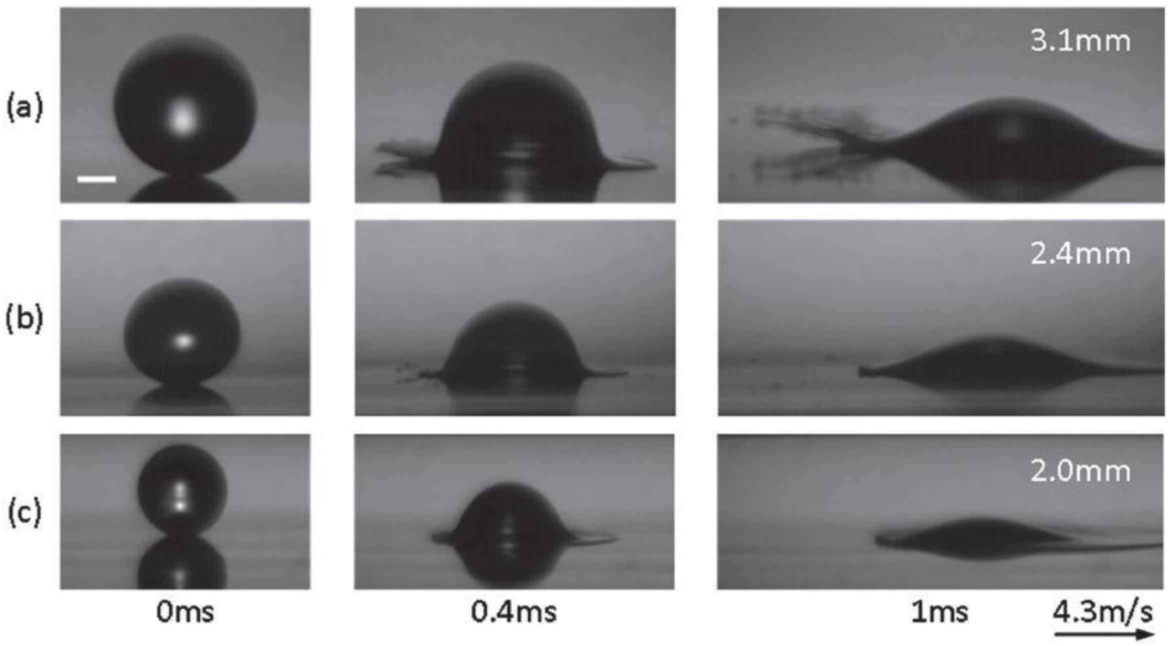


Fig. 9: Different shapes of drop upon changing the drop diameter (a) 3.1 mm (b) 2.4 mm (c)2.0 mm

Now, with by varying the diameter of the drop as shown in Figure 9. Keeping all the operating conditions same, it was observed that bigger drop splashes more as compared to smaller drop which is quite sensible because bigger drop has higher inertia in the vertically downward direction. In figure 9(a), it was observed to have corona splashing at time 1 millisecond after the impact. Prompt splashing occurs in figure 9(b) and finally for small drop size, spreading is shown in figure 9(c). Ref. **[10]**

2.3 Effect of Surface Roughness (Textured surfaces)

Chamakos et al. **[11]** proposed a novel method of modelling in which the liquid-solid and the liquid-air interfaces are handled in single same approach. In their computations, dynamic contact angle (DCA) is calculated implicitly. The solid surface is having surface roughness which creates a liquid and solid interactions at micro level. The Navier-Stokes equation is modified with a separate pressure term and implementing new boundary conditions. Chamakos et al. **[11]** also studied the spread of a drop on horizontal surface and observed that if the surface roughness is increased then the results converge to experimental measurements.

Chakaneh et al. **[12]** investigated the effects of changing the surface roughness on the drop shape after its impact. With the help of image processing software's, the drop size, velocity and other parameters are determined. Three types of surfaces having different average surface roughness values 2.24 micrometre, 6.04 micrometre and 30.2 micrometre were used. They considered water droplets with 2.9 mm in diameter and 1 ms^{-1} impact velocity. When the surface roughness is high, the maximum spreading will become less due to high frictional force. They also observed that there is not much dependency of contact angle on surface roughness. Consequently, high surface roughness value does not allow generation of fingers and also the formation of other smaller droplets.

By increasing the surface roughness, the number of fingers at early stages of the drop spread decreases. The surface roughness decreases the droplet kinetic energy after making contact with the surface. If the viscous dissipation caused by surface roughness is not high enough for Smooth and Medium surfaces, the droplet kinetic energy will exceed a threshold value for forming the secondary droplet. If the impact surface is a relatively smooth surface, the secondary droplet will be formed under the action of capillary and inertial forces. Therefore, increasing roughness not only decreases the droplet kinetic energy but also prevents secondary droplet formation. It should be noted that the lifetime of the secondary droplet in the smooth surface is bigger than that of the medium surface. Since the smooth surface has a lower viscous dissipation, its kinetic energy reduces at a slower rate during the spreading process and, therefore, the secondary droplet can bounce off the surface to a longer distance.

Jiguang et al. **[13]** performed some experiments using water droplets and keeping the surface roughness value very high. of diameter 3.8 mm. We can see in Figure 10(a) that the amount of water splashed is more when the surface roughness value is increased. Here it is a type of corona splashing. But later on if the roughness is increased more, then splashing would be lesser. Even when used a high roughness average value of 9.16 micrometre, a corona splash was observed.

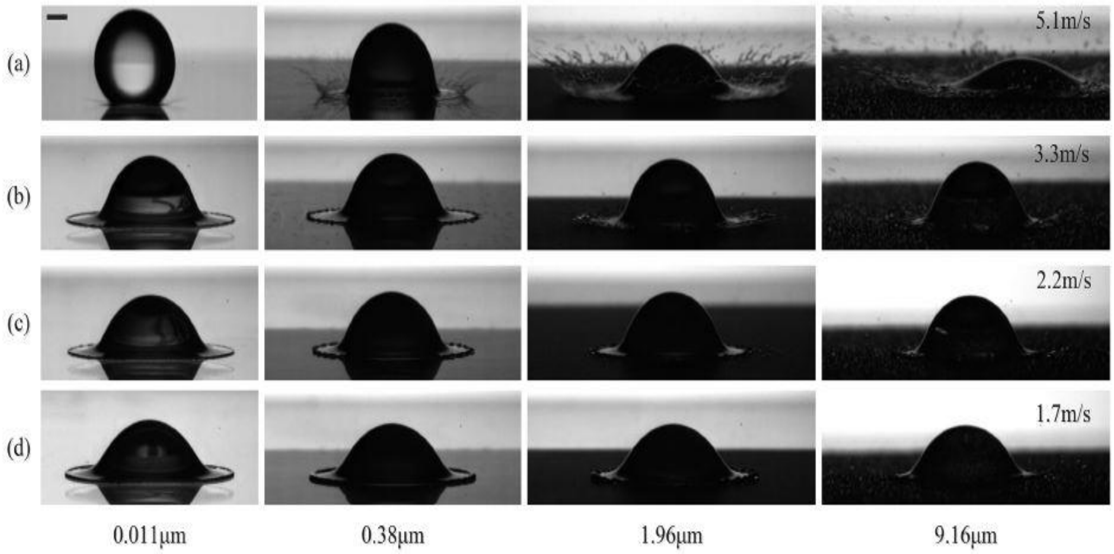


Fig. 10: Drop regimes at different impact velocities and surface roughness values as shown. Ref. **[13]**

When the velocity is very high as shown in Figure 10 (a) i.e. 5.14 m/s, a corona splash was observed irrespective of the surface roughness values either at 1.96 micrometre or 9.16 micrometre. The diameter of drop for each experiment is 3.8 mm. In Figure 10(b), as increase in surface roughness the spreading decreases and splashing (here it is prompt) is increased at same velocity of impact. They decreased the surface velocity to 3.3 ms^{-1} as shown in figure 10(b). It can be seen from Figure 10(c) a low impact velocity of 2.2 ms^{-1} gives prompt splash when the average roughness value increased. Lastly, in Figure 10(d) they used very low velocity of impact and spreading behaviour was observed. The spreading is more for low roughness values and spreading decreases as we go from left to right in figure increasing roughness.

2.4 Governing equations

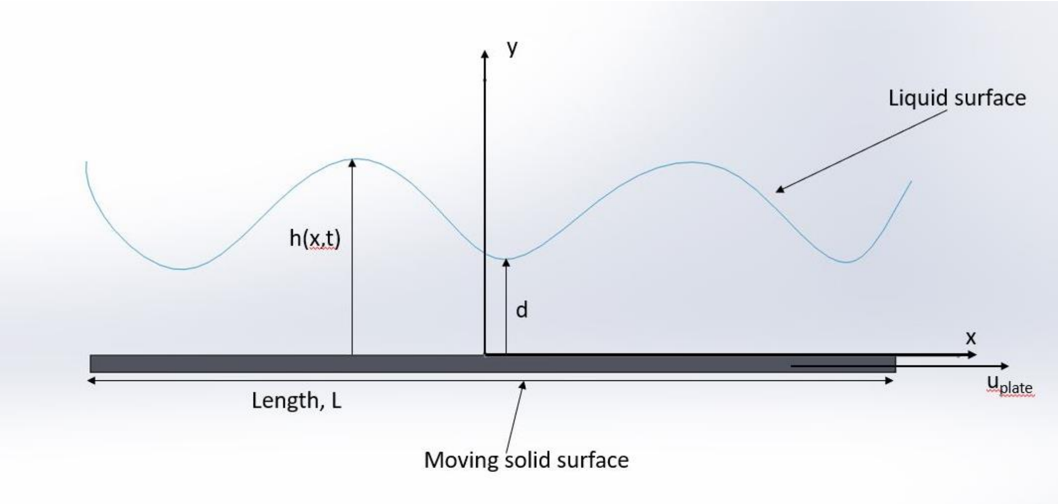


Fig. 11: Schematic figure of a top surface of a liquid drop on a solid surface

After the impact of a drop on the solid moving plate, it will start to spread and move radially in all directions. The above schematic figure shows a liquid surface with a height of a liquid surface, which is a function of distance, x and time, t. The solid surface is given a horizontal velocity in x-direction, u_{plate}.
Assumptions are taken for the film thickness becoming non-uniform from its initial thickness, d. The characteristic length scale in x direction is L. Similarly, the characteristic velocity in x-direction is U. The three governing equations are as follows:

Continuity equation: $$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \qquad \text{---(1)}$$

X momentum equation:

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y} = -\frac{1}{\rho}\frac{\partial P}{\partial x} + \frac{\mu}{\rho}\left\{\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}\right\} + F_b \qquad \text{------------(2)}$$

Where F_b is the body force. In x-direction $F_b = 0$.

Y momentum equation

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y} = -\frac{1}{\rho}\frac{\partial P}{\partial y} + \frac{\mu}{\rho}\left\{\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}\right\} + F_b \qquad \text{-----------(3)}$$

In y-direction, there is gravity force per unit density acting on the drop

$$F_b = -\,g$$

The characteristic velocity in y-direction

$$V = \varepsilon U \text{ where } \varepsilon = \frac{d}{L} \text{ and } \varepsilon \ll 1$$

For low Reynolds number, the viscous effects are dominant over the initial terms. Therefore, neglecting the inertial terms and after taking the Lubrication approximation, the final equations we get,

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \quad \text{---(4)}$$

$$-\frac{\partial P}{\partial x} + \mu\left\{\frac{\partial^2 u}{\partial x^2}\right\} = 0 \quad \text{---(5)}$$

$$-\frac{\partial P}{\partial y} - \rho g = 0 \quad \text{---(6)}$$

After non-dimensionalising these equations, the boundary conditions and with the help of kinematic derivation we get,

$$\frac{\partial \tilde{u}}{\partial \tilde{x}} + \frac{\partial \tilde{v}}{\partial \tilde{y}} = 0 \quad \text{---(7)}$$

$$\frac{\partial \tilde{P}}{\partial \tilde{x}} = \varepsilon^{-3} C_a \left\{\frac{\partial^2 \tilde{u}}{\partial \tilde{y}^2}\right\} \quad \text{---(8)}$$

Where capillary length, $C_a = \frac{\mu U}{\sigma}$
And

$$\frac{\partial \tilde{P}}{\partial \tilde{y}} + B_o = 0 \quad \text{---(9)}$$

Where bond number, $B_o = \frac{\rho g L_x^2}{\sigma^2}$

Applying boundary conditions:
At $\tilde{y} = \tilde{h}(\tilde{x}, \tilde{t})$

$$\frac{\partial \tilde{h}}{\partial \tilde{t}} + \tilde{u}\frac{\partial \tilde{h}}{\partial \tilde{x}} - \tilde{v} = 0 \quad \text{---(10)}$$

$$\tilde{P} = -\frac{\partial^2 \tilde{h}}{\partial \tilde{x}^2} \quad \text{---(11)}$$

$$\frac{\partial \tilde{u}}{\partial \tilde{y}} = -\frac{\partial \tilde{T}^{i}}{\partial \tilde{x}} \quad \text{--(12)}$$

And at $\tilde{y} = 0$ $\quad \tilde{u} = \tilde{u}_{plate}$ --(13)

Finally, the velocity will come

$$\tilde{u} = \frac{1}{2}\frac{\partial \tilde{P}}{\partial \tilde{x}}\left(\tilde{y}^2 - 2\tilde{y}\tilde{h}\right) - \frac{\partial \tilde{T}^{i}}{\partial \tilde{x}}\tilde{y} + \tilde{u}_{plate} \quad \text{------------------(14)}$$

And the relation between the height, h with time and distance is

$$\frac{\partial \tilde{h}}{\partial \tilde{t}} + \frac{\partial}{\partial \tilde{x}}\left\{\frac{\tilde{h}}{3}\frac{\partial^3 \tilde{h}}{\partial \tilde{x}^3} - \frac{\partial \tilde{T}^{i}}{\partial \tilde{x}}\frac{\tilde{h}}{2} + \tilde{u}_{plate}\tilde{h}\right\} = 0 \quad \text{-----------------------(15)}$$

2.3 Numerical Simulations

Siddhartha et al. **[14]** studied the different types of methods which have been used for simulating a drop spreading on the solid surface.
There are various methods used in numerical modelling, for example, the level set method, the lattice-Boltzmann method, the front tracking method and the volume of fluid (VOF) method. From all these methods, the VOF model includes conservation of the mass and it is easier to compute the results for complex surface area and shape problems therefore it is most suitable for the simulation of drop spreading with cheap computational cost.
A detailed study was done on wetting characteristics also affects the spreading behaviour of a drop by Fukai et al. **[15]**. They observed that the drop spreading behaviour is significantly affected by impact velocity. They also included the advancing angles and receding angles in their simulation model. By refining and using adaptive meshing, the results become more accurate.
Šikalo et al. **[8]** already did experiments to analyse the dynamics of glycerine drop spreading on flat wax and glass surfaces and thus these experimental results were used for validating the numerical results. Static contact angle (SCA) and dynamic contact angle (DCA) models were developed, and surface wetting properties were investigated with the help of these models. For the whole domain, Navier–Stokes equations were solved at each grid point for laminar flow. In the VOF model, advection equation is solved for another phase at the interface.
Most of the numerical simulations has been analyzed on horizontal surfaces using SCA model only. Still, the dynamics of drop spread by numerical methods is not studied well. From their experiments and numerical observation, they observed that the SCA method is describing the spreading phenomena well.

The limitation of the VOF model is less accuracy at interfaces as compared with level set method or front tracking methods. For a glycerine drop released on the wax surface as shown in Figure 12, we can see that the spreading behaviour of the droplet in the horizontal direction is nearly same for the SCA and DCA models till 1 millisecond. But after 1 ms, the shape of drop is significantly different in SCA and DCA model. The diameter of drop was 2.45 mm and weber number used was 51 with the contact angle of 93.5◦.

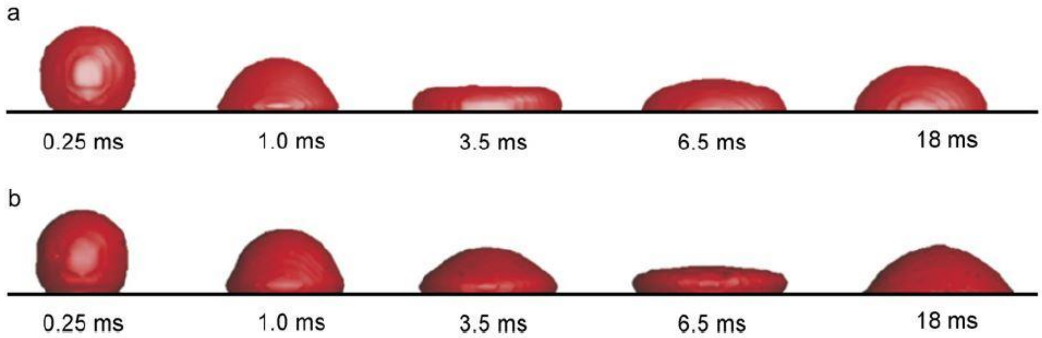


Fig. 12. Simulation results of droplet shapes using (a) SCA model and (b) DCA model. Ref. **[14]**

The results of numerical simulations using VOF model were justified with experimental results of Šikalo et al. **[8].** For less wettable surfaces i.e. contact angle is greater than 90◦, the results for SCA and DCA approaches are similar. When the angle of contact is less than 90◦, SCA model cannot predict accurately as compared to DCA model which can be clearly seen in Figure 12(b).

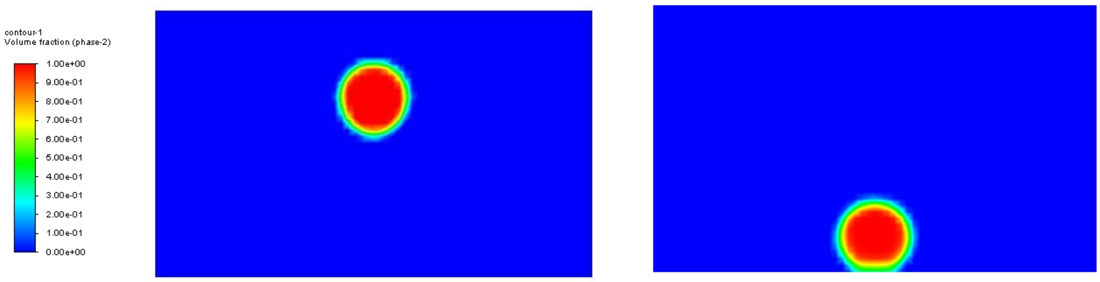
Zyuzina et al. **[16]** worked on work on two-dimensional numerical simulation technique In which a drop strikes in a flat surface. They also studied about the particle spreading and rebounding behaviours of drop. Instead of VOF, they used level set method to understand the dynamics at of interface boundary. Navier Stokes equation is solved using FEM. They inserted some particles inside the drop and then simulation is run by giving initial velocities to these particles and traced the paths of particles. In this manner, the behaviour of drop motion is determined. Due to these particles, the spread decreases and also the retraction speed become slow.

Results

As per the review from all the literature, we found that the suitable method for our CFD simulations is VOF. We created our domain in millimeter-scale in which a drop is released from a given height so that it attains some velocity when it strikes with the moving surface.

For our study, we change the velocities of drop impact and the solid plate velocity and observed the behaviour of drop motion. Surface roughness is also a key parameter that affects the droplet dynamics which will be further studied in the future.

There is a domain of 25 mm × 15 mm. We are using a drop size of 2 mm which is initially at the height of 10 mm from the surface before releasing. The velocity of the surface is taken as 0.1 m/s. These parameters are only for one case which is shown here. The atmospheric pressure condition is taken as 101 KPa. We have used water drop which has a surface tension value of 0.072 N-m, and the contact angle for the solid surface is taken as 130° which is having a hydrophobic nature. PISO scheme is used for numerical calculations. As per our computational facility for now, the simulations are done using medium-mesh grid size and all simulations are done in ANSYS Fluent.



(a) **(b)**

Fig. 13: (a) Initial position of drop before releasing from height 10 mm
(b) The drop is about to impact on the moving surface (from left to right direction)

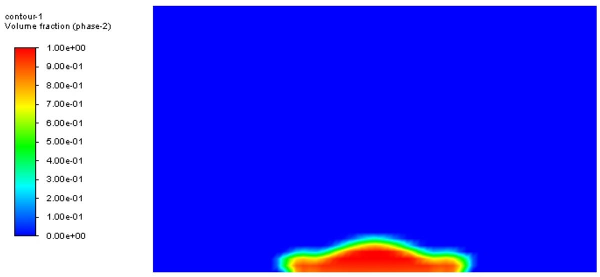


Fig. 14: Spreading of drop on moving plate

The initial center point coordinate od drop is at (12.5 mm, 10mm). The moving surface is considered as smooth as no surface roughness value is given yet.

Conclusions

There are several critical factors that can affect the droplet impact significantly. It was also found that the wettability of the surface affects the downstream behaviour of the lamella significantly. For the hydrophobic surface, a larger portion of the lamella lifts off the surface in comparison to the hydrophilic surfaces. In addition, it was experimentally found that an increase in liquid viscosity decreases the splashing threshold.

Two of the major factors is surface velocity and surface roughness. Although other factors are also important, like drop size and impact velocity but from our review, we found that most of the research has been done with changing drop size and velocity.

The surface roughness will dissipate the kinetic energy of the drop after the impact. The surface velocity can stretch the lamella of the drop, reducing the splashing in the upstream region. This area of study on surface roughness and with moving plate is still not discovered well. This might be beneficial for the industry's purpose where spraying of liquid is done. We need to incorporate the surface roughness term in our simulations and validate our results with experimental observations. Later on, we will also do the parametric study to find the threshold velocity for the splashing of drop on a moving plate with different surface roughness values.

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