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Impacting of droplets on moving surface and inclined surfaces

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Abstract

Drop impact onto inclined and moving surfaces are seen in various applications, e.g. inkjet printing, spray coating, or in agriculture; droplets impact on either the surface that is moving, inclined, or a combination of both. Studies in the literature have examined the phenomenon of drop impact in isolation, i.e. either for a moving surface, or an inclined surface. Therefore, we conducted a comparative study for drop impact onto moving and inclined surfaces to see if they can be considered as equivalent systems. We used high speed imaging and examined the spreading and splashing of droplet impact onto both inclined and moving surfaces, having the same normal and tangential (in-plane) velocities. Various liquids with viscosities and surface tensions in the range of 1-5 cSt 17.4-72.8 mNm, respectively, were used. We demonstrated that both systems are equivalent to one another considering either the initial spreading behavior of droplets, or splashing. For splashing it was also shown that different types of splashing seen on inclined and moving surfaces are similar regardless of system. Finally, a new type of splashing named “split splashing” was also reported. This type of splashing is seen only when the normal velocity relative to tangential velocity is very low.

Keywords: Drop Impact; Inclined surface; Moving surface, splash; spreading; surface tension; viscosity; tilted surface.

Nomenclature

Bo	Bond Number
D	Droplet diameter [mm]
g	Acceleration due to gravity [m/s^2]
t	Time [ms]
V	Velocity [m/s]
We	Weber number

Greek letter

ρ	Density [kg/m^3]
σ	Surface tension [mN/m]
φ	Azimuthal angle [°]
θ	Inclination angle [°]
θ_A	Advancing contact angle [°]
θ_R	Receding contact angle [°]
ν	Kinematic viscosity [m^2/s]

Subscript

D	indicates droplet
max	indicates maximum value
n	Normal velocity
o	indicates initial value
t	Tangential velocity
s	Surface velocity

1. Introduction

Droplet impacting on a surface can be widely seen in different industrial applications such as inkjet printing(Jang et al., 2009; Minemawari et al., 2011), spray coating (Huang et al., 2018; McPherson, 1981), and in agriculture (Massinon et al., 2017; Wirth et al., 1991). In these applications most of the time either the surface is moving, or inclined, or in a combination of both. In recent years, there are a few works that have focused on drop impact onto a moving surface (Almohammadi and Amirfazli, 2017a, 2017b; Chen and Wang, 2005; Fathi et al., 2010; Schremb et al., 2017; Zen et al., 2010) or on inclined surfaces (Aboud and Kietzig, 2015; Antonini et al., 2014; Bird et al., 2009; Cui et al., 2009; LeClear et al., 2016; Liang et al., 2014; Shen et al., 2016; Šikalo et al., 2005; Yeong et al., 2014); experiments with various liquids i.e. low and high surface tension liquids with low and high viscosities are done. However, for both surfaces, most of the literatures generally examines droplet impact behavior (spreading, splashing or rebound), or mainly focused on capturing the splashing threshold. For both moving and inclined surfaces, the presence of a tangential (in plane or surface) velocity changes the behavior of a spreading lamella compared to a stationary horizontal surface. So, it is interesting to see, if the droplet impact outcomes and behavior is the same regardless of the configuration in the presence of a tangential velocity component for the drop.

On a rigid horizontal dry surface, a droplet after impact will spread or splash radially (axisymmetrically) depending on the Weber number ($We = \frac{\rho\, dv^2}{\sigma}$; where ρ is the liquid density [kg/m^3], d is the droplet diameter [m], V_D is the normal droplet velocity [m/s] and σ is the surface tension [N/m]); the effect of gravity is evaluated using the Bond number $Bo = (g\rho)D^2/\sigma$, where $Bo > 1$ represents influence of gravity (Hager, 2012). The outcomes of drop impact may also vary depending on the liquid viscosity (Almohammadi and Amirfazli, 2017b; Wal et al., 2006; Xu, 2007), surface roughness (Xu, 2007; Xu et al., 2005) and surrounding gas pressure (Hao and Green, 2017; Liu et al., 2010). The spreading lamella will have a larger maximum diameter and the time to reach this maximum spread is smaller when We increases (Antonini et al., 2012). Increase in We will eventually change spreading to prompt splashing; a prompt splash is a type of splash where the kinetic energy stored in the droplet allows satellite droplets to eject at the very beginning of the lamella spreading. Further increase in the We leads to a corona splash, where the lamella lifts off from the surface and makes a crown before satellite droplets detach from jets protruding from the crown.

On an inclined surface, when a droplet impacts with a velocity V_D, the velocity has two components: the normal velocity ($V_n = V_D\, cos\,(\theta)$) and the tangential velocity ($V_t = V_D\, sin\,(\theta)$). For a moving surface, the velocity of the droplet driven by gravity is called the normal velocity V_n, and the tangential velocity is the velocity of the surface, $V_s = V_t$. In the presence of a tangential velocity, the lamella will not be symmetric unlike the case for drop impact onto a horizontal stationary surface[10]. For cases where a tangential velocity is present, the spreading lamella can be divided into two regions. The first region is the part of the droplet which moves against the surface for a moving surface system (or moves down the plane for an inclined surface system); to be consistent with the literature, we call this region “upstream”. The back side of the droplet that moves with the surface (or moves against the gravity for inclined surface) is called “downstream”; the two regions and the position of the maximum width of the lamella (as observed normal to the direction of tangential velocity on the plane of the surface) are, shown in Figure 1.

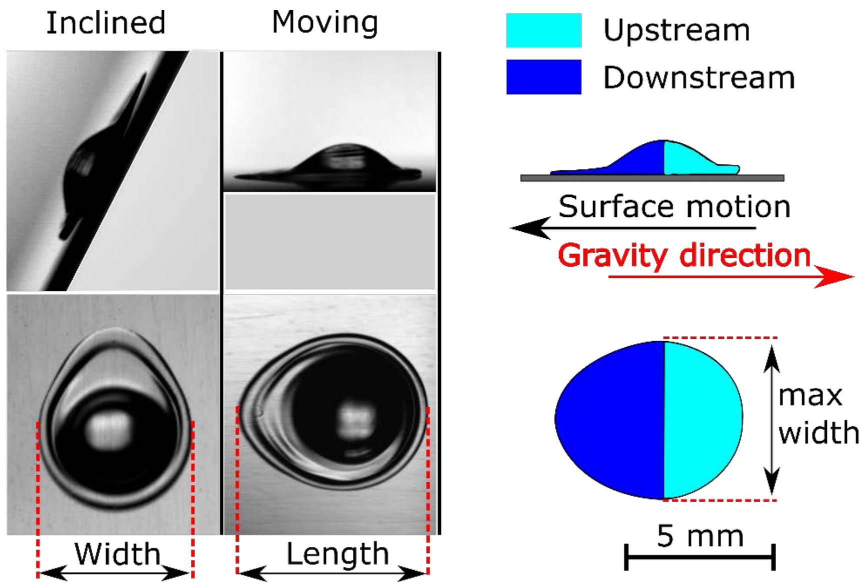

Figure 1 Showing images of droplet spreading on a moving, and inclined surfaces. The schematics shows the side and top views of the droplet to define upstream and downstream regions.

In the presence of a tangential velocity, different spreading behavior is seen. At initial time, right after impact, droplet will spread radially (i.e. symmetrically), and this is mainly due to the high kinetic energy stored in the droplet. As time progresses, the kinetic energy of the spreading of lamella decreases and the tangential/surface velocity changes the circular shape of the lamella to an egg or oval shape. With an increase in tangential velocity, the spreading lamella will be stretched longer in the direction of surface motion (or of the tangential velocity). However, further increase in tangential velocity can lead to an azimuthal splashing (see Figure 2a), where the spreading takes place at the downstream region and the upstream region splashes to the extent of an azimuthal angle, φ. On the other hand, if the normal velocity is increased, an all-around (360° splash, see Figure 2b) axisymmetric splashing will result. Almohammadi and Amirfazli (Almohammadi and Amirfazli, 2017b) proposed a "X-Y notation" to denote different types of splashing, where, X denotes the downstream region of the droplet and Y denotes the upstream. They identified four types of splashing: spreading-prompt, spreading-corona, prompt-corona, and asymmetric-corona splash (this will be discussed later in Section 3.2).

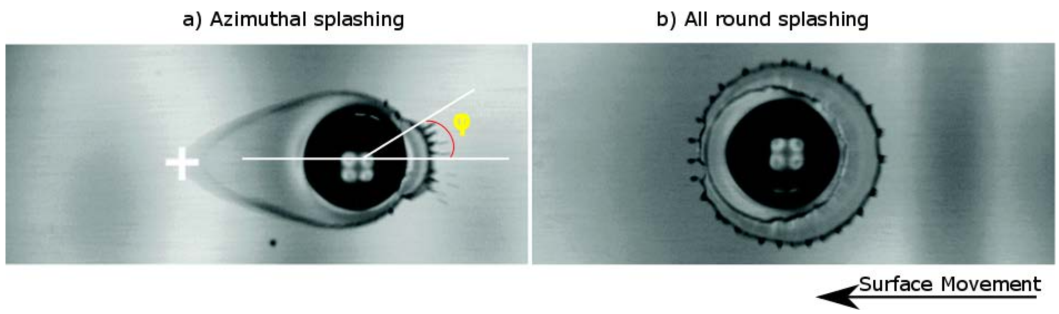

Figure 2 Different splashes seen on a moving surfaces (a) Azimuthal splashing V_n= 2.90 m/s V_t= 14.9 m/s; (b) All round splashing V_n= 3.2 m/s V_t= 1.5 m/s. The white cross refers to the point of impact, and φ represents the azimuthal splashing angle. Reprinted with permission from [Almohammadi, H. & Amirfazli, A. Understanding the drop impact on moving hydrophilic and hydrophobic surfaces. Soft Matter ***13,*** *2040–2053 (2017).]. Copyright (2017) Royal Society of Chemistry.*

Most of the works in the past have used side view images, however, for a better characterization of different splashing behaviors, an overhead view is essential. Almohammadi and Amirfazli (Almohammadi and Amirfazli, 2017b) showed that the azimuthal splashing angle varies with a slight deviation of the normal and tangential velocity components, this information cannot be gathered from side view images.

For both inclined and moving surfaces, different factors can affect the spreading of droplets, such as, the gravity, which affects the tangential velocity component of the spreading lamella on an inclined surface (see Figure 3a). Also for a moving surface, the entrained air above the surface may create an additional drag force on the spreading lamella, and affect the spreading/splashing behavior (see Figure 3b). However, from the literature, it is not yet clear, if the droplet behavior upon impact onto inclined and moving surfaces are identical for the same V_D or the same ratio of normal and tangential velocities. There is no concrete evidence in the literature to prove or disprove the preceding statement either in the form of experimental or numerical work for identical dynamic conditions. In this paper, by conduction a series of systematic experiments with liquids of different viscosities and surface tensions, we will answer the question whether drop spreading and splashing are similar or different for moving and inclined surfaces, whenever the dynamic conditions are the same.

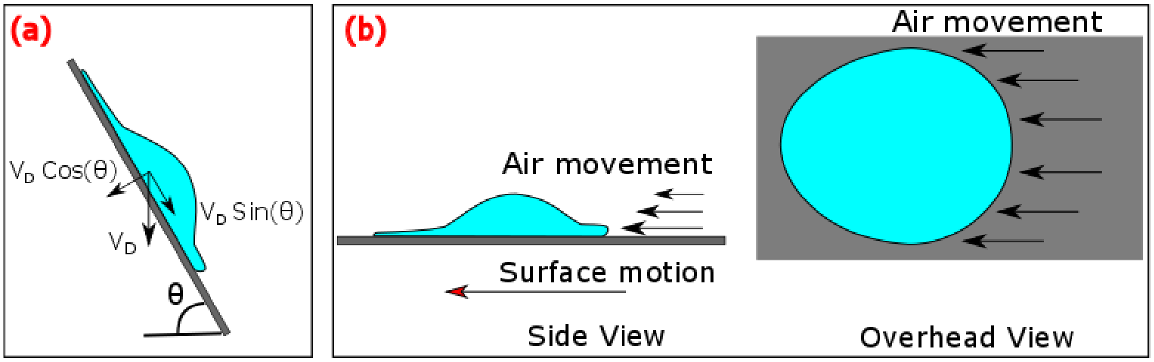

Figure 3: *Schematic of droplet impacting on (a) inclined and (b) moving surface.*

We will examine the following hypotheses for the drop impact on moving and inclined surfaces having the same V_D and V_t:

Hypothesis 1: a) The value of the length and width of lamella are similar for inclined and moving surfaces. b) the lamella propagation should be same for both cases, from the initial time of impact until the maximum width of the lamella is reached (i.e. the shape of lamella is similar for both cases).

Hypothesis 2: a) the splashing behavior should be similar for both surfaces i.e. if azimuthal or all-around splashes are seen for the same impact condition. Secondly, the azimuthal splashing angle, φ should also be similar quantitatively for both cases.

2. Methodology and experimental setup

The experimental setup in Figure 4 consisted of a glass syringe and needle to generate droplets of water, glycerol-water mixture and silicone oil. The liquids chosen for the experiments cover a range of surface tension (17.4~72.8 mNm) and viscosity (1~5 cSt), see Table 1. The experimental setup for the inclined surface consisted of a stainless steel surface, a 3D printed surface holder with slots at (25°- 65°) to keep the angle of inclination constant; see Fig. 4. For the moving surface, the setup consisted of 10 (180 mm X 20 mm) strips of stainless steel surface mounted on a bicycle wheel (radius 284.5 mm). The wheel was attached to a servo motor whose velocity was controlled using the software ROBORUN+. For both setups the same stainless steel surfaces with average roughness of R_a = 29±2 nm were used.

Drop impact experiments were initially performed on inclined surfaces. The drop normal velocity was adjusted by changing the distance between the needle and the surface. Normal and tangential velocities were changed by varying the angle of inclination of the surface with respect to horizon from 25° to 65°. Side view images were used to measure the velocity of the falling droplet just before impact, which were used to calculate the normal and tangential velocities. Both velocity components were replicated on a moving surface, where normal velocity was fixed by adjusting the syringe height and the tangential velocity by controlling the surface motion. The maximum velocity difference between the two cases was ± 0.05 m/s for both V_t or V_n. Images from top and side views were taken at 10,000 fps using a Phantom Miro M310 (overhead view) and a Phantom v 1610 (side view). Both cameras were synchronized and triggered instantly as the droplet was released. Each experiment has been repeated 3 times, and the surface was cleaned with acetone and DI water before every experiment to remove remaining liquids from the surface.

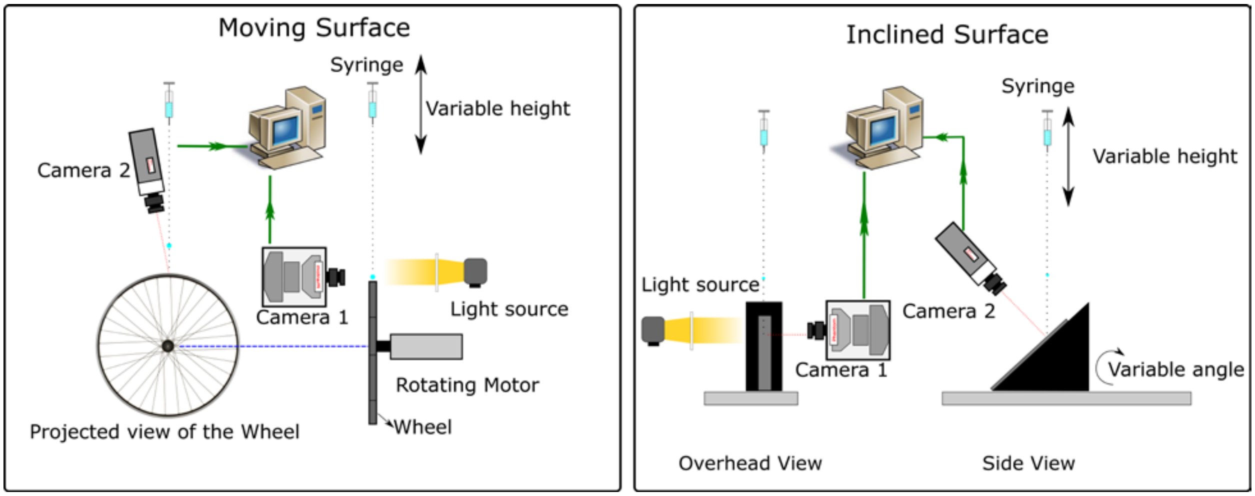

Figure 4 *Schematic of the experimental setup for moving and inclined surfaces.*

For droplet spreading we started analyzing our results from the time of the initial impact until the maximum spreading was reached, which varies from about 3 ms (for high surface tension liquids) to about 7 ms (for low surface tension liquids)

Table 1 Properties of liquids used, range of velocities studied, and the wettability of surface with test liquids

Liquids	**D_0 (mm)**	**Normal Velocity (m/s)**	**Tangential Velocity (m/s)**	**Bo**	**Density (kg/m^3)**	**Kinematic viscosity (m^2/s)**	**Surface tension (mN/m)**	**θ_A**	**θ_R**
Water	2.5 ± 0.1	1.2-2.9	1.2-2.9	0.088	998 (Chen and Wang, 2005)	1.0 (Chen and Wang, 2005)	72.8 (Chen and Wang, 2005)	88° ± 2°	32° ± 2°
Glycerol - water(40% vol)[b]	2.6 ± 0.1	1.2-2.9	1.1-2.7	0.097	1104 Glycerine Producers' Association. (1963)	4.4[b]	69.8 Glycerine Producers' Association. (1963)	82° ± 3°	45° ± 3°
Silicone oil (1 cSt)	2.5 ± 0.1	1.0-2.4	1.0-2.4	0.288	818[a]	1.0[a]	17.4[a]	<5°	<5°
Silicone oil (5 cSt)	2.5 ± 0.1	0.4-2.4	0.6-2.4	0.285	918[a]	5.0[a]	19.7[a]	<5°	<5°

a) data has been taken from http://www.powerchemical.net/library/Silicone_Oil.pdf
b) http://www.met.reading.ac.uk/~sws04cdw/viscosity_calc.html [Accessed: 17-Jun-2018]
c) at 21.5° C

3. Results

The results will be presented in terms of spreading and splashing. In the first part we will compare the spreading results on moving and inclined surfaces for all liquids. Next, splashing for liquids except water will be discussed; the We number for water could not be increased to a suitable value to observe splashing.

3.1 Spreading

When a droplet impacts on a moving/ inclined surface, initially a radial spreading occurs, see yellow circle on Figure 5a and 5b; Figure 6c shows that the width and length of the lamella until 0.3 ms are the same. The spreading is radial, because the lamella velocity at initial times is higher than the tangential velocity. However, as time progresses, the lamella velocity decreases and the tangential velocity starts affecting the spreading of lamella, causing the radial spreading to change.

Low surface tension liquids spread differently on a moving surface compared to high surface tension liquids. On a moving surface, for high surface tension liquids, at t_{max}, the spreading lamella makes an egg shape and its maximum width is positioned closer to edge of the upstream than the downstream region (Almohammadi and Amirfazli, 2017a, 2017b; Schremb et al., 2017). Whereas, for low surface tension liquids, the spreading lamella makes an elliptical shape (with maximum width near the centroid of lamella). Our experimental results for water (high surface tension) and silicone oil (1cSt) (low surface tension) shows that on inclined and moving surfaces, the spreading is similar for each system (see Figure 5 *a* and *b*).

High viscous liquids also spread radially at initial time after impact (see Supplementary info. Figure S1*c*), and also the spreading behavior on inclined and moving surfaces is similar. Figure 5*c* shows that silicone oil (5 cSt) makes an elliptical shape and 40% glycerol-water mixture makes an egg shaped as it approaches t_{max} in Figure 5*d*.

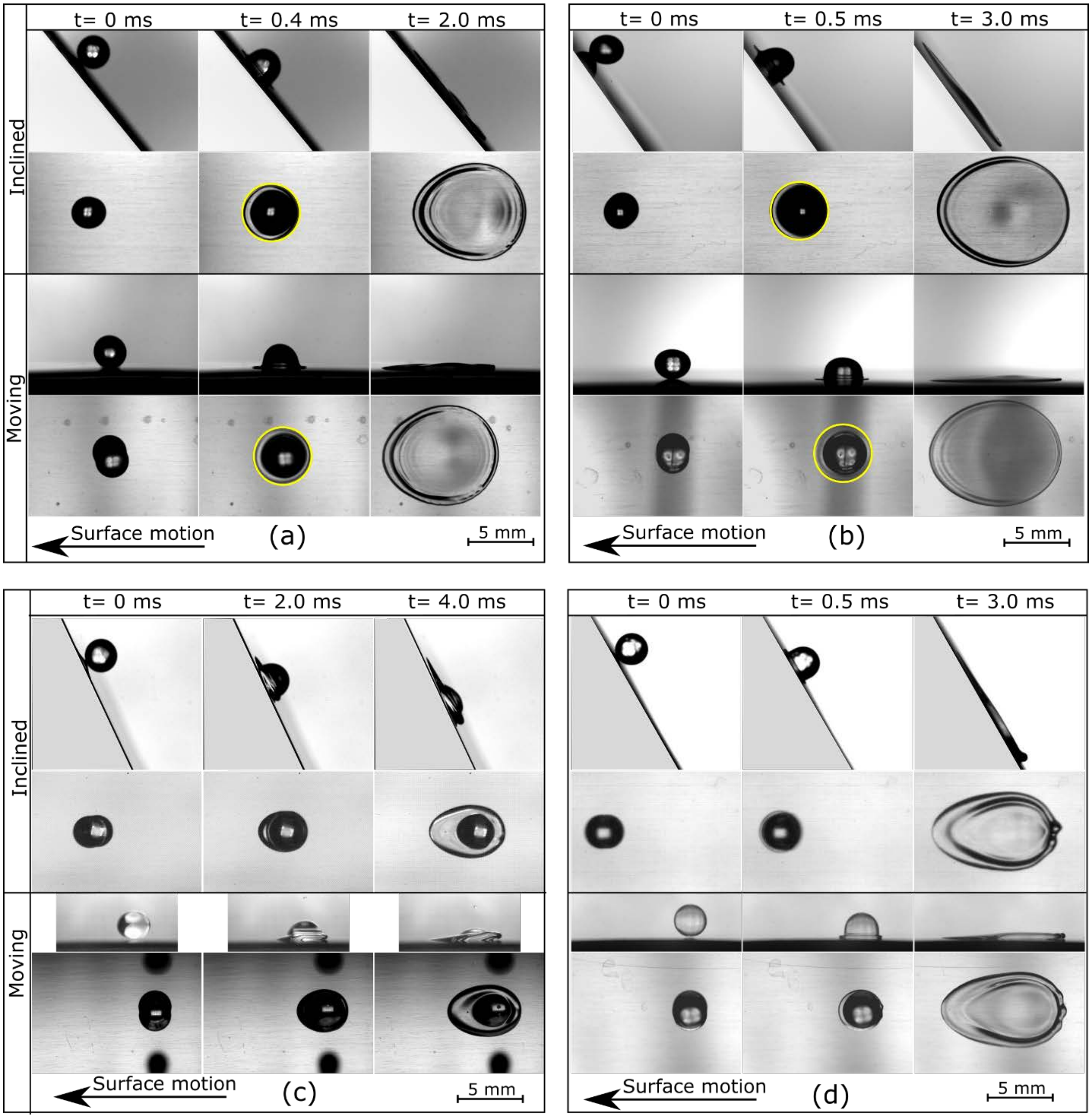

Figure 5 Showing the spreading of liquids on moving and inclined surfaces at different time intervals on a hydrophilic surface (a) Water D_0=2.5 mm V_n=1.67 m/s V_t= 2.0 m/s; (b) silicone oil (1 cSt) D_0=2.5 mm V_n=1.22 m/s V_t= 1.52 m/s; (c) silicone oil (5 cSt) D_0=2.6 mm V_n=0.38 m/s V_t= 0.81 m/s and (d) 40% Glycerol-water mixture D_0=2.5 mm V_n=1.23 m/s V_t= 2.16 m/s.

Figures 6 *a* and *b* show the length and width of the lamella at different time intervals plotted along with their error bars. The data represented here has the highest tangential/surface velocity for which spreading is seen. This means that for these cases, spreading lamella should experience the highest resistance from the air moving over the surface. However, at different time intervals, the rate of increase in width for all liquids are the same for both inclined and moving surfaces. This means the air movement over the surface do not affect the width of the spreading lamella. Figure 6b, shows that the length of the lamella is also similar for both inclined and moving surfaces for all types of liquids, which suggests the gravity do not affect the lamella on inclined surface for the initial impact period (also see Figure S1 for other velocities in Supplementary Information). This validates our hypothesis 1a for spreading on inclined and moving surfaces.

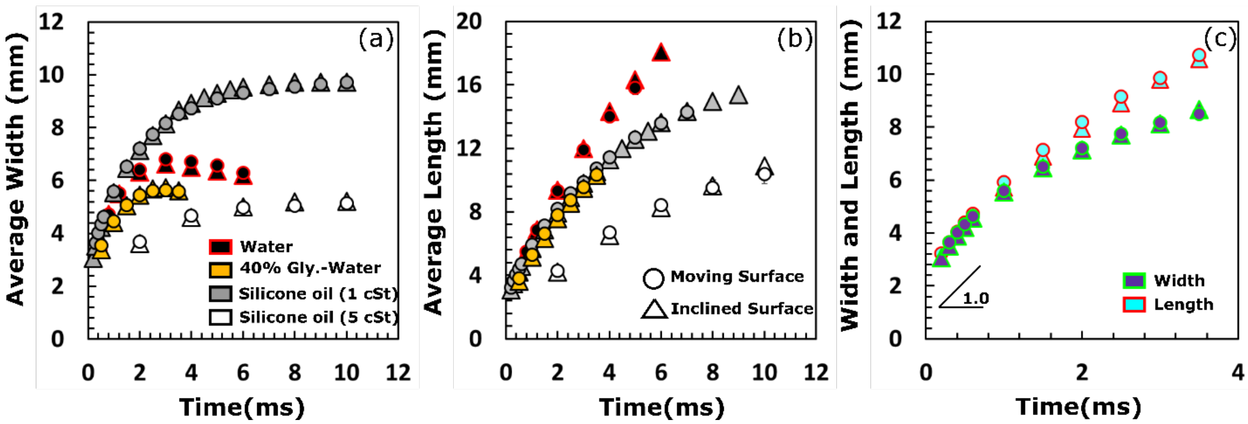

Figure 6 Showing the (a) average width; (b) average length on inclined (triangle) and moving surfaces (circle). Water D_0= 2.5 mm V_n= 1.35 m/s V_t= 2.90 m/s (Black), 40% glycerol-water D_0= 2.6 mm V_n= 1.25 m/s V_t= 2.15 m/s (Yellow), Silicone oil (1 cSt) D_0= 2.5 mm V_n= 1.20 m/s V_t= 1.50 m/s (Grey) and silicone oil (5 cSt) D_0= 2.5 mm V_n= 0.50 m/s V_t= 0.90 m/s (Hollow); (c) shows the average width and length of silicone oil (1 cSt).

3.1.1 Applying the existing spreading models

Hypothesis 1b can be validated, if the time evolution spreading model for low and high surface tension liquids which was developed for a moving surface (Buksh et al., 2019) can be also used for spreading lamella on an inclined surface. The time evolution spreading model (Buksh et al., 2019) can predict the shape of the lamella at any given time until t_{max} (i.e. when a lamella reaches its maximum width). The model was developed starting with the case of the spreading on a stationary surface (symmetric spreading) at different time intervals. In the presence of tangential velocity, an equation was proposed (Buksh et al., 2019) to predict the spreading of lamella over time (which results in egg or elliptical shapes), depending on a few parameters such as surface tension, V_n and V_t.

We used the results of general spreading model from our previous work (Buksh et al., 2019) for moving surfaces and compared it to experimentally observed spreading of silicone oil (1 cSt) and water, on an inclined surface, replacing V_s with V_t when using the model (see Supplementary Information) .

In Figure 7 each contour represents the extent of lateral and upstream spreading of the lamella at 0.4ms intervals; each contour represents the outline of the lamella at a given time. The spreading model predicts well the spreading of both low and high surface tension liquids at different time intervals for drop impact on an inclined surface. This proves that the lamella spreading on a moving surface behaves as the spreading over an inclined surface. Therefore, we can argue that the air movement above the surface (and its resultant drag force) does not affect the spreading of lamella; also, the gravity does not pull the lamella towards upstream region. Thus, for the range of normal and tangential velocities tested (corresponding to majority of tests done in literature) we can claim that the initial spreading of a droplet upon impact on a moving and an inclined surface are the same.

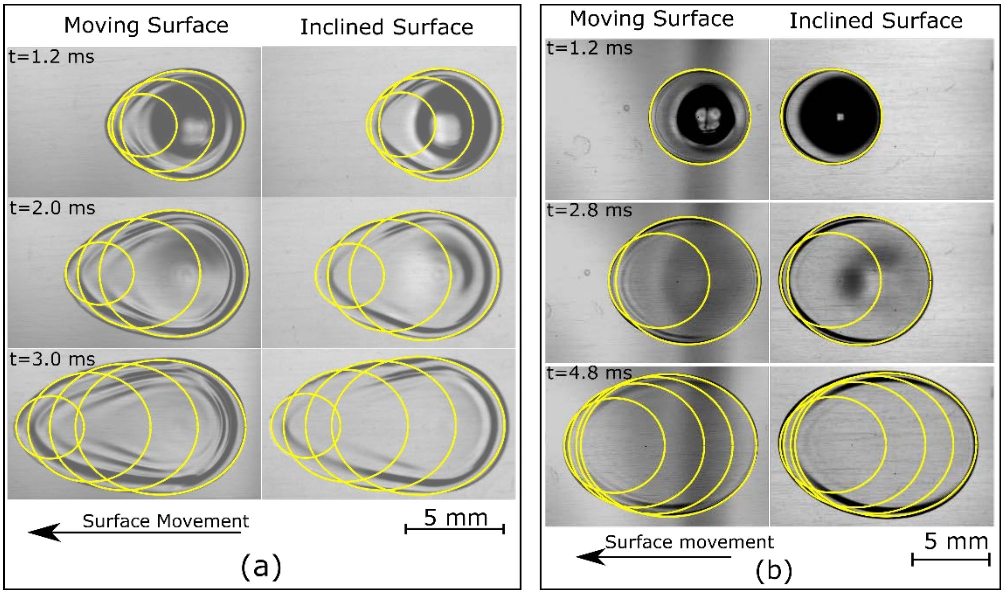

Figure 7. Time evolution spreading model from Ref. [30] applied on drop impact onto an inclined surface for (a) water V_n = 1.36 m/s, V_t = 2.9 m/s; and (b) 1 cSt silicone oil V_n = 1.24 m/s, V_t = 1.55 m/s.

To summarize, the spreading is initially dominated by the inertia of the liquid; the inertia creates a tangential velocity on an inclined surface which allows the liquid to move down the plane. Spreading is a fast phase (around 3-4 ms), and the force of gravity is not significant (since $Bo < 1$) to overcome inertia and viscous forces, which are accelerating or decelerating the lamella, respectively; hence the *initial* spreading on an inclined surface is not affected by gravity. On a moving surface, the results suggest that the air velocity above the surface is not a significant factor under the test conditions to the initial spreading of the drop on a moving surface. On a moving surface, the surface motion cannot change the spreading lamella because the viscous boundary layer thickness ($c\sqrt{\nu t}$) (Pasandideh-Fard et al., 1996; Roisman, 2009) during the spreading phase is too small compared to the rim thickness to affect the rim and hence the dynamics of its spreading (see Figure S2 in Supplementary Information for more Details). Taken all together, then the initial spreading of a drop upon impact on to an inclined or a moving surface is similar.

3.2 Splashing

Increasing the normal velocity and/or the tangential velocity of the droplet changes the drop behavior form spreading to azimuthal splashing (azimuthal angle, φ, refers to the in-plane angular extent that the drop splashes; see Fig. 2), or all-around splashing [10] (all-around splashing is when the droplet splashes from all of its outline, i.e. φ=360°). There are two types of azimuthal, and two types of all-around splashing seen for both inclined and moving surfaces; they are as follows:

1. Spreading-Prompt splash: Here the downstream region of the droplet spreads while some tiny droplets are generated near the upstream region (Figure 8a).
2. Spreading-Corona splash: The lamella in the upstream region lifts off from the surface and droplet detaches, while the downstream region spreads (Figure 8b).

Both types of splashing take place within a limited azimuthal angle.

3. Prompt-Corona splash: For this case, tiny droplets were generated near the advancing contact line at the downstream region, and lifting off of the lamella was seen at the upstream region (Figure 8c).
4. Asymmetric-Corona splash: All-around corona splash was seen for both upstream and downstream regions (Figure 8d).

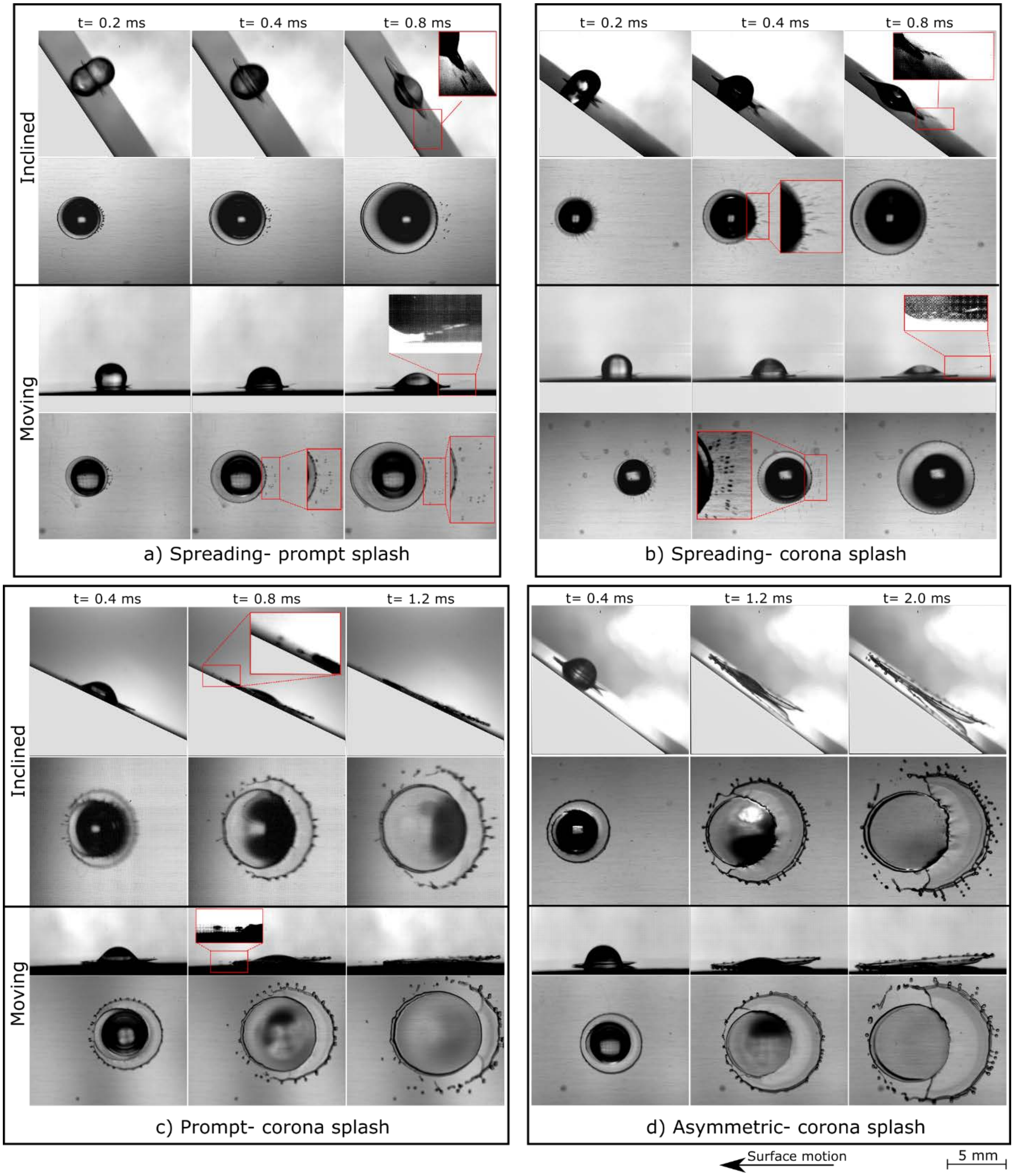

Figure 8. Side and overhead views of different types of splashes seen on inclined and moving surfaces: (a) 1 cSt silicone oil V_n =1.68 m/s V_t = 2.38 m/s; (b) 1 cSt silicone oil V_n = 2.00 m/s V_t = 1.42 m/s; (c) 40% Glycerol-water V_n = 2.90 m/s V_t = 1.36 m/s; and (d) 5 cSt silicone oil V_n = 2.00 m/s V_t = 1.36 m/s.

The change of spreading to different types of splashing was seen for all liquids except water (for water the tangential velocity was not sufficiently high on inclined surfaces for a splash to occur). However, both azimuthal and all-around splash is seen for water drop impact on a moving surface at high V_t in literature (Almohammadi and Amirfazli, 2017b).

Splashing threshold for 40% glycerol-water, silicone oil 1 and 5 cSt can is shown in Figure 9 where, the solid line delineates various droplet behaviors. Results shows that when the surface velocity is increased, spreading changes to azimuthal splashing (see V_n= 1.6 m/s and V_t= 2.4 m/s, for 1 cSt silicone oil). Azimuthal splashing was seen for all three liquids on both systems. In azimuthal splashing, the φ value for a given drop impact conditions are the same for both moving and inclined surfaces (for details see next section).

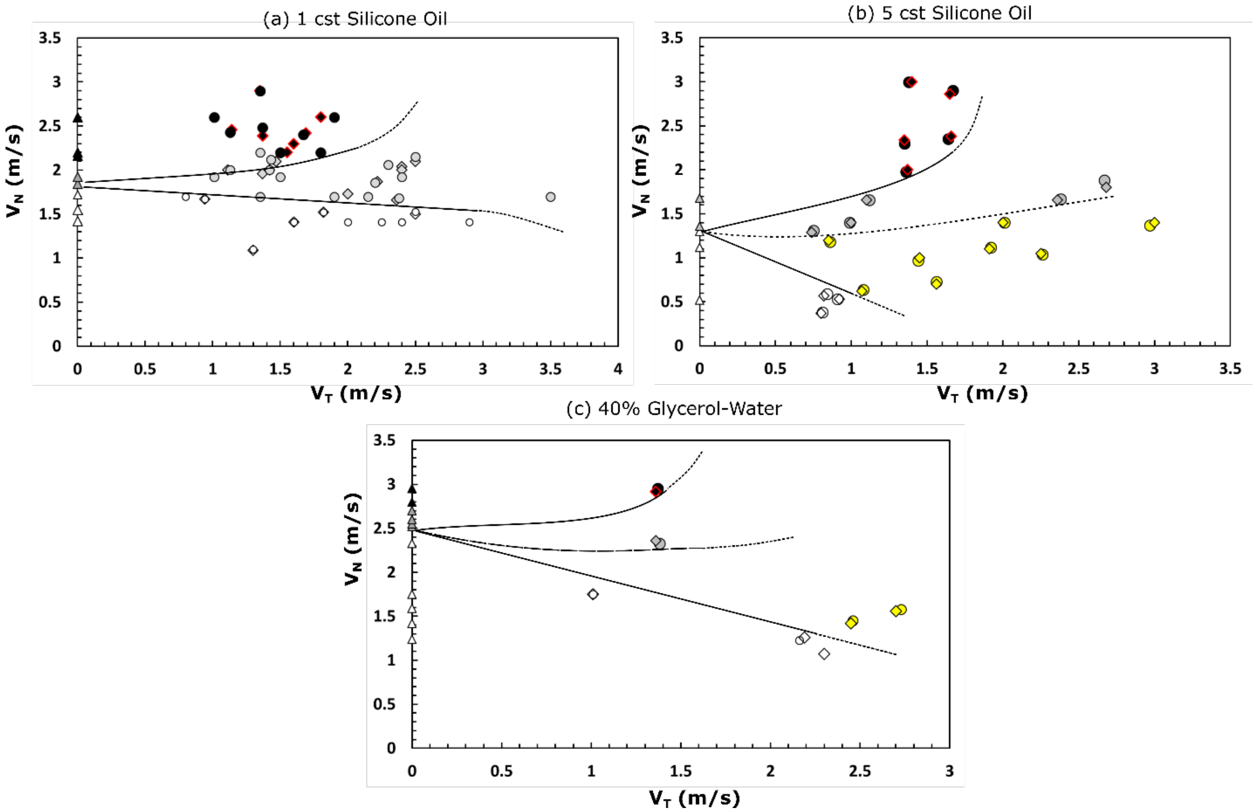

Figure 9 The solid lines delineate various droplet behaviors for silicone oil (1 and 5 cSt) and 40% glycerol-water on stationary (triangle), inclined (diamond) and moving surfaces (circle). Hollow symbols represent spreading, solid grey symbol represents azimuthal splashing, solid black represents all-round splashing and solid-yellow represents new splashing for high viscous liquids. The solid and dashed line are only drawn for graphical clarity of the splashing threshold.

For all liquids, an increase in normal velocity changes an azimuthal splashing to all-around splashing. Same type of all-around splashing is seen for both inclined and moving surfaces. So, the results for splashing thus confirms our first hypothesis for splashing, i.e. the overall splashing behavior is similar for both systems; in the next section we will provide evidence for the validity of the second part of the hypothesis for splashing.

3.2.1. Similarities in splashing

From literature (Almohammadi and Amirfazli, 2017b), azimuthal splash can take place to different extents (i.e. various φ values). The value of φ can vary rapidly when there is a small change in normal velocity or tangential velocity (Almohammadi and Amirfazli, 2017b). During azimuthal splashing, if the normal velocity is low, the relative velocity between the surface and the lamella in the upstream region is high which enhances detachment of tiny droplets from lamella/rim. On the other hand, if the droplet has a high normal velocity, the relative velocity between the surface and the lamella's downstream region is low; this suppress the splashing at the downstream region. Figure 10 shows the azimuthal splashing angles, φ for silicone oil (1 and 5 cSt). For both liquids, the azimuthal splashing can be seen right after impact. For both liquids, at different conditions, we found that the azimuthal splashing angles for both moving and inclined surfaces are similar as the error bars overlaps each other. This means the air flow over the moving surface do not affect the splashing. Hence our second hypothesis is validated, and we can conclude that drop impact on both inclined and moving surfaces are the same for the given drop impact conditions.

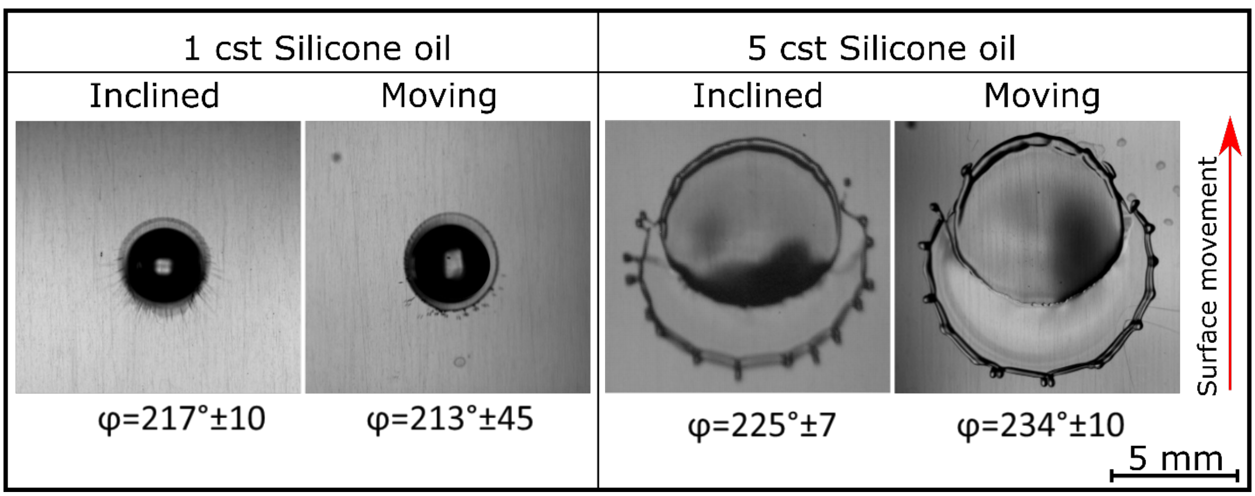

Figure 10: Azimuthal splashing for 1 cSt silicone oil (Inclined: V_n=2.0 m/s, V_t= 1.42 m/s, moving: V_n=1.99 m/s, V_s= 1.42 m/s) and 5 cSt silicone oil (Inclined: V_n=1.66 m/s, V_t= 1.10 m/s, moving: V_n=1.66 m/s, V_s= 1.12 m/s).

3.3 A new observation

In closing, we also report an interesting and hitherto unreported drop behavior upon impact onto a surface. For silicone oil (5 cSt) and 40% glycerol-water mixture, an unusual type of splashing was observed for both inclined and moving surfaces (see Figure 11). The phenomenon is similar to a rebounding on a stationary surface, where the energy in the recoiling phase allows the liquid to jump off from the surface. However, in presence of the tangential velocity a split-rebounding is taking place, i.e. droplet splits into two parts: one part rebounds at an oblique angle, and another remains on the surface in the form of a lamella. The new type of "splash" is seen when the normal velocity of the droplet is very low and the tangential/surface velocity is relatively high (note if the normal velocity is high, the split splash changes to azimuthal splashing, which was seen for other liquids; see Fig. 9b and c for the dashed line separating azimuthal splash (grey symbols) from "split splash" (yellow symbols).

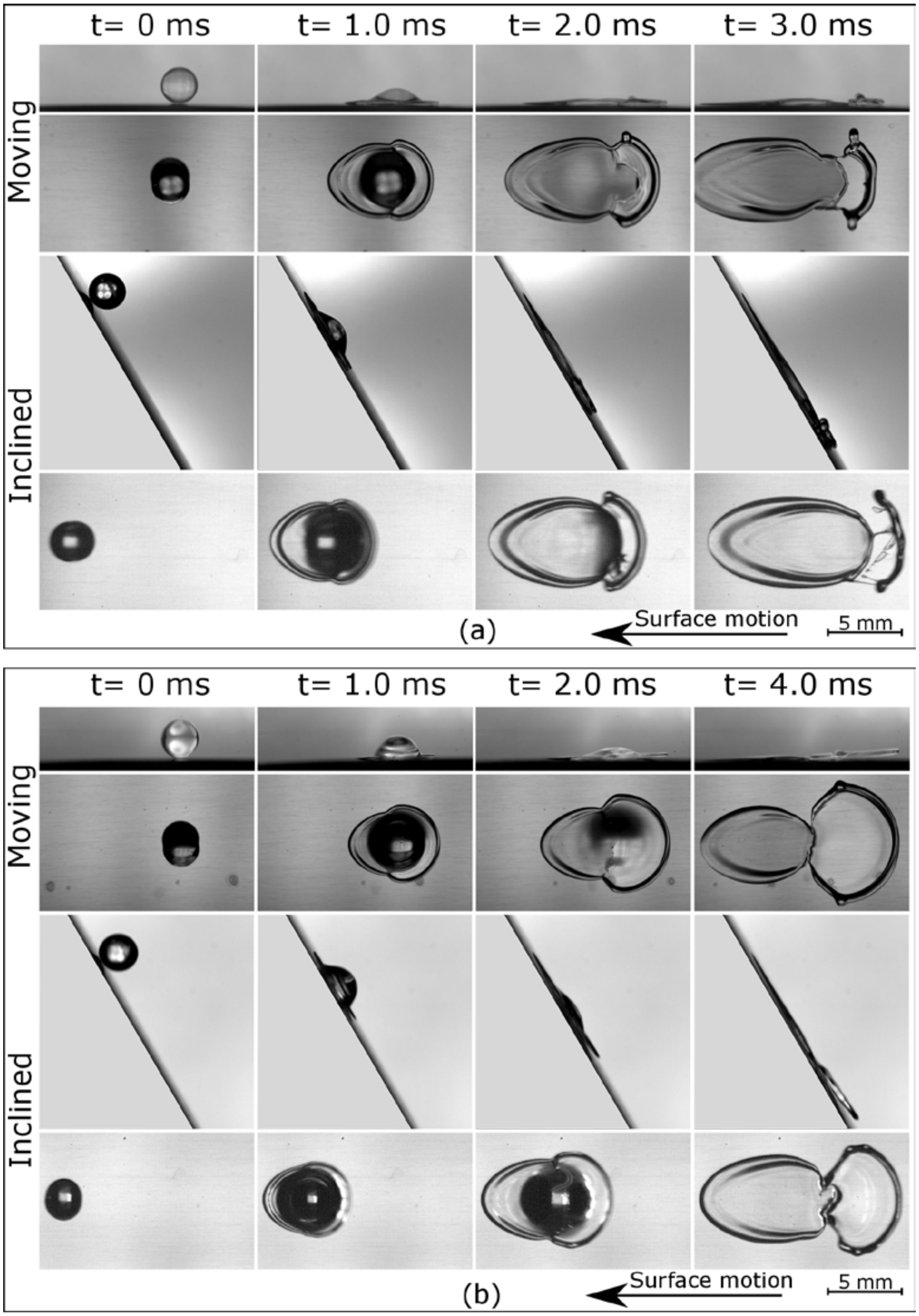

Figure 3 Showing split splash on inclined and moving surfaces for viscous liquids (a) 40% glycerol-water, V_n = 1.58 m/s V_t = 2.73 m/s; (b) 5 cst silicone oil at V_n = 1.10 m/s V_t = 1.91 m/s.

Such behavior at the first instance can be explained as follows. Right after impact the droplet starts to spread slowly due to low V_n, while, kinetic energy from the liquid pushes the liquid (at upstream region) against the tangential velocity. The resultant velocity creates a shear force, which eventually forces part of the liquid to be ripped from the slow moving lamella as it spreads. The pinching off behavior is similar to a partial rebounding on a stationary surface where a part of the liquid with higher momentum near the top of a receding droplet detaches from source bound slow moving liquid near the surface.

Our results in this paper has shown that droplet spreading, and splashing are same on both inclined and moving surfaces. Such similarity can provide an opportunity for analogue studies where one type of experiments can replace the other when there are limitations. For example, in inkjet printing, often the substrate is moving, and to study that one may replace study of drop impact onto a moving surface (a relatively complicated setup) with that of the drop impact onto an inclined surface.

Conclusion

In this paper, we investigated the impact of different types of liquids onto inclined and moving surfaces. It was shown that both systems are equivalent to one another considering either the initial spreading behavior of droplets, or splashing. For splashing it was also shown that different types of splashing seen are similar regardless of system (i.e. inclined surface or a moving one) as long as the same normal and tangential velocities are kept for each system. As such, the airflow, in case of the moving surface, or gravity, for an inclined surface system, does not affect the initial spreading of a droplet upon impact onto a surface, nor its splashing. A new type of splashing named “split splashing” was also reported for the first time. This type of splashing is seen only when the normal velocity relative to tangential velocity is very low.

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