Static and dynamic wetting of porous Teflon® surfaces
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Document Version
Publisher's PDF, also known as Version of record

Publication date:
2006

Link to publication in University of Groningen/UMCG research database

Citation for published version (APA):

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Download date: 12-12-2019
Chapter 7

Behaviour of Water Drops on Impact

This chapter investigates the dynamic behaviour of drops of water on impact with self-cleaning surfaces made from Teflon® colloids in comparison with the behaviour on a smooth Teflon® film and a glass surface.

7.1 Introduction

There are numerous examples in our daily life where drops of liquid impact on a solid surface. Rainfall is a good example of a natural phenomenon, but there are also many industrial processes such as ink-jet printing and spraying techniques where liquid impact plays an important role. One can imagine that the behaviour of ink when it impacts on paper during ink-jet printing influences the quality of the print. It is therefore not surprising that considerable research has been done on the impact behaviour of liquids. Since these impact phenomena occur on the very short time scale of several microseconds, high-speed imaging is an obvious technique for studies in this particular field.

Many theoretical and experimental studies have been performed over the years in order to get a complete understanding of the impact behav-
iour of liquids on solids, solids on liquids and liquids on liquids. One pioneer in this field was the English physics professor A.M. Worthington,\textsuperscript{43} working at the Royal Naval Engineering College in Devonport. Already at the end of the nineteenth century, he did a considerable amount of research on these impact phenomena. One famous example is his research on drops of water hitting milk. One impact phenomenon is named after Professor Worthington: The Worthington jet. When a solid sphere or a liquid drop impacts on a liquid surface, a jet shooting out of the liquid can often be observed, for instance rain drops hitting a puddle. Professor Worthington also discovered that a sphere with a high surface roughness causes a much higher Worthington jet than a smooth sphere.

Another person who became famous for research on this particular topic, is professor H. Edgerton, who worked at the MIT. Many of his photographs appeared in magazines and in books. His work became very popular among the general public. Even nowadays his pictures are available on postcards.

In order to get a better understanding of the impact phenomena, scientists have divided the impact into several stages, and tried to describe the behaviour of the drop at every stage, both empirically and mathematically.\textsuperscript{56–58} Another interesting study subject is the effect of surface roughness. It has been observed that surface roughness can destabilise the impacting drop and cause splashing.

Not much is known about the impact behaviour of drops of liquid on self-cleaning surfaces. It is an interesting field, however, since self-cleaning surfaces have, on one hand a high roughness and, on the other hand, a very low interaction with water. Most of this research was limited to low impact rates. On low impact, drops of water show a bouncing behaviour.\textsuperscript{44} In this work high-speed imaging was used to study the behaviour of drops of water on a self-cleaning surface made from Teflon\textsuperscript{®} colloids, as described in Chapter 5, in comparison with the impact behaviour on a smooth Teflon\textsuperscript{®} surface and a glass surface for different impact rates.
7.2 Theoretical Background

When a drop of liquid hits a solid surface, it forms a rim and spreads radially until it reaches a certain maximum diameter. If the liquid does not wet the substrate, it then retracts again. During this phase, the drop can show different types of behaviour, as shown in Figure 7.1. The drop can either stick to the surface, called deposition (7.1a), or it can show a partial (7.1b) or a full (7.1c) rebound. In the case of a partial rebound, the drop partially sticks to the surface, while the other part is ejected from the sticking liquid. In the case of a full rebound, the entire drop lifts off the surface. The drop can also exhibit a break-up behaviour (7.1d), in which satellite drops are ejected, and the main drop and satellite drops all show a bouncing behaviour. Another possibility is receding break-up or splashing, in which secondary drops form during the contraction of the liquid (7.1e). The surface roughness can influence the drop behaviour. The surface topology can introduce vertical velocity perturbations that can lead to splashing behaviour.

7.2.1 Dimensionless Numbers

A drop of liquid is held together by the surface tension of the liquid. Forces acting on the drop can deform the drop or destabilise it so that it falls apart. On impact, the inertial force resulting from the fall deforms the drop. The ratio of the inertial force to the surface tension determines the magnitude of the deformation. This ratio is given by the dimensionless Weber number:

\[ We = \frac{\rho V^2 D}{\sigma} \]  

- \( D \) is the drop diameter.
- \( V \) is the drop velocity at impact.
Figure 7.1: Different types of drop behaviour: a) deposition, b) partial rebound, c) full rebound, d) break-up, and e) splashing.

- $\rho$ is the liquid density.
- $\sigma$ is the surface tension of the liquid.

For values lower than 1, the surface tension is dominant and the drop is likely to be stable on impact. For values above 1, the inertial forces dominate.

When a drop of liquid hits a surface, it deforms and experiences a shear force, of which the magnitude is determined by the shear viscosity $\eta_s$. For a Newtonian liquid, the shear stress increases linearly with the shear rate. For a non-Newtonian liquid however, the correlation between shear stress and shear rate is non-linear. The shear viscosity can either
increase or decrease with increasing shear rate. In the first case, the liquid is “shear-thickening”, in the second case it is “shear-thinning”. The ratio between the inertial and viscous forces is given by the Reynolds number:

\[ Re = \frac{DV\rho}{\eta_s} \]  

(7.2)

In this equation, \( \eta_s \) is the shear viscosity.

Another number often used when describing the behaviour of fluids on impact is the Ohnesorge number, in which the viscous force is compared to the surface tension force:

\[ Oh = \frac{\eta_s}{\sqrt{\rho\sigma D}} = \frac{\sqrt{We}}{Re} \]  

(7.3)

### 7.2.2 Dissipation of Energy upon Impact

Several factors have to be taken into account when describing the energy dissipation of a drop of liquid upon impact.\(^{44}\) A list of interactions that can play a role is given here:

- Viscous dissipation is an important mechanism for a liquid to dissipate energy. The Reynolds number (Equation 7.2) gives the ratio between the viscosity (energy dissipation) and the surface tension (energy conservation).

- The contact angle hysteresis is another factor. The contact line can pin to the surface, and energy is viscously dissipated near the contact line.

- After lift-off, the drop may rotate and oscillate. This means the drop also dissipates energy by internal modes of vibration.

Some of these interactions are interactions between the liquid and the surface it impacts on. In a static situation, the interaction between a drop of water and a self-cleaning surface is minimal. This should also apply to the dynamic situation where a drop impacts on such a surface.
7.2.3 Bouncing Behaviour of Drops

As mentioned in the previous section, the interactions between a drop of water and a self-cleaning surface are very small. Research performed by D. Richard and D. Quéré\textsuperscript{44} confirms this. They showed that viscous dissipation plays only a minor role for a drop hitting an ultra-hydrophobic surface. Because of the negligible viscous losses during drop spreading and retraction, most of the inertial energy is conserved and the drop rebounds. This behaviour can be very persistent, especially for drops with a small volume since they dissipate less energy by internal modes of vibrations. For small drops, a coefficient of restitution of 0.9 has been observed, meaning that the drop stores 90\% of the kinetic energy in its surface energy. These drops behave as a quasi-ideal spring\textsuperscript{49}.

The coefficient of restitution is a measure for the elasticity of an impacting object. The coefficient of restitution of a rebounding object is given by:

\[
c = \frac{V_f}{V_i} = \sqrt{\frac{h}{H}} \quad (7.4)
\]

In this equation \(V_f\) and \(V_i\) are the velocity after and before impact, respectively, \(h\) is the height to which the drop bounces after impact, and \(H\) the height from which the drop was originally dropped.

7.2.4 The Final Diameter of Drops after Impact

After the kinetic energy of the impact has dissipated, the drop is in a static equilibrium. The diameter of the drop can be calculated from the contact angle of the drop\textsuperscript{56}.

\[
\frac{d_f}{D} = 2 \left[ \frac{\sin^3 \theta_f}{2(1 - \cos \theta_f)(2 - \cos \theta_f - \cos^2 \theta_f)} \right]^\frac{1}{3} \quad (7.5)
\]

There are many equilibrium states because of the contact angle hysteresis. The drop attains an advancing contact angle for very low impact
rates, but for higher impact rates the drop spreads to a diameter between the advancing and the receding contact angle, or even overshoots the diameter corresponding to the receding contact angle. In the latter case, the drop will contract. If the retraction speed is slow enough, the drop will remain at the receding contact angle. For higher retraction speeds, the drop will reach a contact angle between the receding and the advancing contact angle.\textsuperscript{56}

### 7.2.5 The Maximum Diameter of Drops on Impact

In the literature, several estimates of the maximum spreading of drops on impact can be found,\textsuperscript{57,58} in addition to empirical correlations. C. Clanet \textit{et al.} studied the maximum deformation of impacting drops on a super-hydrophobic surface. They found that the maximum diameter of a drop scales as:

\[
D_{\text{max}} \sim D_0 W e^{1/2} \tag{7.6}
\]

In the same study more wettable surfaces were investigated, and the same scaling was found.

### 7.3 Experimental

For the experiments reported here a Kodak EktaPro EM Motion Analyzer high-speed camera was used. The needle of a liquid dispenser was filled with reversed osmoses water and was then fixed at a certain height above the sample using a retort stand. Drops of 5 µl were released from heights of 1, 2.5, 5, 10, 20, and 40 cm. The sample was illuminated by a glass-fibre light source. The high-speed camera was mounted at an angle of 45° with respect to the surface. Figure 7.2 shows a schematic drawing of the setup. The size of the imaged area was calibrated using grid paper. The captured frames were transferred from the high-speed camera memory to a mini digital video (mini-DV) tape after each experiment.
The data on the mini-DV tapes was captured onto a computer for image analysis. Relevant image frames were selected in order to measure the speed of the drop immediately before impact and the drop diameter at different stages of the experiment.

Experiments were performed on three different types of surfaces: glass, smooth Teflon® surfaces, and self-cleaning surfaces. The smooth Teflon® surface was prepared by spin-coating Teflon® colloids onto a glass substrate and subsequently heating the film to a temperature of 340 °C in order to fuse the colloidal particles together.
7.4 Results

7.4.1 The Behaviour of Drops on Inclined Surfaces

In the first experiments performed using the high-speed camera, a drop was placed onto an inclined surface. Chapter 2 describes that drops of water slide off most surfaces, but roll off self-cleaning surfaces, taking away particles from such surfaces. The sliding and rolling behaviour of drops of liquid on inclined surfaces was studied before the detailed description of ultra-hydrophobic surfaces.\textsuperscript{45, 46} A classic example of a non-wetting liquid rolling off a surface is mercury. This behaviour is probably the origin of the name \textit{quicksilver}. Some research has been done on the behaviour of drops of water on inclined ultra-hydrophobic surfaces.\textsuperscript{47, 48} L. Mahadevan and Y. Pomeau made a model for the velocity of a drop with a contact angle of 180°, and D. Richard and D. Quéré conducted experimental research on drops rolling off an inclined non-wettable solid. They made the surprising discovery that the velocity of a drop increases with a decreasing diameter. This contradicts with the behaviour of sliding drops, for which gravity causes large drops to slide off faster than small drops.

The sliding and rolling behaviour was verified by capturing the motion of drops on smooth and self-cleaning Teflon\textsuperscript{®} surfaces using a high-speed camera. In Figure 7.3 a sequence of 4 images is shown for both types of surfaces. A dirt particle was placed on the self-cleaning surface. It was removed by the drop of water rolling off the surface. The drop of water on a smooth Teflon\textsuperscript{®} surface moves much more slowly and sluggishly down the surface, suggesting that the drop is slowed down by defects on the surface. The contact angle at the front of the drop is higher than at the tail end. The drop spreads down the smooth surface, but it rolls off the self-cleaning surface.
7.4.2 Quantitative Description of the Behaviour of a Drop on Impact

In this section an overview of the drop behaviour on the three surfaces for different Weber numbers is given. The behaviour of the drops has been visually observed, and the data has been graphically represented in Figure 7.4.

For the glass surface, only deposition of the drops occurs. In the case of smooth Teflon® films, deposition occurs for a low Weber number. At higher Weber numbers, a partial rebound occurs. The drop first assumes a figure of eight like shape, and the upper part of this figure is ejected. The size of the upper part increases for higher Weber numbers, but in most cases stays connected to the bottom part. For the highest impact rate, the rim of the drop becomes unstable, but splashing does not occur on contraction.

For the self-cleaning surface, deposition does not occur at all. For low Weber numbers, bouncing behaviour can be observed. The drop bounces many times and in most cases bounces off the 2 x 2 cm² substrate. For higher Weber numbers of about 20 to 150, break-up of the drop occurs. Other work shows that capillary waves are exited when drops impact on ultra-hydrophobic surfaces, and form pyramid structures. The oscilla-

Figure 7.3: A drop of water a) sliding off a smooth Teflon® surface, b) rolling off a self-cleaning surface and removing a dirt particle.
tions of the capillary waves then cause the formation of an air cavity in the centre of the drop, and the subsequent collapse of this cavity leads to the formation of a jet\textsuperscript{51} that shows break-up behaviour. Both the main drop and the satellite drop bounce several times after break-up occurs. For Weber numbers above 200, the drop splashes. Also in this case, parts of the drop bounce several times. Break-up in combination with a splash has not been observed. The drop dissipates enough energy during the splash to suppress break-up. A similar observation can be found in the literature.\textsuperscript{56} Research performed by D. Bartolo et al.\textsuperscript{62} shows that drops impacting on an ultra-hydrophobic surface made of a pillar structure, can irreversibly enter the Wenzel’s regime upon impact for high impact
rates, causing pinning of the drops to the surface. This kind of behaviour has not been observed in this research, neither for the main drops nor for the smaller satellite drops.

Even though the rebound behaviour is different on the three surface types, the drop remains intact for low Weber number in all three cases. Compared to the inertial energy, the surface tension is high enough to keep the drop together.

It is clear that the behaviour of the drops is different for the three different surfaces. Rioboo et al.\textsuperscript{59} already concluded that there is no critical Weber number or other dimensionless group that defines the threshold between the different drop behaviours, because the numbers do not take factors such as the surface roughness and the contact angle into account. They studied the effect of several physical parameters on the drop impact behaviour. One of the trends they found is that a high contact angle and a low contact angle hysteresis make the occurrence of receding break-up, partial and complete rebound more likely. This is in agreement with the results found in this work. For the substrate with the lowest contact angle, the glass substrate, only deposition and none of the three mentioned phenomena is observed. For the Teflon\textsuperscript{®} surface, partial rebound is the dominant phenomenon, and for the self-cleaning surface, with the highest contact angle and a negligible contact angle hysteresis, complete rebound or break-up occurs.

\subsection*{7.4.3 Evolution of the Drop Diameter}

In order to get a better understanding of the behaviour of drops of water on the investigated surfaces, the relative diameter of the drops (i.e. the diameter ratio of the drop before and after rebound), was determined in 1 millisecond intervals after impact. When the drop is asymmetric at the moment of impact, it spreads in a slightly oval way. Typical results are shown in Figure 7.5. The graph shows that the spreading of the drop takes 2 milliseconds for all three surfaces. The maximum
Figure 7.5: The relative diameter after impact for a Weber number of 50 for a self-cleaning, a smooth Teflon®, and a glass surface.

relative diameter is also quite similar in all three cases, with the highest diameter for the glass surface. The main difference was observed for the retraction speed. The retraction starts immediately after reaching the maximum diameter for the self-cleaning surface and for the Teflon® surface. For the glass surface, the drop maintains its maximum diameter for 3 milliseconds. This behaviour has been observed in other work, and is related to the contact angle hysteresis: The contact angle of the head of the rim changes from advancing to receding when the drop starts to contract. The diameter of a drop of water on a self-cleaning surface contracts in about 7 milliseconds to below its original diameter, before
it starts to lift off the surface. The time it takes the drop to contract and to lift off the surface appears to be independent of the impact rate. This corresponds to other research,\textsuperscript{53} in which it has been shown that the contact time of a bouncing drop with the surface is independent of the impact velocity, similar to a bouncing ball considered by the German physicist Heinrich Hertz. On a Teflon\textsuperscript{®} surface, the drop contracts in approximately 9 milliseconds. Also in this case the retraction rate is independent of the impact rate. Other work shows similar results for hydrophobic surfaces with a small contact angle hysteresis,\textsuperscript{61} in which was shown that the retraction rate is governed by the Ohnesorge number and is independent of the impact rate.

On a glass surface the retraction takes even longer. In case of glass, the diameter remains above its original diameter, as is shown in Figure 7.6. This has to do with its low contact angle: of the three investigated surfaces, it is the only hydrophilic surface. Very clean glass can show complete wetting, but this has not been observed in our experiments. In the graph, dashed lines indicate the minimum and maximum final diameter based on the advancing and receding contact angle and using Equation 7.5. For the drops with a Weber number of 220 and 290, the drop is still contracting after 16 milliseconds, and probably will reach the maximum calculated diameter. The drops with a Weber number of 50 and 90, have reached a final diameter between the maximum and minimum diameter. The drop with a Weber number of 20 reaches a diameter close to the minimum diameter. It is surprising to see that the drop contracts after reaching the maximum diameter after 2 milliseconds, since it was expected that it would retain that diameter. The drop with a Weber number of 7 does not comply with the theoretical value at all. A steady increase in the diameter could be expected until the drop reaches the minimum diameter corresponding with the advancing contact angle. An explanation for this result might be found in the inhomogeneities on the surface, which cause the drop to have an irregular shape.

It is likely that the slower retraction speed for both the glass and Tef-
Figure 7.6: The evolution of the relative diameter of a drop of water impacting on a glass surface for different Weber numbers.

lon® surfaces is caused by interactions between the surface and the drop, such as pinning. This gives rise to a significant contact angle hysteresis.

In Figure 7.7, the maximum diameter as a function of the Weber number is shown, and compared to the correlation described in section 7.2.4. Drops impacting on the glass substrate show a similar trend as the mentioned correlation. The Teflon® and self-cleaning substrate show the $D_0 W e^{1/4}$ scaling, but the numerical coefficient has a lower value of about 0.8 instead of 0.9.

In Figure 7.8, the retraction speed as a function of the Weber number
is shown. The dashed lines in the graph show the transitions between different types of impact behaviour. Bergeron et al.\textsuperscript{66} reported a study of drop impact on a surface with a contact angle of 120°, similar to the contact angle of water on Teflon\textsuperscript{®} surfaces. They reported that no rebound occurs below a critical retraction speed of 0.3 m·s\(^{-1}\). This agrees with our results. This critical value for the retraction speed also seems to be valid for the self-cleaning surface, but in this case it applies to the transition from bouncing to break-up. For the self-cleaning surface,
the maximum diameter of the drop overshoots the final diameter much further than on a glass or Teflon® surface, and therefore the retraction speed increases.\textsuperscript{56} This increase in speed makes the occurrence of break-up or splashing behaviour much more likely.\textsuperscript{59}

In Figure 7.9, pictures of drops at their maximum diameter are shown for 3 different Weber numbers. For a low value of the Weber number, the drops are not strongly deformed. For a Weber number with a value of 50, the drops are much more strongly deformed in all three cases. It can clearly be seen that rims have formed. For Weber numbers of approximately 200, the rim is stable on a glass substrate. For Teflon®,

Figure 7.8: The retraction speed of the drop for a glass, a Teflon®, and a self-cleaning surface as a function of the Weber number.
the rim shows an instability, but the drop remains intact on contraction. On the self-cleaning surface, several fingers and satellite drops form on contraction.

One possible reason why the rim is the most unstable on a self-cleaning surface is connected to the surface roughness. During the expansion of the drop, the liquid flow is destabilised by the surface texture, and therefore forms an unstable rim which is the cause of the splashing behaviour. A second possibility is an enhanced Rayleigh instability\textsuperscript{54} of the rim of the spreading drop. The Rayleigh instability is the destabilisation of a liquid cylinder into a series of drops. One aspect of the rim instability is analogous to the Rayleigh instability:\textsuperscript{55} on self-cleaning surfaces, only a very thin layer of water remains inside the spreading rim.
compared to drops spreading on the other surfaces. This may be due to the reduced surface friction of the water. In addition, the contact lines of the rim have a very high contact angle, giving the rim the nearly cylindrical shape shown in Figure 7.10b. This cylindrical shape may lead to an enhancement of the Rayleigh instability of the rim, compared to the situation depicted in Figure 7.10a. Clearly, further research is required to better understand the enhancement of the rim instability on self-cleaning surfaces.

### 7.4.4 The Elasticity of a Bouncing Drop

As mentioned in Section 7.2.3, a drop of water can bounce many times on a self-cleaning surface. If the drop breaks up or splashes for high Weber numbers, both the large main drop and the small satellite drops tend to bounce as well. The coefficient of restitution has been determined for the main drop for different values of the Weber number. The results for the first 2 rebounds are represented in Figure 7.11.

In all cases, the coefficient of restitution is similar for the second rebound, and also for subsequent rebounds, with values of about 0.75. This value is lower than the value of 0.9 found by D. Richard and D. Quéré. This is most likely because they used smaller drops with less internal modes of vibration. Different values can be observed for the first rebound. For Weber numbers with a value of 7 and 20, corresponding to bouncing behaviour of the drop, the coefficient of restitution has a value.
of about 0.75, similar to the second rebound. For Weber numbers with values of 50 and 90, corresponding to break-up behaviour, the coefficient of restitution decreases to a value of about 0.30. For a splashing drop, the coefficient of restitution decreases even further for the first rebound, to a value of about 0.15.

This data clearly shows that the drop dissipates energy by breaking up or splashing. In Figure 7.12, the relative remaining volume of the main drop is shown after the ejection of the satellite drops.

It is obvious that for a normal rebound, the volume of the drop is
Figure 7.12: The relative remaining drop volume after the first rebound.

100 % of its original volume for subsequent bounces. For a drop that breaks up, about 85 % of the original drop volume is remaining. For higher Weber numbers, the total volume of the ejected satellite drops increases. In case of splashing, a similar effect can be seen. For a Weber number of 220, the volume is still about 85 % of the original volume, but decreases to about 75 % for a Weber number of 290. One satellite drop was ejected for a Weber number of 50, and three for a Weber number of 90. For splashing drops, more than 10 very small satellite drops are ejected.

In Figure 7.13, the speed of the drop at the moment of impact is
shown. The graph shows the dramatic decrease of the drop speed for the drops in case of high Weber numbers. Due to drop break-up and splashing, the kinetic energy is reduced so that the drop speed is much lower before the second impact. The speed at the second impact is the highest for the drop with a Weber number of 20. Since the coefficient of restitution for the subsequent bounces is basically constant for all drops, this drop has the potential to rebound the largest number of times. In the graph the maximum speed for rebound to occur is approximately $1 \text{ m} \cdot \text{s}^{-1}$. The drop with a Weber number of 20 rebounds 9 times, which indeed is the largest number of rebounds of all drops. The drops typically stop bouncing when the speed at impact is below $0.1 \text{ m} \cdot \text{s}^{-1}$, which corresponds to the value found by D. Richard and D. Quéré.\textsuperscript{53} The coefficient of restitution only takes the speed of the drop at impact into account. The decrease in kinetic energy for the drops with a high Weber number at initial impact is even larger, since the main drop loses part of its mass by ejecting satellite drops. For the drop with a Weber number of 90, it was possible to calculate the coefficient of restitution when taking the satellite drops into account. This was done by measuring the speed and size of the drops upon impact, and calculating the kinetic energy of each drop. The coefficient of restitution calculated this way, has a value of 0.53. This is significantly lower than the 0.75 for a drop that remains intact. This implies that energy lost during the break-up of the drop is due to viscous dissipation. It was not possible to do similar calculations for other drops, since the satellite drops often ended up outside the field of view of the camera.

\section*{7.5 Conclusions}

In this chapter, the behaviour of drops of water upon impact on a glass, a smooth and a self-cleaning Teflon® surface has been investigated with a high-speed camera. While on the glass and the smooth Teflon® sur-
face a drop sticks to the surface upon impact, drops impacting on a self-cleaning surface rebound. This difference in behaviour upon impact occurs because viscous dissipation only plays a minor role for a drop impacting on a self-cleaning surface. Therefore, enough energy remains for the drop to rebound off the surface. This bouncing behaviour is quite persistent. This is especially the case for low impact rates, corresponding to a low Weber number, for which the impacting drop remains intact. For higher Weber numbers, break-up or splashing of the drop occurs, and the drop dissipates energy during these processes. The drop also loses kinetic

Figure 7.13: The speed of the drop at the moment of impact for a sequence of impacts for different Weber numbers.
energy by ejecting satellite drops. These satellite drops also show bouncing behaviour. The number of satellite drops increases with the Weber number. For drops that break-up, their number is relatively small, up to 3, compared to a splashing drop, for which many more smaller satellite drops are ejected. Energy dissipation factors that play a role for all drops are oscillations or drop rotation after lift-off, resulting in the dissipation of energy by internal modes of vibration. An advantage of the self-cleaning surfaces used in this work over the more traditional pillar structures is that no irreversible transition to the Wenzel state occurs on high impact rates.

The maximum diameter of a drop upon impact increases with the Weber number, and scales as $We^{1/4}$. For similar Weber numbers, the largest relative diameter is obtained on the glass surface, but it does not differ much from the maximum diameters measured on smooth and self-cleaning Teflon® surfaces. The retraction speed is the fastest for the self-cleaning surface, because there is little interaction and therefore little friction between the drop and the surface. The drop starts to retract immediately after the maximum diameter has been reached on the smooth and self-cleaning Teflon® surfaces. On the glass surface, the drop maintains its maximum diameter for 3 milliseconds. During this time the contact angle of the head of the rim is changing from advancing to receding.

The behaviour of drops of water placed onto an inclined smooth and self-cleaning Teflon® surface has been investigated. On a smooth Teflon® surface, the drop spreads sluggishly down the surface. On a self-cleaning surface, the drop rolls off the surface. It even carries away dirt particles from the surface. Our further interest concerns the influence of the bouncing behaviour of drops on its cleaning power. The contact a drop makes with a self-cleaning surface is small, and it is likely a drop just bounces off the surface avoiding most dirt-particles on that surface. This may not be a problem for some biological self-cleaning systems, since particular water plants (such as the Lotus plant) are in
contact with an abundance of low-velocity water. Drops rolling off the surface make contact with a much larger fraction of the surface area and are therefore more efficient in cleaning the surface. Impacting drops are probably most likely to interact with a dirt particle upon the initial impact, during which the drop spreads to its largest diameter on the surface. What is also interesting is to what extent dirt particles influence the bouncing behaviour of rebounding drops. Possibly, drops interacting with small dirt particles might show bouncing behaviour, whereas larger dirt particles suppress bouncing, causing the drop to roll off the surface, thereby carrying away the dirt particles.