Influence of wetting behavior on macroscopic film flow pattern

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ABSTRACT

Liquid film flow and surface wetting are physical processes that are highly relevant in various industrial applications, but actually not completely understood. The propagation of liquid films on flat surfaces strongly depends on wetting properties like equilibrium contact angle and dynamic contact angles. A thorough investigation of these properties is required to be able to set up numerical liquid film simulations for a specific surface material.

Objective of this study is to experimentally investigate the wetting properties of a fluorescent water-uranine solution on glass in single droplet experiments, and global film flow characteristics in rivulet experiments. Apparent contact angles are measured for single droplets, impinging on a flat surface under a certain angle, by means of goniometric measurements. These measurements are realized using different cameras with high spatial or temporal resolution. This provides detailed insight in contact angle evolution and contact line motion as the droplet impacts and spreads. The single droplet wetting parameters are utilized in film flow simulations including a surface wetting model. Numerical film simulations are carried out in an Eulerian frame work using OpenFOAM software for water-uranine solution on glass. In particular, the film thickness and film spreading/contraction angles are used for validation. Corresponding experimental results are obtained from the analysis of fluorescence imaging, together with an innovative fluorescence calibration method, which enables film thickness quantification over a wide range of thickness values without relying on mechanically produced calibration vessels. The presented experimental and numerical methodologies may assist in improving film flow models and help to get a further insight concerning surface wetting behavior for various applications.

1. Introduction

The determination of important film quantities such as thickness, velocity or wave structure is of primary importance for various engineering applications, for instance when considering vehicle soiling (Hagemeier et al. 2011). Existing film modeling approaches rely mostly on approximate, empirical models and must always be validated by comparison with experimental results. In order to develop, validate and improve further film models, reliable measurement data are thus needed. Using a fluorescence imaging approach relying on Light Emitting Diodes (LED) for excitation, a simple and reliable method has been developed to quantify the liquid film thickness as well as the
apparent contact angles, as explained in Hagemeier et al. (2012a). However, there is still a lack of reliable experimental data concerning the measurement of contact line velocity, together with contact angle and droplet thickness, as well as film thickness in rivulets formed on inclined surfaces. Such simultaneous measurements are very important to support or improve current model developments.

Such measurements are realized in this study, using different cameras with high spatial or temporal resolution. This provides detailed insight in contact angle evolution and contact line motion as the droplet impacts and spreads. Corresponding experimental results are obtained from the analysis of fluorescence imaging together with an innovative fluorescence calibration method, which enables film thickness quantification over a wide range of thickness values, without relying on mechanically produced calibration vessels. Additionally, numerical film simulations are carried out in an Eulerian frame work, using OpenFOAM software for water-uranine solution on glass. In particular, the film thickness and film spreading/contraction angles are used for validation.

2. Experimental setups and procedures

The contact angle measurements have been conducted using a specific hardware setup, which relies on previous installations described in Hagemeier et al. (2012b) and Hagemeier et al. (2014). It is suitable for the acquisition of shadow images of 30 µl droplets (corresponding to a spherical drop diameter of approximately 4 mm), which have been generated in a reproducible manner by a syringe pump. All components are fixed on a mounting rail that can be tilted up to approximately 45°. A sketch of the complete setup is shown in Fig. 1.
The experimental procedure starts with the deposition of the droplet on a solid substrate. Then, shadow images are taken from the static or dynamically moving droplet with an appropriate camera. The first contact angle measurements were carried out with an exposure time of 250 µs and a recording rate of 5 Hz. The scale factor was 117 pixel per mm and images were recorded for 4 s. Later on, additional high-speed camera experiments have been performed. In connection with a higher frame rate (1000 Hz), the geometrical resolution was reduced, due to camera parameters and to provide a larger field of view. The scale factor in these measurements was only 44 pixel per mm. The reduced resolution leads to a lower accuracy and larger scattering of contact angle values, as will be shown later.

The wetting behavior strongly depends on the material properties and the ambient conditions. While the ambient conditions (temperature, pressure and humidity) are reported for each trial, the material properties have been measured only once, previously to the contact angle measurements. Particularly, the surface tension, conductivity and pH-value were analyzed for deionized water and Uranine-solution (simply called “Uranine” throughout the paper, though the dominant component is of course water). The fluorescent Uranine-solution was used in the rivulet experiment, which is why the difference in material properties is interesting. The results are listed in Table 1 without giving details concerning the measurement procedure, since all quantities were measured using standard commercial equipment. The ambient conditions are measured together with the contact angle experiments. Pressure, temperature and relative humidity have been recorded twice, before and after each contact angle measurement.

<table>
<thead>
<tr>
<th>Property</th>
<th>Deionized water</th>
<th>Uranine solution (0.05 g/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH-value (probe)</td>
<td>5.69</td>
<td>6.49</td>
</tr>
<tr>
<td>Conductivity (probe)</td>
<td>2 µS/cm</td>
<td>23.2 µS/cm</td>
</tr>
<tr>
<td>Surface tension (pendant drop method)</td>
<td>68.3 mN/m (21.7°C)</td>
<td>68.7 mN/m (21.7°C)</td>
</tr>
</tbody>
</table>

Table 1: Material properties of deionized water and Uranine-solution

For post-processing, the apparent contact angles are evaluated from the tangents of the droplet profile at the contact points (front and back side). Both values are almost identical for the basic configuration (0° inclination angle) but deviate for tilted plate conditions. It has to be mentioned that an inclined plate does not automatically lead to a dynamic regime. The motion of the droplet starts for an identical drop volume at different inclination angles when investigating various
liquid-solid configurations. Fig. 2 shows an exemplary image of a sessile droplet (left) and the three solid material samples used in the contact angle measurements (right).

For the determination of film thickness in rivulets, formed from a continuous liquid film, a special orifice has been mounted on a substrate plate (Fig. 4 left). The inner of the film generator was filled with mesh and wire material, which ends just before the orifice. This ensures homogeneous liquid distribution and outflow conditions. The orifice is pressed onto the substrate by two clamps. A sealing ensures that there is no leakage. The glass substrate and orifice were mounted on a rotatable frame together with the camera (equipped with a long pass filter, cut-off wave length at 555 nm) and the LEDs for illumination. An array of 10 green LEDs, each with a power of 1.8 W and a luminous flux of 55 lm has been employed. The emission of these LEDs is centered around 520 nm with an FWHM of 35 nm.

The whole arrangement (Fig. 3, right image) allowed predefining different inclination angles. Particularly, inclination angles of 20° and 30° have been investigated in these experiments. The camera ran at a frame rate of 5 Hz with an exposure time of 50 ms. This exposure time is acceptable for quasi-steady conditions as found in these experiments.
The orifice was provided with a liquid volume flow rate that was measured by a flow meter and was manually controlled by a valve. Flow rates were possible in the range of 400 to 1900 ml/min. No continuous liquid film was produced below the minimum flow rate of 400 ml/min. All experiments were carried out using Uranine solution at a concentration of 0.05 g/l, identical to the contact angle measurements. The experiments included a geometrical calibration, a fluorescence calibration and the final film thickness measurements.

**Film thickness calibration**

The physical background of the fluorescence imaging method is given by the Beer-Lambert law

\[
I_e = \Phi I_0 \left[1 - \exp\left(-c_{dye} \delta \varepsilon_\lambda\right)\right].
\]

It includes \(I_e\) the emitted light intensity, \(\Phi\) the quantum yield, \(I_0\) the incident light intensity, \(c_{dye}\) the molar fluorescent dye concentration [mol/l], \(\delta\) the film thickness [m] and \(\varepsilon_\lambda\) the molar absorption coefficient [l/mol m]. Now, we are looking for a relationship between the emitted light intensity as input and the film thickness as output values. Equation (1) constrains the form of this calibration curve in the following way:
\[
\delta_r = \frac{\ln\left(1 - \frac{I_e}{\Phi I_o}\right)}{-c_{dye} E_\lambda}.
\]

The emitted light intensity corresponds to the intensity values on each individual pixel of the image, the molar concentration being known in advance. The quantum yield together with the incident light intensity and the absorption coefficient are unknown. However, they are constant and can be handled as fitting parameters \( A \) and \( B \) in a reformulated equation:

\[
\delta_r = \frac{\ln\left(1 - \frac{I_e}{A}\right)}{-c_{dye} B},
\]

which is solved as part of a minimization problem. In this minimization problem, a droplet with a defined volume, here 50 µl is deposited on the substrate and imaged under real measurement conditions. Then, a background image is subtracted to reduce illumination inhomogeneity (noise on the image). What remains are the pixel intensities belonging to the droplet. These intensities correlate with film thickness values. The droplet volume can be obtained, when summing all the thickness values and multiplying them with the pixel area.

The minimization algorithm seeks for best fitting constants \( A \) and \( B \) to minimize the difference between the known droplet volume and the calculated droplet volume. This procedure is most reliable and highly accurate. It is advantageous compared to previously used methods based on a hardware calibration device with increasing manufacturing tolerances for low dimensions, usually leading to a linear calibration curve but with limited accuracy.

The calibration curve and associated constants for the present fluorescence imaging investigations are shown in Fig. 5.

Fig. 5: Calibration curve and best-fit constants \( A \) and \( B \) (left)

The validity of the calibration has been checked by applying the calibration function to single droplets of various sizes. A good agreement between nominal (dosed) and calculated droplet
volume was observed for all cases (Fig. 5, right). Minor deviations are the results of manual droplet deposition using a micro-liter pipette or of correction operations to remove small reflection spots in the droplet images.

3. Contact angles: results

Starting with the configuration Uranine on metal, the results are shown in Fig. 6. A typical behavior was observed for the advancing angle, which is the angle on that side towards the droplet bends when the plate is inclined. At 0° inclination, the contact angle takes the so-called “equilibrium contact angle” value of $\theta_{\text{equ}} = 78.03^\circ$ and is equal for advancing and receding side. For a higher plate inclination angle a different behavior was observed for advancing and receding sides. While the advancing contact angle first increases slightly and stays afterwards constant at $\theta_{\text{adv}} = 81^\circ$, the receding angle decreases throughout all plate inclinations. The receding angle decreases linearly and can be described using the following correlation: $\theta_{\text{rec}} = -0.57\alpha_{\text{incl}} + \theta_{\text{sta}}$.

\begin{figure}
\centering
\includegraphics[width=0.5\textwidth]{app_angle.png}
\caption{Apparent contact angle of Uranine droplet on metal}
\end{figure}

Corresponding mean values and standard deviations are listed together with averaged droplet height and width for the Uranine on metal configuration in Table 2. The last three measurements have been done with a high-speed camera at lower spatial resolution. The motivation for these measurements was to identify the transition point between stagnant and moving droplet.

For the “Uranine on metal” configuration, no droplet motion could be found. That is why some additional measurements at higher inclination angles ($50^\circ$ and $55^\circ$) have been carried out. These measurements were conducted using a high-speed camera to obtain image series of the initial drop impact with higher temporal resolution and to identify a configuration of dynamic contact angle. However, after initial spreading and sliding of the droplet on the inclined plate, the droplet
eventually remained static after the impact momentum was dissipated. It was neither possible to further increase the inclination angle without changing the complete experimental setup, nor to produce larger stable droplets without changing the dosing equipment.

<table>
<thead>
<tr>
<th>Inclination</th>
<th>$\Theta_{adv}$</th>
<th>$\Theta_{rec}$</th>
<th>$\sigma_{adv}$</th>
<th>$\sigma_{rec}$</th>
<th>Drop height [mm]</th>
<th>Drop width [mm]</th>
<th>Regime</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>78.03</td>
<td>77.41</td>
<td>0.63</td>
<td>0.47</td>
<td>2.01</td>
<td>5.35</td>
<td>static</td>
</tr>
<tr>
<td>10°</td>
<td>80.56</td>
<td>71.89</td>
<td>0.23</td>
<td>0.07</td>
<td>2.01</td>
<td>5.44</td>
<td>static</td>
</tr>
<tr>
<td>20°</td>
<td>80.23</td>
<td>65.83</td>
<td>0.38</td>
<td>0.9</td>
<td>1.97</td>
<td>5.53</td>
<td>static</td>
</tr>
<tr>
<td>45°</td>
<td>80.33</td>
<td>51.60</td>
<td>0.41</td>
<td>1.17</td>
<td>1.82</td>
<td>5.7</td>
<td>static</td>
</tr>
<tr>
<td>50°</td>
<td>79.81</td>
<td>54.77</td>
<td>-</td>
<td>-</td>
<td>1.88</td>
<td>5.37</td>
<td>static</td>
</tr>
<tr>
<td>55°</td>
<td>79.63</td>
<td>55.57</td>
<td>-</td>
<td>-</td>
<td>1.95</td>
<td>5.03</td>
<td>static</td>
</tr>
</tbody>
</table>

Table 2: Averaged values for advancing and receding contact angles, associated standard deviations and drop height and width for the “Uranine on metal” configuration

Most important findings of these high-speed imaging were the height and width ratios of the droplets during the early impingement phase. The ratios appear to be very similar for the high inclination angles, as can be seen from Fig. 7.

The general behavior of the impinging droplet shows typical oscillations in the early stage, mainly concerning the height ratio. During this process, the impact momentum is dissipated and the droplet reaches equilibrium at constant width and height values. A similar trend was reported earlier, e.g. by Fujimoto et al (2007). They globally found the same curve progression for much smaller droplets, but with less oscillations. This shows, that the oscillations are affected by droplet size, impact velocity and wetting properties.

![Fig. 7 Droplet height and width normalized by spherical drop diameter (3.8 mm) corresponding to a droplet volume of 30 µl for Uranine on metal](image-url)
Similar measurements have been accomplished for the Uranine-solution on glass (Fig. 8 left) and on acrylic glass (Fig. 8 right).

For glass, droplet motion was observed for inclination angles larger than 40°. The droplets slowly moved down the inclined plate with advancing contact line velocities in the range of approximately 5 to 20 mm/s and receding contact line velocities roughly ranging from 5 to 15 mm/s. For plate inclinations of 0°, 10° and 20°, the droplets stayed static. Similar to the “Uranine on metal” case, the advancing contact angle was found initially to be almost constant at $\Theta_{\text{adv}} = 35^\circ$, while the receding contact angle decreased with increasing inclination angle. In order to figure out at which inclination angle the droplet starts to move, additional measurements have been carried out at 40° and 50°. They were also conducted using a high-speed camera. The results for contact angle, droplet height, width and velocity are listed in Table 3.

<table>
<thead>
<tr>
<th>Inclination</th>
<th>$\Theta_{\text{adv}}$</th>
<th>$\Theta_{\text{rec}}$</th>
<th>$\sigma_{\text{adv}}$</th>
<th>$\sigma_{\text{rec}}$</th>
<th>height [mm]</th>
<th>width [mm]</th>
<th>Regime</th>
<th>Velocity (frontline/backline) mm/s</th>
</tr>
</thead>
<tbody>
<tr>
<td>0°</td>
<td>36.33</td>
<td>35.07</td>
<td>0.23</td>
<td>0.24</td>
<td>1.11</td>
<td>7.79</td>
<td>static</td>
<td>-</td>
</tr>
<tr>
<td>10°</td>
<td>34.4</td>
<td>20.99</td>
<td>0.37</td>
<td>0.9</td>
<td>0.99</td>
<td>8.71</td>
<td>static</td>
<td>-</td>
</tr>
<tr>
<td>20°</td>
<td>37.42</td>
<td>14.15</td>
<td>2.5</td>
<td>0.81</td>
<td>1.02</td>
<td>9.20</td>
<td>static</td>
<td>-</td>
</tr>
<tr>
<td>45°</td>
<td>55.75</td>
<td>19.67</td>
<td>2.02</td>
<td>0.85</td>
<td>1.26</td>
<td>7.6</td>
<td>dynamic</td>
<td>6.3</td>
</tr>
<tr>
<td>40 (case 1)</td>
<td>48.93</td>
<td>22.97</td>
<td>-</td>
<td>-</td>
<td>1.08</td>
<td>7.25</td>
<td>dynamic</td>
<td>5.9 / 6.1</td>
</tr>
<tr>
<td>40 (case 2)</td>
<td>52.76</td>
<td>27.23</td>
<td>-</td>
<td>-</td>
<td>1.13</td>
<td>6.86</td>
<td>dynamic</td>
<td>5.2 / 4.6</td>
</tr>
<tr>
<td>50 (case 3)</td>
<td>63.95</td>
<td>8.19</td>
<td>-</td>
<td>-</td>
<td>1.39</td>
<td>8.26</td>
<td>dynamic</td>
<td>21 / 16</td>
</tr>
<tr>
<td>50 (case 4)</td>
<td>52.82</td>
<td>10.38</td>
<td>-</td>
<td>-</td>
<td>1.20</td>
<td>7.87</td>
<td>dynamic</td>
<td>11 / 12</td>
</tr>
<tr>
<td>Uranine on acrylic glass</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<td></td>
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<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>0°</td>
<td>74.36</td>
<td>74.54</td>
<td>0.26</td>
<td>0.29</td>
<td>1.92</td>
<td>5.46</td>
<td>static</td>
<td>-</td>
</tr>
<tr>
<td>10°</td>
<td>73.74</td>
<td>63.65</td>
<td>0.43</td>
<td>1.01</td>
<td>1.82</td>
<td>5.66</td>
<td>static</td>
<td>-</td>
</tr>
<tr>
<td>20°</td>
<td>70.54</td>
<td>52.31</td>
<td>0.8</td>
<td>2.03</td>
<td>1.72</td>
<td>6.08</td>
<td>static</td>
<td>-</td>
</tr>
<tr>
<td>45°</td>
<td>77.24</td>
<td>47.97</td>
<td>0.51</td>
<td>0.58</td>
<td>1.73</td>
<td>5.79</td>
<td>static</td>
<td>-</td>
</tr>
</tbody>
</table>

Table 3: Averaged values for advancing and receding contact angles, associated standard deviations, drop height and width, regime and velocity for the “Uranine on glass” and “Uranine on acrylic glass” configurations.

In the case of acrylic glass, once more the advancing contact angle was found to be almost constant at \( \Theta_{\text{adv}} = 75° \), while the receding contact angle decreases linearly until it appears to remain constant as well. No dynamic droplet movement could be detected in that case.

Statistical mean values and standard deviations are listed together with averaged droplet height and width for the Uranine on acrylic glass configuration in Table 3 as well.

4. Film thickness: results

All measurements at inclination angles of 20° and 30° and flow rates from 400-1900 ml/min were conducted 3 to 5 times each, to evaluate the consistency and repeatability of the film formation process. The film pattern turned out to be very stable for multiple trials at the same flow rate. Exemplarily, the liquid film pattern is shown for an inclination angle of 20° and a flow rate of 1800 ml/min in Fig. 9. The gray scale corresponds to the film thickness, where white means large and black means low film thickness. The film edges are usually found to be thicker than the center of the film in all configurations. The bright spots (intensity saturation) are caused by isolated reflections from the LEDs and occur where the liquid surface is highly curved and close to the image boundaries. These areas cannot be evaluated for film thickness and were automatically removed during post-processing. The red lines in Fig. 9 represent coordinates, along which the film thickness is evaluated.
At an inclination angle of 20°, a film thickness continuously increasing with the flow rate can be seen in Fig. 10, on the centerline as well as on all cross lines. At 1600 ml/min the aspect of the second and third cross line change and get a third peak in the center of the rivulet, which becomes very pronounced at the highest flow rate on line 3. At the same time, the width of the rivulet does not change significantly.

When increasing the inclination angle to 30° the same tendencies can be recognized on Fig. 11, where only the lowest and highest measured flow rates are represented. In that case, the cross line profiles stay broader than in the case of 20° inclination.
Fig. 10: Film thickness at 20° inclination for different flow rates. Centerline left, cross lines right.
The macroscopic appearance of the liquid film or rivulet is affected by the wetting properties of the glass substrate. First, the wetting limitation forces the liquid into a narrow V-shaped film, and this observation holds over a large range of flow rates. When increasing the inclination angle, the body force acting on the liquid overcomes the former wetting limitation, leading to a broader liquid film. The transition between static and dynamic contact angle regime, as shown previously when discussing the contact angle results, may also have an influence here. Future measurements, particularly exploring the inclination angles between 20° and 40° will improve our understanding of the whole process.

These experimental data are already useful for comparison and validation of numerical simulations, as presented in the following section.
5. Simulation of film flows

Film flows of the Uranine solution along an inclined glass wall were simulated using the OpenFOAM software using an Eulerian model inside the *reactingParcelFilmFoam* solver, which is a transient PIMPLE solver able to describe surface films. The PIMPLE algorithm, a combination of SIMPLE and PISO algorithms, was used to solve the pressure-velocity coupling of the fluid phase. As in the experiments, the height and width of the film generator orifice were set to 3 mm and 80 mm, respectively. The dimensions of the glass substrate inclined by 20° were 100 × 120 mm². The numerical grid involves 43200 hexahedral cells for spatial discretization of the film flows. The liquid volume flow rate was kept at 1200 ml/min and the initial thickness of the liquid film was set to 3 mm. Main wetting properties of the Uranine solution used in the simulations are listed in Table 4. The ambient air was considered as a stagnant continuous phase at 20 °C and 1 atm. The time step was set to $10^{-4}$ s to guarantee that the maximum Courant number stayed smaller than 0.5. The total physical time considered in the simulation was 2 s which corresponds to 2.5 flow-through times (averaged film velocity by plate length).

<table>
<thead>
<tr>
<th>Wetting properties</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surface tension</td>
<td>68.7 mN/m</td>
</tr>
<tr>
<td>Density</td>
<td>998.2 kg/m³</td>
</tr>
<tr>
<td>Dynamic viscosity</td>
<td>$1.002 \times 10^{-3}$ Pa·s</td>
</tr>
<tr>
<td>Contact angle</td>
<td>Normal distribution: 20° (minimum), 50° (maximum), 35° (expectation), 50° (variance)</td>
</tr>
</tbody>
</table>

Table 4: Main wetting properties of Water-Uranine solution used in the simulation

The final, quasi-steady film flow at 20° inclination is depicted in Fig. 11. During the initial, transient period, a liquid film is generated by the constraints of the orifice, but the interfacial surface between the liquid and gas is not smooth. This unstable film flow is able to extend to about 20 mm. After that, a channeling flow including both, a film flow and rivulet flows, is gradually formed on the inclined substrate, due to the effect of surface tension, that tends to minimize the interfacial surface and acts against the inertial force. At later times, the initially dry areas between different rivulets become slowly wetted, when the initially separated rivulets come together and form a larger, V-shaped film. Finally, a relative stable film flow is formed in the investigated region, whose pattern is similar to the experimental result in Fig. 9. Similar dynamics were also observed in the initial stage of the experiments.
The detailed thickness profiles of the quasi-steady film flow (for a flow time > 1 s) are shown in Fig. 12, including again one center line and three cross lines. The position of these lines is the same as for the experiments (see again Figs. 8 to 10). Compared to the experimental result of flow rate 1200 ml/min at 20° inclination, the simulation predicts well the global pattern and thickness distribution of the film flow. The pattern is not completely symmetric, which is found in both simulation and measurement. The thickness of the film edges is larger than that of the central film; fluctuations of film thickness (wave-like structures) exist in both, flow and crosswise directions. The peak height computed from all thickness profiles is very close to that of the measurements. The simulation slightly overestimates the film height in general, but the width of the film is reproduced with a very good agreement.

The observed deviations between experimental and numerical results may have different origins. On the one hand, any small defect within the experimental hardware, like a microscopic scratch of the surface, may alter the flow pattern of the film in our wetting experiments, which are dominated by capillary effects. These defects are not captured by the perfect simulation setup.

Additionally, the wetting model itself and the numerical grid employed for discretization turn out to be decisive for the outcome of the simulations. The finally obtained accuracy is deemed acceptable when seen in the context of even more complex simulation chains, as used for instance to describe vehicle aerodynamics and soiling processes. Simplified surface film models including
surface (de)wetting yield an acceptably accurate and cost-efficient approach compared to far more complex approaches, like volume of fluid (VOF).

![Graph of film thickness profiles](image)

**Fig. 13:** Instantaneous film thickness profiles after 1s of the film flow on a 20° inclined glass plate for 1200 ml/min (compare to second row in Fig. 9)

Other flow rates have been calculated as well and will be presented in the oral presentation.

The wetting behavior of the inclined substrate is influenced by many properties, most prominently by wetting properties of the solution (surface tension, contact angle), inclination angle of the plate and liquid flow rate. Thus, systematic studies accounting for variations of all relevant dimensionless groups will be in focus of future work.

6. Conclusions

Surface wetting has been investigated experimentally and numerically in this work. The main focus was on the experimental determination of wetting parameters, such as apparent dynamic contact angles, together with propagation velocity of the advancing and receding contact lines. Furthermore, fluorescence imaging was applied to investigate global film flow properties, including liquid film height and film spreading. These experiments featured a new calibration approach that relies only on fundamental physics of fluorescence and is independent from any calibration tool, except for an accurate dosing of small-volume droplets.

Experimental results have been presented for wetting of glass, acrylic glass and painted metal by a water-uranine solution. While glass was found a good wetting material, where sliding droplets could be observed, acrylic glass and painted metal behaved similarly, both as non-wetting materials, with stagnant droplets only.
The contact angle values of the water-uramine solution on glass served as input parameters for accompanying simulations. These film simulations were carried out with Kistlers’ wetting model, which is implemented in OpenFOAM.

The results showed a reasonable agreement with the experimental data. However, further experiments are required to fully understand the behavior and to improve wetting modeling. Future work should first focus on improving experimental methodology and hardware. Particularly, the size of the experimental setup seems to be decisive. The smaller the initial orifice, the larger are the effects of (unknown) defects and impurities on the wetting process. Consequently, it is suggested to use larger experimental setups involving simultaneous measurements of film thickness, contact angle and contact line velocity for the investigation of the relevant film flow properties, like surface wetting or even film break-up.

7. Acknowledgements
Authors would like to thank Dr. Erich Jehle-Graf from Daimler AG for the cooperation and support of this project.

8. Literature


Hagemeier T, Thévenin D, Zähringer K (2012b) Stereoscopic fluorescence analysis of films, droplets and rivulets. 16th Int Symp on Applications of Laser Techniques to Fluid Mechanics Lisbon, Portugal, paper 282