

NUMERICAL INVESTIGATION OF DROPLET IMPACT SPREADING IN SPRAY COATING OF PAPER

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Abstract

Impact spreading of droplets in spray coating of paper was investigated using numerical simulation based on a volume-of-fluid (VOF) model. The results include the effects of droplet size, droplet impact velocity, liquid viscosity, liquid surface tension and paper web velocity on droplet spreading. Pressure and strain rate fields as well as timescales of spreading are reported. The results help understanding the parameters and mechanisms that control the droplet spreading and provide information on possible operating windows of the spray coating process.

Introduction

Recently, the spray coating process has been introduced as a new, noncontact technique to coat paper at high speeds [8,9]. Although a number of pilot scale trials have been carried out, relatively little is known about the fundamental mechanisms that control spray coating. The experience that has been gained so far indicates that spray coating requires a different type of coating formulation when compared to traditional paper coating processes. E.g., use of low viscosity coating suspensions (100mPas and less) and blocky, non-platy pigments has been suggested.

The spray coating process can be divided into subprocesses such as droplet formation through atomization, droplet impact spreading, secondary leveling of droplets, and consolidation and drying of coating layer. All the subprocesses influence the coating outcome. Therefore, fundamental aspects of each of the subprocesses should be understood if optimal operation of spray coating is to be achieved. The present work focuses on the subprocess of droplet impact spreading. This very short duration event where droplets come in contact with the base paper at high velocities and spread due to the kinetic energy of droplets is currently not well understood. An adequate spreading of droplets is a prerequisite for a successful spray coating operation. Reduced spreading can lead to rough coating surfaces with low gloss and non-uniform coating coverage. The object of this investigation is to provide information on fundamental aspects of droplet spreading in spray coating of paper using numerical simulation. The results should be useful when defining operating requirements of the spray coating process.

Previous work

Earlier work related to droplet impact spreading has mostly used low viscosity liquids such as water and inkjet inks, and relatively low impact velocities. Fukai et al. [6] studied wetting effects during droplet spreading with experiments and modeling. The maximum droplet spreading diameter was found to decrease as the dynamic advancing contact angle increased. When wetting was limited the droplet impact velocity controlled the spreading. Pasandideh-Fard et al. [14] investigated the influence of surface tension and contact angle on the impact dynamics of water droplets that were dropped onto a flat, solid surface. Both experiments and numerical modeling showed that surfactant addition did not influence significantly the droplet spreading, whereas droplet shape during recoil was affected by it. Authors concluded that capillary effects in droplet impact can be neglected if Weber number is much larger than the square root of Reynolds number, $We \gg Re^{1/2}$. Chaidron et al. [4] used high-speed visualization to investigate collision dynamics of 2mm water droplets impinging on variety of surfaces at velocities 0,3-3m/s. Early stages of the impact spreading were found to be controlled by droplet inertia. The porosity of the substrate did not influence the maximum spreading of droplets. Bergeron et al. [2] studied the influence of non-Newtonian elongational viscosity on droplet spreading and rebound. They report that certain flexible polymers can be used to inhibit drop rebound without increasing shear viscosity of low viscosity liquids.

The popularity of inkjet printers has generated large amount research that focuses on ink droplet spreading. It is interesting to note that the objective in inkjet printing is opposite of that in spray coating; one tries to limit the spreading of ink droplets on paper. Oliver [13] studied initial stages of inkjet droplet impact with a high-speed camera. The mechanical forces in low speed (ca. 1m/s) droplet impact were found to dissipate within a few milliseconds. On highly absorbent paper, prewetting of paper increased the initial spreading. In experiments the droplet diameter was ca. 250 μ m. Asai et al. [1] investigated spreading of ink droplets on paper using microscopy and stroboscopic lighting. A correlation formula based on Weber and Reynolds numbers could explain the experimentally observed ink droplet spreading. Very small differences in spreading between various base papers were observed. The droplet diameter and the impact velocity were in the range of 44-81 μ m and

2,5-20m/s, respectively. Splashing (generation of small secondary droplets) of ink drops in continuous inkjet printing has been studied by Mähönen et al. [12]. Their experimental setup allows microsecond resolution in visualization of ink droplets impinging paper at velocities up to 10m/s. Splashing of low viscosity (3,3mPas) inks increased with increasing surface roughness and hydrophobic character of paper.

Dynamic surface tension effects during droplet spreading were investigated experimentally by Mourougou-Candoni et al. and Zhang and Basaran [11,18]. The main conclusion from the studies was that since surface area of a spreading droplet increases rapidly by almost one order of magnitude due to the shape change from a sphere to a flat disk, the dynamic surface tension should be considered rather than the equilibrium tension. A conclusion was also that a non-uniform distribution of surfactant along the free surface can give rise to Marangoni stresses that can reduce the drop spreading. Droplet diameters in the experiments were 2-3mm and impact velocities 0,5-3,5m/s.

Scheller and Bousfield [15] report spreading of Newtonian droplets of varying viscosities up to 300mPas on a flat, solid surface. They correlate the maximum spreading diameter of droplets to Reynolds and Ohnesorge numbers. Solid-liquid interaction was found to have minimal or no influence on drop spreading for high Reynolds numbers. The drop diameters of ca. 3,5mm and impact velocities up to 5m/s were studied. Crooks and Boger [5] investigated the influence fluid elasticity on the droplet spreading. The splash threshold of Newtonian fluids depended on Weber and Ohnesorge numbers as well as substrate roughness. Increasing elasticity and extensional viscosity increased the splash threshold.

In most previous investigations the maximum droplet impact velocities have been low (<5m/s), droplet sizes large (>1mm) and liquid viscosity that of water, which makes it difficult to draw conclusions that are applicable to spray coating of paper. Very little is published on spreading of pigment suspensions on porous substrates. Bousfield and Toivakka et al. [3,16,17] have investigated surface tension driven leveling of thin films of pigmented coatings. In these studies an immobilized layer of pigment particles caused by the liquid absorption into the paper was found to reduce leveling.

Theoretical considerations

Droplet spreading in spray coating is influenced by droplet size, speed, impact angle (depends on relative velocities of paper web and droplets), liquid surface tension, liquid rheology and paper properties such as surface energy, surface roughness and porosity. The spreading can be divided into impact spreading where the flow is driven by the droplet kinetic energy, and leveling where wetting and surface tension driven flow take place. Present work focuses on the impact spreading of droplets and does not consider leveling that should be studied separately.

When a droplet encounters a surface, its initial spherical shape is forced into a pancake-like form as illustrated in figure 1. The amount of spreading is determined by the balance of driving and resisting forces. The driving force for impact spreading is kinetic energy of the droplet, whereas flow resistance is provided by viscosity and surface tension of the liquid. Contact angle will either promote or resist the spreading. The relative magnitudes of the kinetic and surface energies can be expressed with Weber number:

$$We = \frac{\rho u^2 d_0}{\sigma}, \quad (1)$$

where ρ is the liquid density, u the impact velocity, d_0 the droplet diameter before impact and σ the surface tension. For large values of Weber number the kinetic energy of the droplet is able to overcome the surface tension of the liquid and spreading takes place. For low values of Weber number, e.g., low impact velocity, the droplet tends keep its spherical shape on the surface provided no wetting takes place. The relative importance of kinetic energy vs. viscous resistance for the spreading can be assessed with Reynolds number:

$$Re = \frac{\rho u d_0}{\mu}, \quad (2)$$

where μ is the liquid viscosity. For large Reynolds numbers the droplet kinetic energy is large enough to overcome the viscous resistance whereby the droplet spreads. High viscosities reduce the spreading due to increased viscous energy dissipation. By choosing reasonable values of parameters that could be used in spray coating of paper as $\rho = 1500\text{kg/m}^3$, $u = 10\text{m/s}$, $d_0 = 50\mu\text{m}$, $\sigma = 70\text{mN/m}$ and $\mu = 100\text{mPas}$, we can estimate the dimensionless numbers to be $We = 107$, and $Re = 7.5$. Since both are larger than one, this suggests that the kinetic energy of droplets can overcome both the liquid surface energy and the viscous resistance. However, the viscosity seems to provide more resistance to the spreading than

surface tension. While droplet impact velocities on paper have been suggested to be about 10m/s in spray coating, true velocities are difficult to measure or estimate. Droplets are generated in an atomization process with high pressure (ca. 100bar). The jet velocity at the nozzle can be on the order of 100m/s, but this velocity is reduced as the cross sectional area of the spray fan increases and the surrounding air slows down the droplets. The exact distance from the nozzle exit where the droplets have formed is also unknown. Typical droplet sizes given in literature fall between 20-80 μm [9].

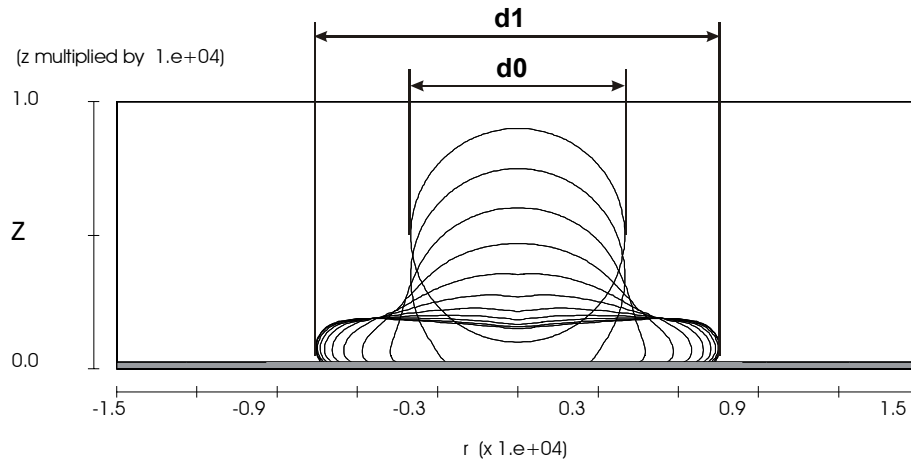


Figure 1. Impact spreading of a droplet. The initial droplet diameter is 80 μm , impact velocity 10m/s, viscosity 50mPas, surface tension 73mN/m and static contact angle 90 degrees. The droplet shape is shown at 1,5 μs intervals.

Ideal droplet spreading

An estimate of the amount of droplet spreading needed in spray coating of paper is illustrated in figure 2. The figure plots theoretical spreading for three target coat weights assuming that spherical droplets of a given diameter transform to flat disks on paper. It is assumed that the application solids content is 60%, coating color density 1500kg/m³, there is full coverage, droplets form a monolayer of disks and no overlap between disks occurs. Spreading factor d^* is expressed as the ratio between the disk and droplet diameters $d^*=d_1/d_0$. The required spreading varies from no spreading ($d^*\approx 1$) for small droplets ($d_0 < 20\text{-}30\mu\text{m}$) to the highest spreading ($d^*\approx 3$) for large 100 μm droplets at 6g/m² coat weight. Large droplets and low coat weights require more spreading for full coverage of base paper. Application solids content determines the thickness of the wet coating layer, which means that more spreading is needed when solids content is increased. The spreading factors in figure 2 can be considered to be lower estimates due to the assumption of perfect coverage and that no droplet overlap takes place.

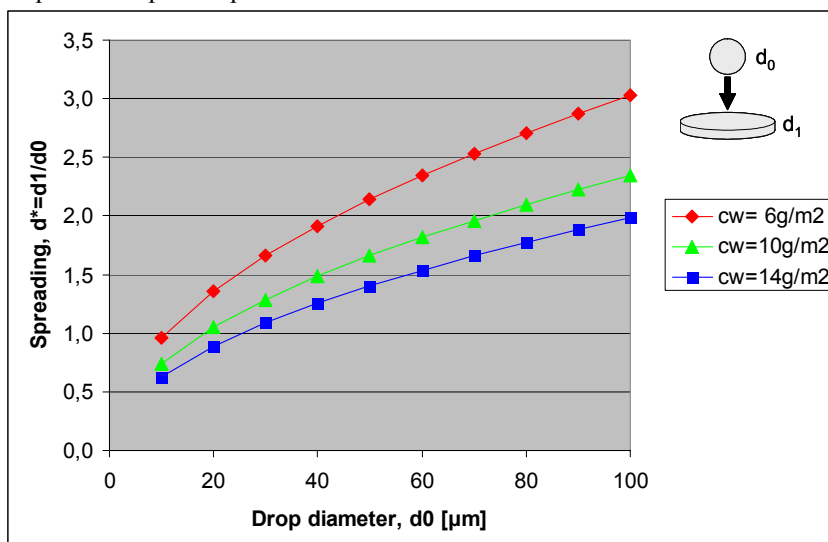


Figure 2. The amount of droplet spreading required in spray coating to form full and uniform coverage.

Model

Droplet spreading calculations were carried out with VOF (volume of fluid) software *Flow3D* (Flow Science Inc., Santa Fe). While standard computational fluid dynamics tools usually have difficulties in calculating problems that have deforming free surfaces, Flow3D uses special algorithms to circumvent the problem. The software has been used to calculate several free surface problems, e.g., formation of droplets from inkjet printer nozzles and spreading of metal droplets on surfaces. In contrast to other VOF software Flow3D applies true stress boundary conditions at free surface and there is no “diffuse” boundary layer between liquid and air. The contact angle at the point where air, liquid and solid phases meet, is treated by defining an adhesion force between the liquid and solid phase that results in a desired static contact angle. Dynamic contact angles are recovered from calculations and not defined *a priori*. A typical calculation mesh consisting of 150x100 rectangular cells using a cylindrical coordinate system is shown in figure 3. Calculation time for a problem on a single processor Athlon 1700XP processor varies from a few minutes up to an hour.

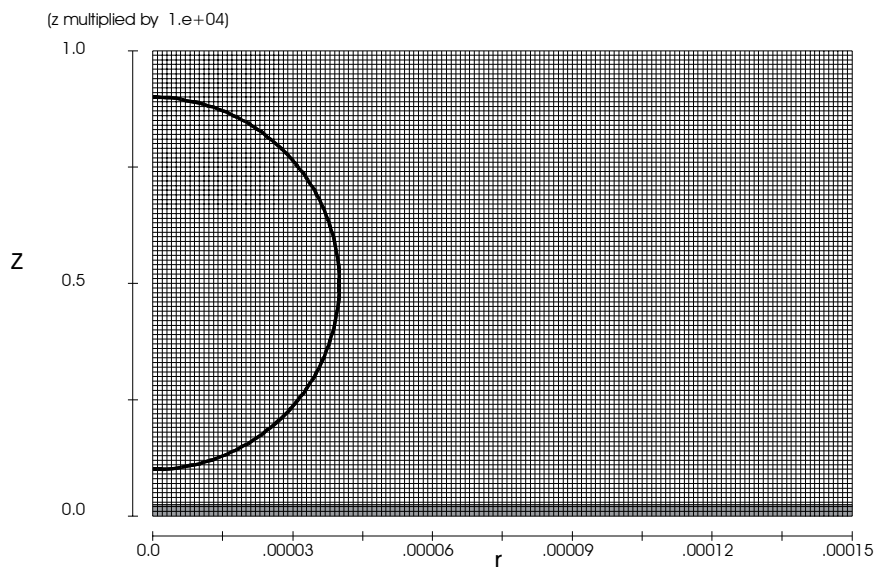


Figure 3. Typical calculation mesh consisting of 150x100 rectangular cells.

An important assumption of the simulation model is that coating color is treated as a one-phase fluid. No filter cake formation due to loss of liquid into the base paper is taken into account. The coating fluid can be non-Newtonian but not elastic. The base paper is modeled as an impermeable, non-porous surface. The surface tension is assumed to be constant in time.

Results and discussion

Figure 1 shows an example calculation of droplet impact spreading. The initial droplet diameter is 80 μ m, impact velocity 10m/s, viscosity 50mPas, surface tension 73mN/m and static contact angle 90 degrees. Figure shows the calculated droplet shape at 1,5 μ s intervals. The final shape is shown at time 15 μ s. After that time only minimal liquid movement takes place as the static contact angle adjusts itself to 90 degrees. The time scale for impact spreading is very short, on the order of microseconds. This makes it fairly difficult to visualize the droplet impact experimentally. The surface tension driven leveling and wetting processes are considerably longer, usually taking place at time scales measured in milliseconds [17].

A number of simulations were carried out in order to understand the role of various parameters on the impact spreading of droplets. If not otherwise noted the parameters used in the calculations are the same as in figure 1. The spreading factor that is reported is defined as the maximum droplet spreading after impact divided by the initial droplet diameter as illustrated in figure 1.

Influence of impact speed, droplet size, viscosity and surface tension

Figure 4 shows the final shapes of three droplets impinging on a smooth surface at velocities 2,5m/s, 10m/s and 40 m/s. The other parameters are the same as in figure 1. The spreading increases with increasing impact velocity as expected. The spreading factors are 1,38, 1,89 and 2,60. At low impact velocities the droplet spreading is minimal. The viscosity and

possibly surface tension are able to resist the spreading effectively. It seems clear that one should try to maximize the impact velocity in the spray coating process. This can be achieved by placing the spray nozzles as close to the paper as possible. The minimum distance is in part determined by the atomization process, since a certain distance is required for the small droplets to form after the nozzle exit. It should also be kept in mind that very high impact velocities can result in splashing, i.e., generation of small secondary droplets. The secondary droplets might be undesirable, lead to dusting and cause problems in calendaring and printing. Besides high impact velocities, high surface roughness of base paper has been shown to increase splashing in inkjet printing. Similar behavior was observed in numerical simulations of present work. In figure 5 the base paper is modeled as a sinusoidal boundary which leads to splashing at impact velocity of 40m/s.

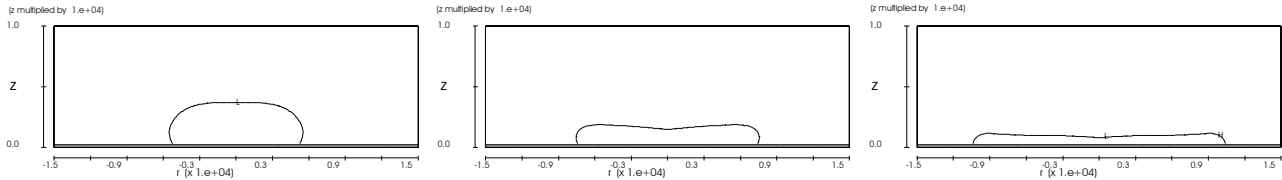


Figure 4. Final droplet shapes after impact. The impact velocities are from left to right 2,5m/s, 10m/s and 40m/s.

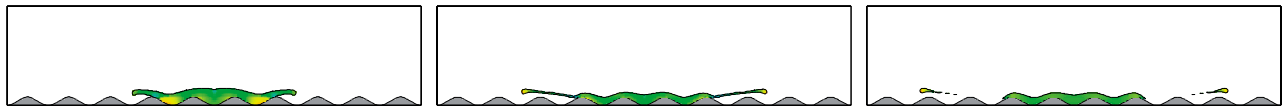


Figure 5. Splashing on rough substrate. The droplet impact velocity is 40m/s and other parameters as in figure 1.

The spreading factor as a function the initial droplet diameter is shown in figure 6. At high impact velocities the relative spreading increases as the initial droplet size increases. However, when targeting a certain coat weight, the *required* spreading of the large droplets increases faster than the predicted spreading in figure 6 (see also figure 2). Therefore, it is advantageous to try to minimize the droplet size in order to obtain a smooth coating surface.

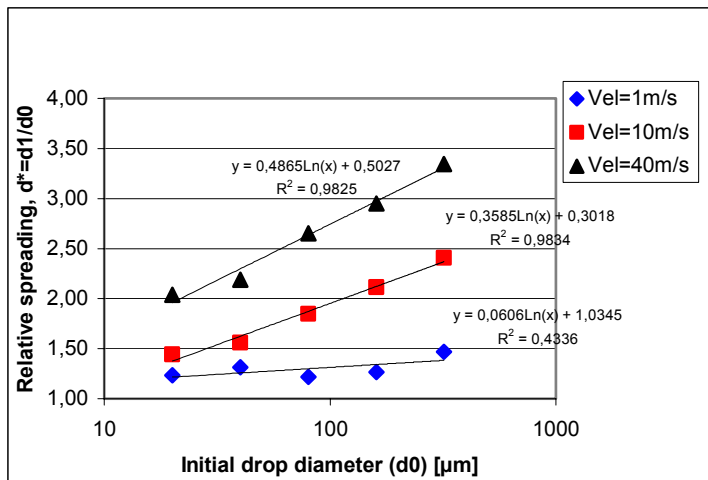


Figure 6. Relative spreading of droplets as a function of initial droplet diameter.

Figures 7 and 8 show the influence of viscosity and surface tension on the relative spreading. Viscosity has a considerable effect and simulations suggest that viscosities larger than ca. 100mPas might be difficult to use in spray coating due to the reduced spreading of droplets. High viscosities will also lead to larger droplets during atomization which magnifies the effect. Surface tension on the other hand seems to have very little or no effect on the impact spreading. Lowering of surface tension from 73mN/m to 50mN/m shows no increase in spreading as is apparent in figure 8. The reason is the dominant role of the viscous resistance that controls the flow. While surface tension does not influence the impact spreading, it might play an important role in atomization process, where smaller droplets should result from lowering the surface tension.

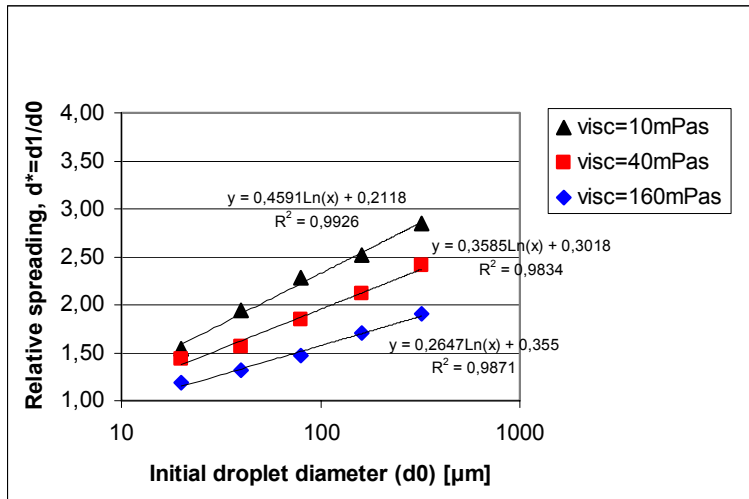


Figure 7. Influence of suspension viscosity on droplet spreading.

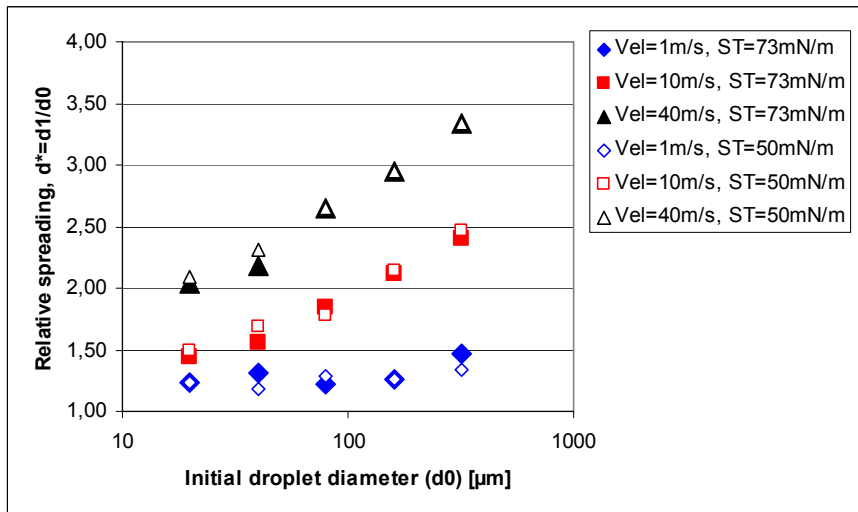


Figure 8. Influence of surface tension on droplet spreading.

Correlation formula

Results in figures 6-8 were successfully collapsed into a single expression. Using non-linear regression the following relationship between the relative spreading and Weber and Reynolds numbers was obtained:

$$d^* = \frac{d_1}{d_0} = 1 + 13,51We^{0,5} \exp[-4,28We^{0,072} Re^{-0,043}]. \quad (3)$$

The form of the equation is similar to that used by Asai et al.[1] and is obtained by balancing the total droplet energy before and after the impact. Figure 9 compares the simulation results and the spreading calculated with equation 3. The equation can be useful, e.g., in defining operating windows for spray coating. Figures 10a-d plot the influence of impact velocity, droplet size, viscosity and surface tension on the droplet spreading as predicted by equation 3. The importance of low viscosity and the small influence of the surface tension can be seen clearly.

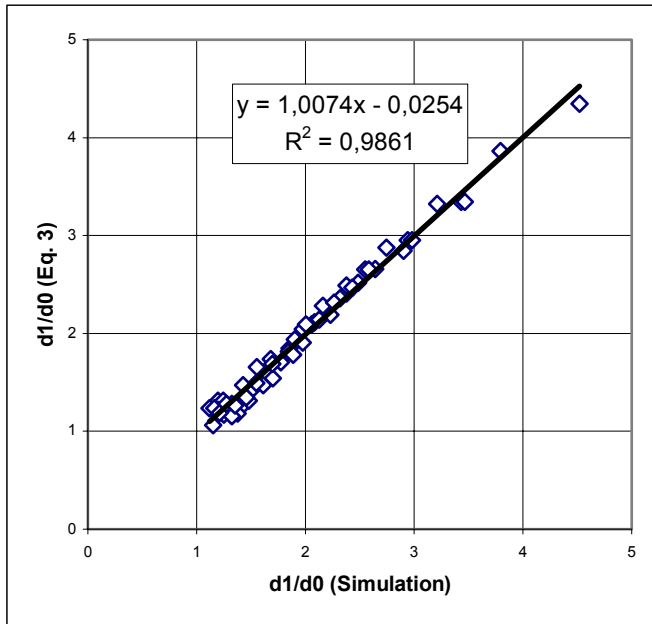


Figure 9. Comparison of the simulation data and the correlation expression for the relative spreading.

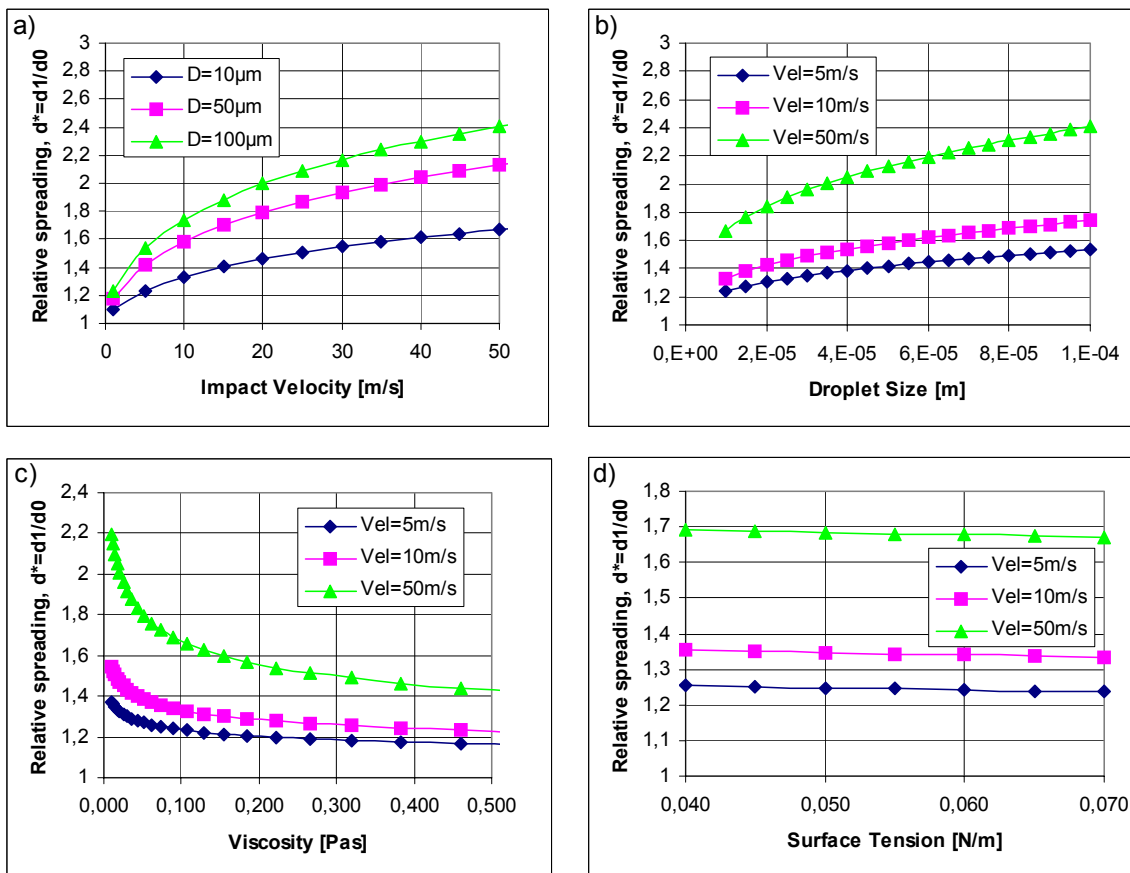


Figure 10. Influence of impact velocity (a), droplet size (b), viscosity (c) and surface tension (d) on the droplet spreading as predicted by equation 3. If not otherwise noted the parameters used are $\mu=100\text{mPa}\cdot\text{s}$, $d_0=100\mu\text{m}$, surface tension= 73mN/m and density= 1500kg/m^3 .

Pressure pulse

Pressure pulse on base paper created by droplet impact can easily be obtained from the numerical simulation. Figure 11 shows the pressure pulses at different times for two droplet sizes ($d_0=50\mu\text{m}$, $100\mu\text{m}$), velocities ($u_0=10\text{m/s}$, 20m/s) and viscosities ($\mu=50\text{mPas}$, 100mPas). According to calculations the maximum pressures during the impact can be over 1MPa. However, the pressures are an order of magnitude smaller than the pressure resulting from a continuous pulsed liquid jet that can be estimated with a so called water hammer pressure equation: $P_{wh} \approx \rho u_0 u_s = 1500\text{kg/m}^3 * 10\text{m/s} * 1624\text{m/s} = 24\text{MPa}$. In this equation ρ is the liquid density, u_0 jet velocity and u_s the speed of sound in water [10]. It should also be noted that the duration of the pressure pulse from a droplet is very short, only a few microseconds, and that only a part of the total substrate surface area is exposed to the pressure pulses. Further investigations are needed to determine how much liquid penetration into the base sheet is caused by the pressure pulse. Droplet velocity seems to have the strongest influence on the impact pressure, as can be seen in figure 12 which plots the pressure profiles corresponding to maximum pressures in each simulation. The viscosity seems to have only a small effect on the pressure pulse.

The impact force on paper can be calculated when the pressure and the contact area of droplet with paper are known. The impact forces as functions of time are shown in figure 13. The maximum force is reached within 1-3 microseconds. As with the impact pressures the impact velocity plays the most important role, and viscosity does not seem to influence the results.

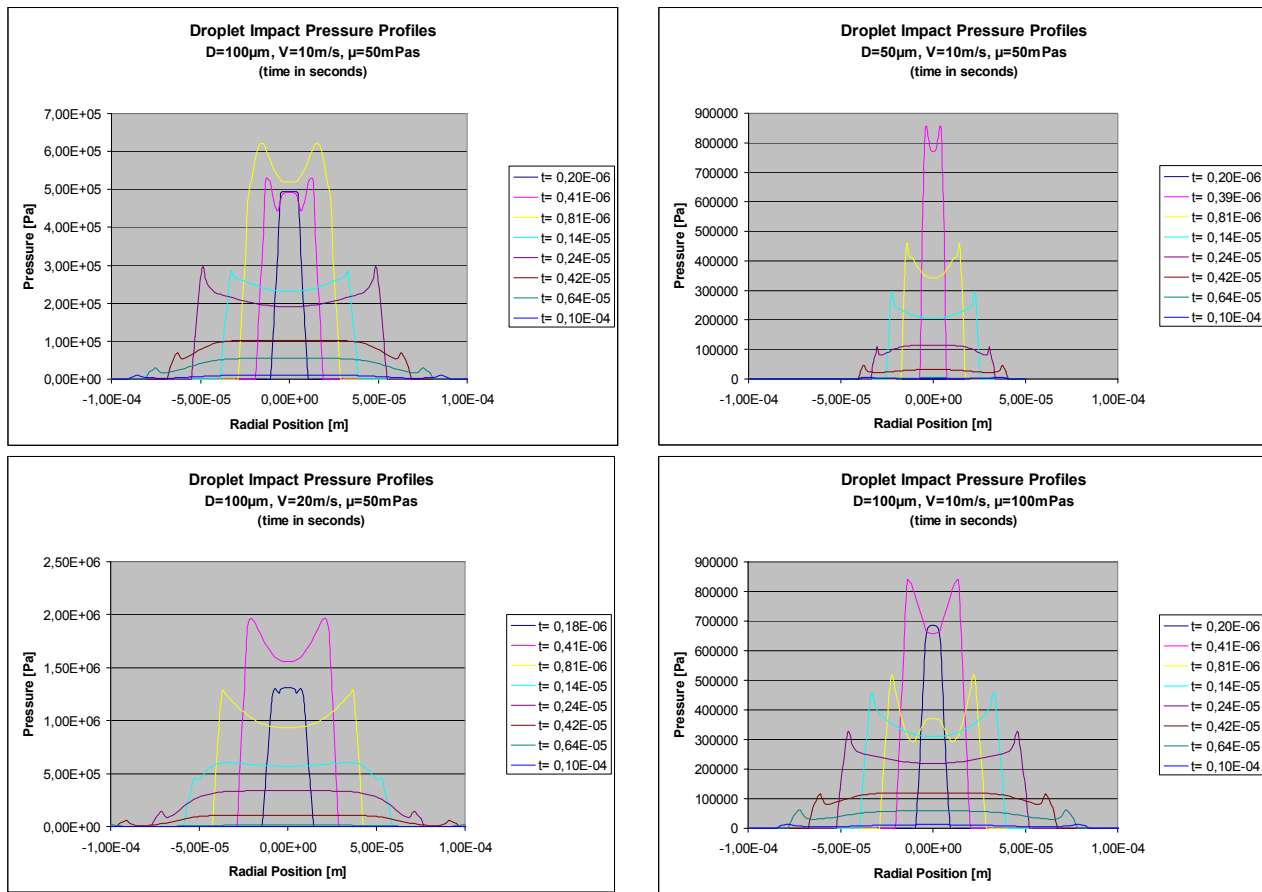


Figure 11. Droplet impact pressure profiles at different times during droplet spreading. Times are given in seconds.

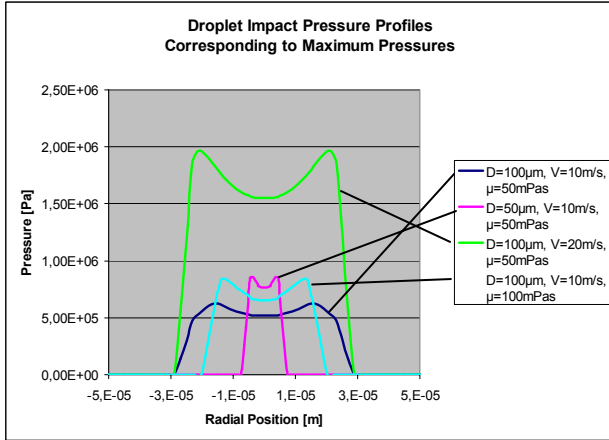


Figure 12. The pressure profiles corresponding to maximum pressures in figure 11.

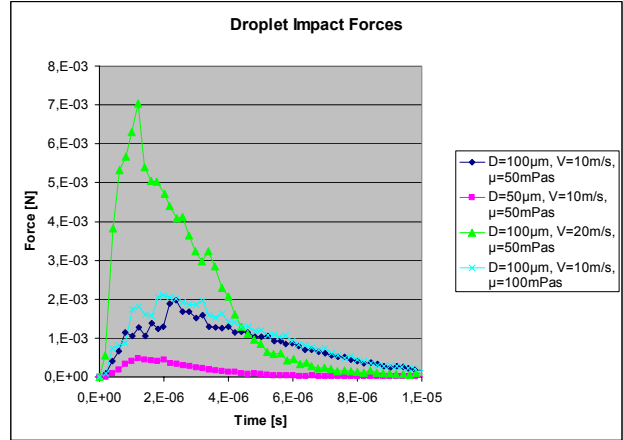


Figure 13. The droplet impact force on paper as a function of time.

Pressure, strain rate and extensional rate fields

Figure 14 shows pressure, strain rate and extensional rate fields during impact spreading of a droplet. Parameters are the same as in figure 1. The highest pressures are at the liquid/base paper interface, and the peak of the pressure pulse moves from the droplet center towards the droplet edge during the spreading. Strain rates (strain includes here both shear and extension) can be very high, momentarily over 10^6s^{-1} . Highest deformations take place close to the advancing liquid front at the edge of the droplet. Considerable extension is apparent in the droplet center where extensional rates can exceed $2 \cdot 10^5 \text{s}^{-1}$. Significant squeezing occurs near the droplet edge. The high strain rates during impact spreading suggest why very low viscosity formulations and blocky pigments are needed in spray coating. Lack of alignment of particles combined with a high particle concentration, might cause dilatancy and reduced spreading of droplets. Calculations suggest that coating color additives that might increase extensional viscosity, such as long polymeric chains or Poly-vinyl-alcohol, should be avoided. While deformation rates seem to be high in spray coating, both the duration is shorter and the total amount of deformation is smaller when compared to, e.g. blade coating: for a 1000m/min coating speed, a 400µm thick coating blade and 15µm gap between the blade tip and base paper, the duration of high shearing in blade coating is ca. 24µs and the apparent shear rate ca. 10^6s^{-1} . In figure 14 the high strain rates occur only during the first few microseconds. By 10µs the strain rates have decayed to one fifth of the initial large values.

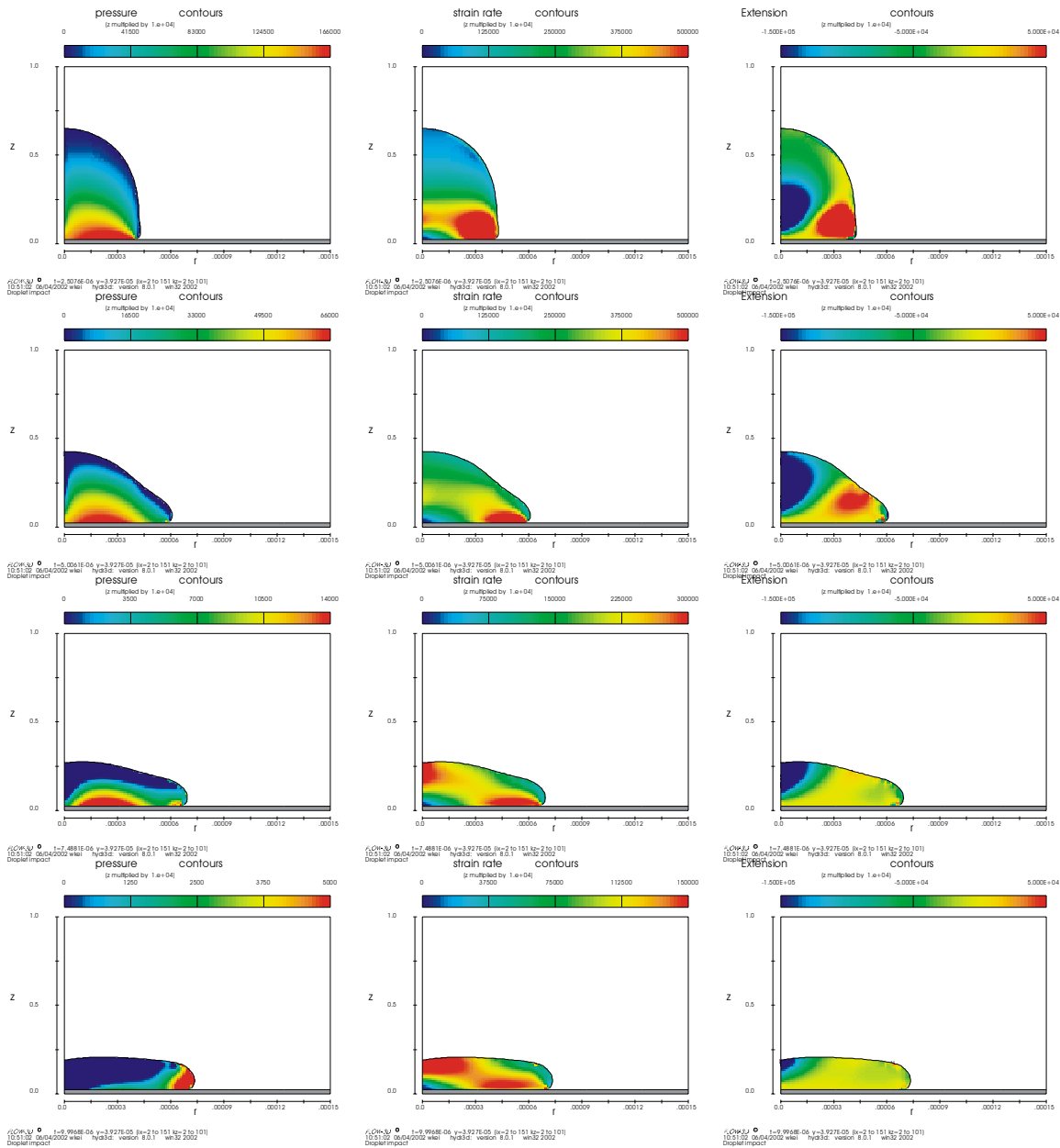


Figure 14. Pressure (left column), strain rate (middle column) and extensional rate (right column) fields during impact spreading of a droplet. Parameters as in figure 1.

Shear-thinning rheology

The results above suggest that the spray coating process requires relatively low viscosity of coating suspension to allow sufficient spreading of droplets during impact. While increasing the spreading, the low viscosity can have negative effects on coating performance including loss of binder and small pigment particles into base paper. Low suspension viscosity is also associated with high immobilization solids that can result in a dense coating microstructure with poor optical properties. To minimize the possible problems, a high suspension viscosity at low shear rates seems desirable. Given the relatively high deformation rates during droplet spreading, a shear-thinning rheology could be beneficial in spray coating. This hypothesis was tested by calculating the impact spreading of three shear-thinning liquids and comparing to a Newtonian liquid. A Carreau model was used make viscosity strain rate dependent:

$$\mu = \mu_{\infty} + (\mu_0 - \mu_{\infty}) \left[1 + (\lambda \dot{\gamma})^2 \right]^{\frac{n-1}{2}} \quad (4)$$

The Carreau model parameters used in calculations are shown in table 1 and the corresponding viscosity-strain rate plots in figure 15. The parameters were adjusted so that the viscosity at 100s^{-1} was 46mPas for all the liquids. The other simulation parameters were the same as in figure 1. The relative spreading of the three shear-thinning and the Newtonian droplets are compared in figure 16. In all cases the shear-thinning rheology improved the spreading considerably. Most spreading was calculated for the liquid having the smallest high shear viscosity. It is interesting to note that the liquid “NonNewt2” that has the highest low shear viscosity is able spread out more than “NonNewt1” due to its lower power law index. Calculations with shear-thinning liquids suggest that relatively high low shear viscosities can be used, if enough shear-thinning can be designed into formulation. The high shear viscosity seems to be an important parameter that controls the impact spreading. However, the short duration of deformation in droplet spreading could make it challenging to find a measurement that would predict the spreading. In practice, it might be difficult to incorporate shear thinning rheology to a suspension that has already relatively low viscosity.

Table 1. Carreau model parameters used in simulations.

	Newtonian	NonNewt 1	NonNewt 2	NonNewt 3
μ_0 [mPas]	46	100	250	100
μ_∞ [mPas]	10	10	10	1
n	1	0,8	0,585	0,8
λ [s]	1,0	1,0	1,0	1,0

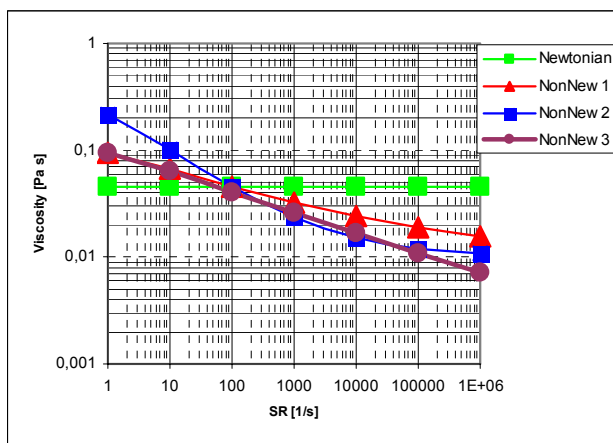


Figure 15. Viscosity-strain rate plots of the shear-thinning fluids used in simulations.

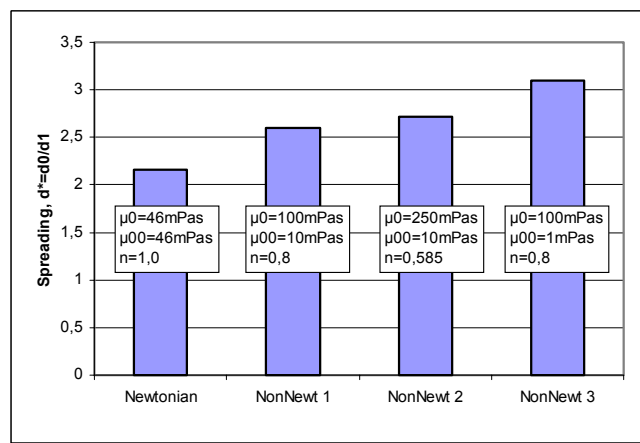


Figure 16. The relative spreading of the non-Newtonian, shear-thinning fluids.

Influence of paper web velocity

Typical coating speeds of modern pigment coating machinery are over $1000\text{m}/\text{min}$ ($16,6\text{m}/\text{s}$). These speeds are comparable to the probable droplet impact speeds in spray coating. Therefore, droplets do not come into contact with the base paper in 90 degree angle. Three dimensional calculations were carried out in order to understand the spreading of droplets on a moving substrate. An example calculation is shown in figure 17 that shows spreading of a $40\mu\text{m}$ droplet moving $10\text{m}/\text{s}$ towards the paper (the bottom boundary) that is moving at velocity $16,6\text{m}/\text{s}$. The liquid viscosity is 40mPas , surface tension $73\text{mN}/\text{m}$, density $1500\text{kg}/\text{m}^3$ and static contact angle 0 degrees. The calculation mesh consists of $135 \times 36 \times 18 = 87480$ rectangular cells. Subfigures to the right show the contact area of the droplet with paper. Velocity ratio of $0,6$ (droplet impact velocity divided by the paper web velocity) results in elongation of the droplet on paper. The ratio of the droplet length to the width is $1,86$. The final droplet shapes for different velocity ratios are in table 2. Small velocity ratios lead to elongated droplets on paper. The air traveling along with the paper web might further decrease the droplet impact angle. With low coating coverage the elongated droplets might cause coated paper properties, e.g. gloss, to differ in machine and cross directions. Experimentally, the information about elongation of droplets on paper could be used to estimate the true droplet impact velocities in spray coating process.

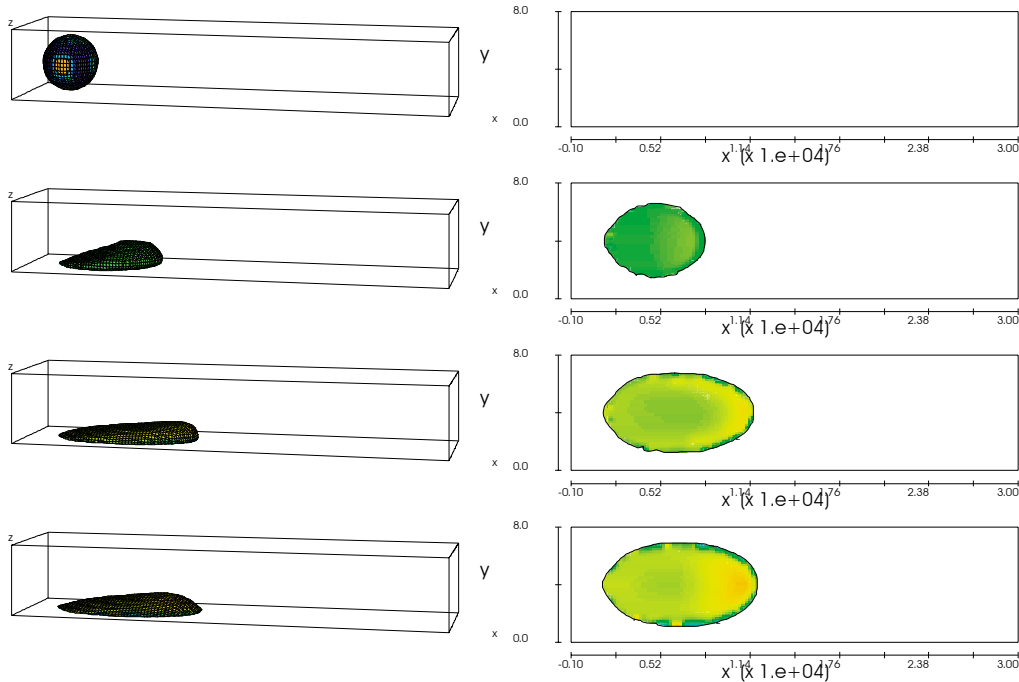


Figure 17. Droplet spreading on a substrate moving to the left at velocity of 16,6m/s. The droplet impact velocity is 10m/s. Figures to the right show the contact area of the droplet. The coordinate system is moved along the substrate.

Table 2. The final droplet shapes for different droplet/substrate velocity ratios. The substrate velocity is 16,6m/s.

Droplet Velocity [m/s]	Velocity Ratio ($u_{\text{droplet}}/u_{\text{paper}}$)	Width [μm]	Length [μm]	Length/Width	Final droplet contact area with substrate
1	0,06	28	220	7,86	
2,5	0,15	36	157	4,36	
5	0,3	47	127	2,70	
10	0,6	58	108	1,86	
20	1,2	69	94	1,36	
40	2,4	84	93	1,11	

Conclusions

Hydrodynamics of droplet impact on paper was investigated with numerical simulation. The results help understanding the parameters and mechanisms that control the spreading of droplets in spray coating process. Far reaching conclusions based solely on the numerical results should be avoided and this work should be complemented with controlled experiments and pilot scale studies. Furthermore, other subprocesses of spray coating; atomization, leveling/wetting and consolidation should also be investigated. Some parameter values that promote impact spreading might not be beneficial in another subprocess. The role of fluid and substrate elasticity in spreading was not included in the study. With these limitations in mind, the main conclusions that can be drawn from present work are:

- The required spreading of droplets increases with increasing droplet size and application solids content. Low coat weights require more spreading.
- The impact spreading is a microsecond time scale event. Leveling that is driven by surface tension and wetting requires considerably longer time.
- Coating suspension viscosity is more important parameter than surface tension for impact spreading. Newtonian viscosities over ca. 100mPas might be difficult to use in spray coating due to reduced spreading of droplets.
- The influence of surface tension and contact angle become negligible at high impact velocities.
- Local pressure peaks resulting from droplet impact can be over 1MPa but the duration of the pressure pulses is very short and the paper area exposed to the pulse small.
- Strain and extensional rates during impact spreading can be very high, but the duration is short and the total amount of deformation is small.
- Shear-thinning rheology seems beneficial for droplet impact spreading.
- Comparable velocities of droplets and a moving paper web lead to elongation of droplets during impact.
- High impact velocities on rough substrate surface might cause splashing of droplets.
- Improved droplet spreading and coating coverage can be achieved with: small droplet size or narrow droplet size distribution, high enough droplet impact velocity and low coating color viscosity, especially at medium and high shear rates.

References

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