Electronic Supplementary Information to "Predicting Inkjet Dot Spreading and Print Through from Liquid Penetration- and Picoliter Contact Angle Measurement"

1. Ultrasonic Liquid Penetration Measurement (ULP)

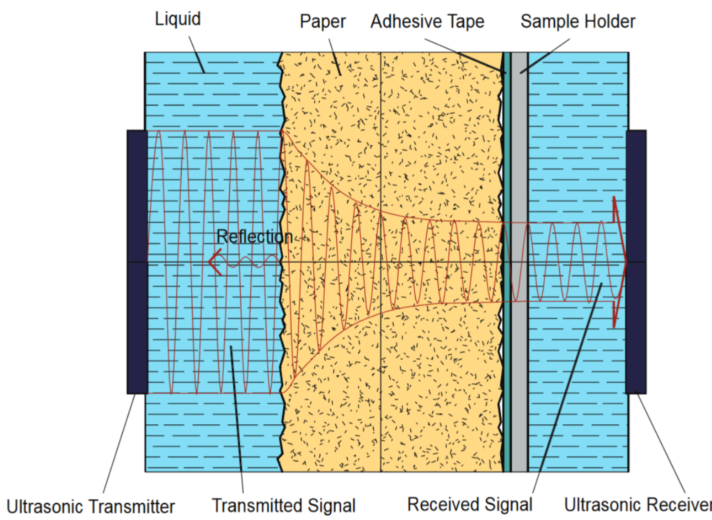


Figure 1: Measurement principle of the ultrasonic liquid penetration (ULP) measurement, drawing not to scale [1, 2].

The Emtec Penetration Dynamics Analyser 2.0 was used for all ultrasonic measurements. Measurement frequency was set to 2 MHz. The paper samples were cut to a rectangle of 7cm×5cm and fastened to the sample holder with a two sided adhesive tape. In the measurement cell an ultrasonic emitter and an ultrasonic receiver are placed to the opposite of each other, shown in Figure 1. When the sample is released into the testing cell filled with liquid, the transmitter instantly starts to send ultrasonic waves through the sample. The receiver measures the intensity of the ultrasonic signal. Sensor area is a circle with a diameter of 35mm. The ultrasonic waves are reflected, scattered or absorbed during the process of liquid penetration, represented through the red lines in Figure 1. As penetration of the liquid in the substrate proceeds, the receiver records the changes in the signal. The result is the ultrasound intensity over time [1].

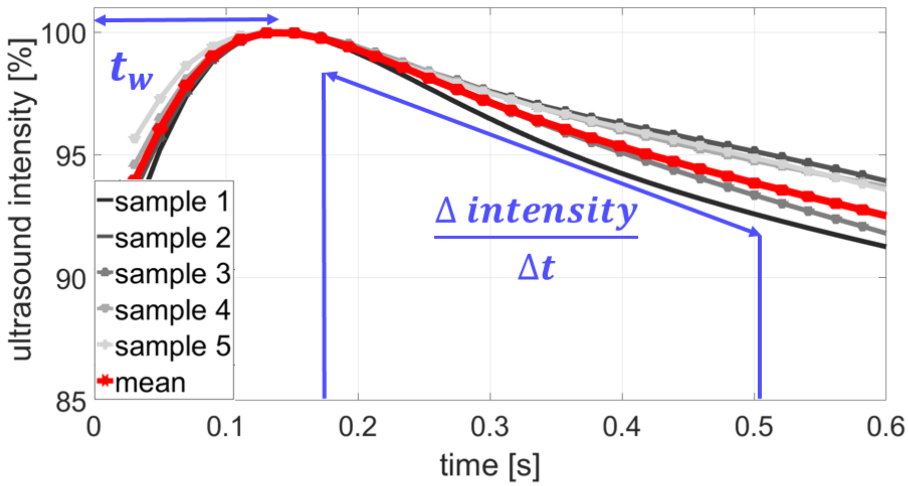


Figure 2: The ultrasonic measurement results show the change of ultrasound intensity over time. Time at the highest intensity $t_w[s]$ is defined as wetting time of the liquid and the slope of the curve as the penetration speed $[\frac{\Delta intensity}{(\Delta t)}]$of the liquid into the paper in $[\frac{1}{s}]$ [2].

A typical measurement result is shown in Figure 2, it is from the AKD sized paper with one dye ink. The curves are results from 5 specimen of the same paper (grey) and their mean value (red). The wetting is represented as the wetting time, which is the time between liquid contact and the highest intensity. (wetting time t_w in Figure 2). The longer it takes to reach 100% intensity, the lower is the wetting. The penetration speed is calculated between the time at the highest intensity and approximately 200ms for unsized papers and around 1s for hydrophobized papers after this time. The faster the liquid penetrates into the paper, the higher is the change in ultrasound intensity and the steeper is the slope of the curve $\frac{\Delta intensity}{\Delta t}$ (Figure 2). This is also available in previous work of our group [2].

2. Automatic Scanning Absorptometer (ASA)

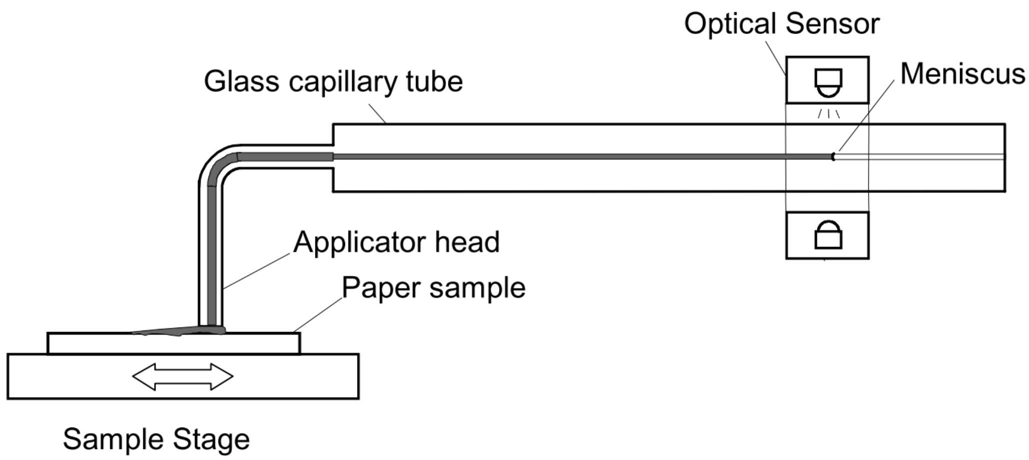


Figure 3: The automatic scanning absorptometer set up. The applicator head on the paper sample is moved over the paper, ink is supplied with the liquid via a glass tube. The meniscus sensor follows the receding meniscus and computes the amount of liquid, which is absorbed in the paper. Adapted from Enomae et al. [3, 2]

The Automatic Scanning Absorptometer measurement, performed with a KM500win Automatic Scanning Absorptometer instrument from KRK Kumagai (Japan), provides quantitative information about the liquid absorption as a function of time on time scales of 10 ms up to 10 s.[3, 4] During an SA measurement, liquid is supplied from a scanning head which moves along a spiral path on the paper. In Figure 3 one can see the head on the paper sample surface, it is supplied with the liquid via a tube. The speed of the head moving over the paper surface is kept constant over a certain part of the track, then it accelerates stepwise to a higher speed which is then again kept constant. By increasing the speed the system measures the liquid penetration for different times of contact between the Orifice and the paper. The ASA measures the total absorbed liquid volume per unit area. The penetration speed is represented by the slope $\frac{\Delta TLV/A}{\Delta\sqrt{t}}$ of the curve. The steeper the slope, the higher the penetration speed (Figure 4). The slope of this curve is calculated within the same time range as the slope of the Ultrasonic liquid penetration measurement is calculated i.e. a contact time between approximately 0.031ms and 0.200ms after contact between liquid and paper was made. This is done for every single liquid/paper combination [2].

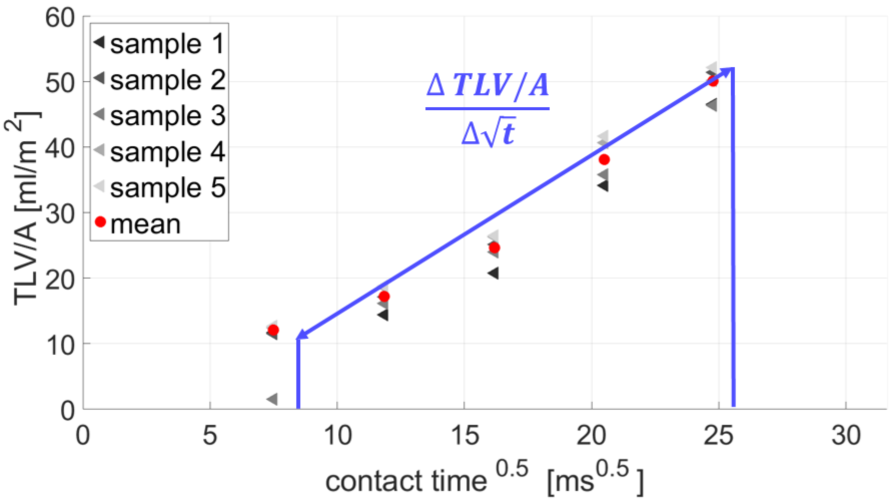


Figure 4: ASA - Measurement results show the absorbed liquid volume (Total Transferred Liquid Volume per unit Area TLV/A) over time. The slope of the curve $[\frac{\Delta TLV/A}{\Delta\sqrt{t}}]$ represents the penetration speed in $[\frac{m}{\sqrt{s}}]$ [2].

3. Print through test

The print through test can be used as a measure for the penetration depth of the printed liquid into the paper. For this purpose, the backside of the unprinted sheet is imaged behind a coloured background. This background has the same colour as the liquid used for the printing. Subsequently, the sheet is fully printed on the top side. Finally, the exact same position of the backside of the printed paper is imaged again. The difference of the grey values between the images represents the print through value. The measurement procedure is illustrated in Figure 5.

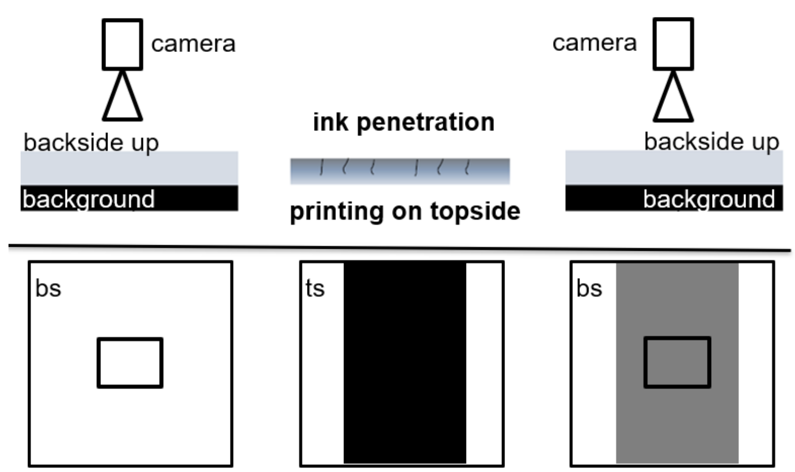
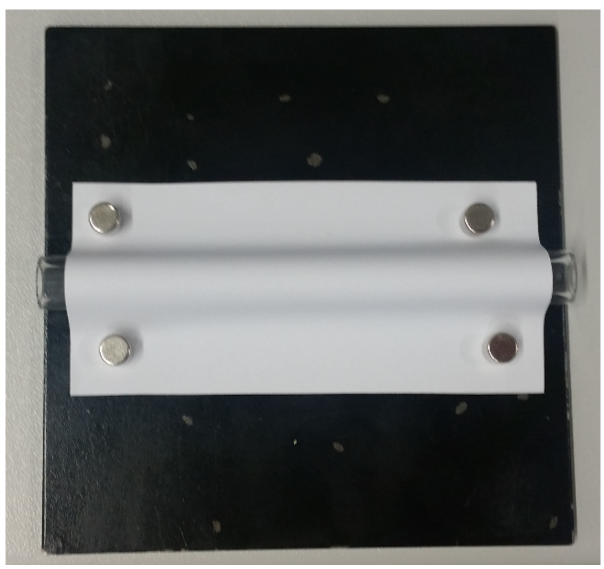


Figure 5: print through test: first the backside of the sample is imaged. Second, the topside of this paper sheet is fully printed. And third, the same area location of the backside, from the now printed sheet is imaged again. The higher the penetration depth is, the higher is the difference in gray value of those two images.

4. Sample Preparation for the Ppicoliter Head Contact Angle Measurement

Figure 6: The cartridge is inserted into the dosing head of the picoliter head. This dosing element is positioned on the membrane cap of the cartridge, enabling to create a pulse which presses the liquid through the orifice of the cartridge.

(a)



(b)

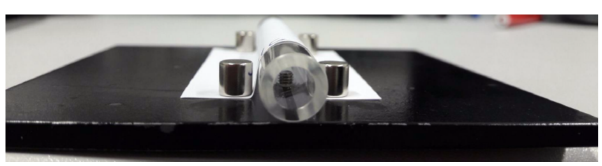


Figure 7: The paper, 90 mm x 50 mm in size, is clamped centrally on the specimen holder using four magnets to fixate it (Subfigure a). The outer diameter of the plexiglas cylinder is 1cm. Importantly can be noted, that the region of the paper where the liquid is applied, is not in contact with the sample holder (Subfigure b).

5. Picoliter Head Settings for Contact Angle Measurement

Table 1: The settings for the pl dot - production vary with viscosity (η), surface tension (γ) and drop size. Picoliter head settings for droplet generation using the liquid High (↑) η - Low (↓) γ are listed in this table.

dropsize	30pl	60pl
Orifice diameter	$30\mu m$	$50\mu m$
Pulse amplitude	92	70
Pulse width	55	52
Pulse frequency	100	100
Sensor treshold	3	3
Number of drops	1	1

Table 2: The settings for the pl dot - production vary with viscosity (η), surface tension (γ) and drop size. Picoliter head settings for droplet generation using the liquid Low (↓) η - Low (↓) γ are listed in this table.

dropsize	30pl	60pl
Orifice diameter	$30\mu m$	$30\mu m$
Pulse amplitude	85	100
Pulse width	40	50
Pulse frequency	100	100
Sensor treshold	2	2
Number of drops	1	1

Table 3: The settings for the pl dot - production vary with viscosity (η), surface tension (γ) and drop size. Picoliter head settings for droplet generation using the liquid High (↑) η - High (↑) γ are listed in this table.

dropsize	30pl	60pl
Orifice diameter	$30\mu m$	$50\mu m$
Pulse amplitude	100	100
Pulse width	100	100
Pulse frequency	100	100
Sensor treshold	0	0
Number of drops	1	1

Table 4: The settings for the pl dot - production vary with viscosity (η), surface tension (γ) and drop size. Picoliter head settings for droplet generation using the liquid Low ($\downarrow$) η - High ($\uparrow$) γ are listed in this table.

dropsize	30pl	60pl
Orifice diameter	$30\mu m$	$30\mu m$
Pulse amplitude	30	30
Pulse width	65	39
Pulse frequency	100	100
Sensor treshold	0	0
Number of drops	1	1

Table 5: The settings for the pl dot - production vary with viscosity (η), surface tension (γ) and drop size. Picoliter head settings for droplet generation using the liquid center($\otimes$) η - center($\otimes$) γ are listed in this table.

dropsize	30pl	60pl
Orifice diameter	$30\mu m$	$30\mu m$
Pulse amplitude	85	90
Pulse width	40	60
Pulse frequency	100	100
Sensor treshold	0	0
Number of drops	1	1

6. Correlation between Base Diameter of the Drop and HSI Printed Dot Area

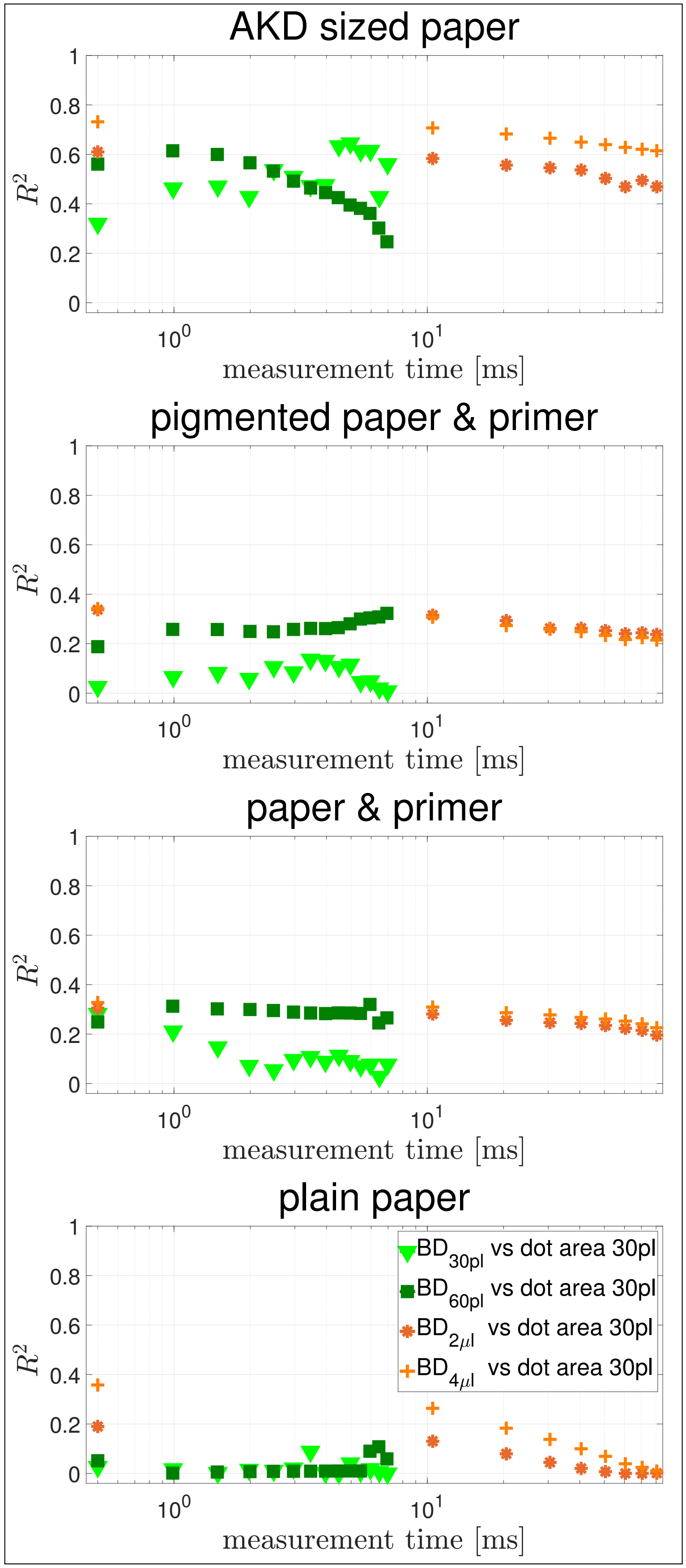


Figure 8: The coefficient of determination for 30pl HSI printed dot area compared to the base diameter of 30pl, 60pl, $2\mu l$ and $4\mu l$ drops plotted versus advancing contact time between drop and paper.

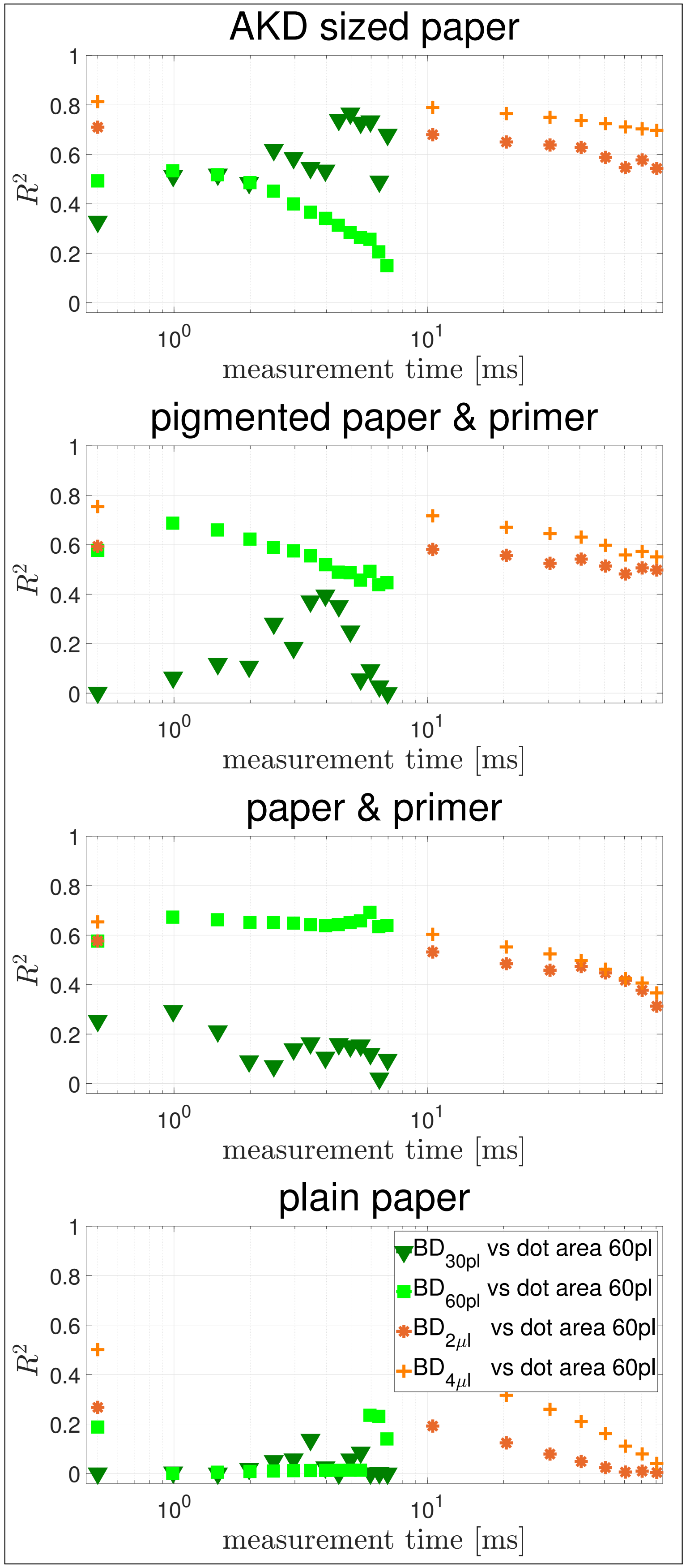


Figure 9: The coefficient of determination for 60pl HSI printed dot area compared to the base diameter of 30pl, 60pl, $2\mu l$ and $4\mu l$ drops plotted versus advancing contact time between liquid and paper.

References

[1] Y J Lee, J J Pawlak, O Rojas, and J Skowronski. Paper and paper machine variables affecting the attenuation of ultrasonic signals during wetting. In *Int. Paper Physics Conference*, pages 143–148, 2007.

[2] Krainer Sarah and Hirn Ulrich. Short timescale wetting and penetration on porous sheets measured with ultrasound, direct absorption and contact angle. *RSC Adv.*, 8(23):12861–12869, 2018.

[3] Toshiharu Enomae, Hiroshi Kataoka, Fumihiko Onabe, Das Papier, and J Robertson. In-Plane Distribution of Paper Absorbency Measured by Liquid Absorption Profilometer. *Sen'i Gakkaishi*, 55(2):265–291, 2004.

[4] Thijs Andrew Per Van Stiphout. *Liquid Absorption in porous Media studied by Automatic Scanning Absorptometer*. PhD thesis, Eindhoven University of Technology, 2016.