Dynamical Analysis of Droplet Impact Spreading on Solid Substrate

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The spray coating process has been introduced as a new, non-contact technique to coat process, which is widely used in thermal spreading [1], spread cooling, ink jet technology, DNA microarrays [2], and other industrial techniques. Although a number of pilot scale trials have been carried out, relatively little is known about the fundamental mechanisms on how to control spray coating. The spray coating process can be divided into droplet formation, droplet impact spreading, consolidation and drying of coating layer, etc. Each sub-process has an influence on the outcome of coating. Therefore, fundamental aspects of each of the sub-processes should be understood if optimal operation of spray coating is to be achieved. The present work focuses on the sub-process of droplet impact spreading. This very short duration event where droplets come in contact with the substrate at high velocities and spread due to the kinetic energy of droplets is currently not well understood [3].

Impact spreading of droplets on the solid substrate is investigated by making use of numerical simulation based on a volume-of-fluid (VOF) model in this paper. The results include the process of droplet spreading, the analysis of the low speed and high speed droplet spreading, and more than one droplet spreading simultaneously. Pressure, velocity and spreading factors during the droplet spreading are presented. These results help understanding the process of droplet spreading and provide advices on the operating of spray coating process.

In this paper, droplet diameter is set to 40μm and impact speedvary in 0-75 m/s, which can be more applicable. The droplet material is assumed to have a dynamic viscosity of 40mPa •s, surface tension of 73mN/m, a fixed contact angle 90° with the solid substrate, and gravity is considered, The axis symmetric coordinate system used in formulating the numerical model and the initial configuration of the droplet at the time of impact *t*=0 are shown Fig 1.

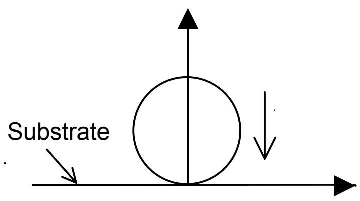
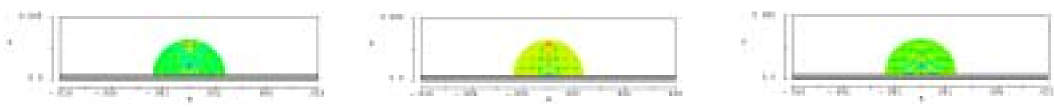


Fig.1 Impact of a droplet on a solid substrate

When a droplet encounters a surface, its initial spherical shape will change to a pancake-like form. According to the spreading factor's evolvement, the process can be divided into spreading phase and recoiling phase. The static states of droplets spreading at low speed of 0 m/s, 1.1 m/s, and 3.0 m/s are shown in Fig.2. There is no much difference on the spreading factors in the range of the three velocities. However, the pressures created by the droplet impacts are quite different. The maximum pressure appears at the time that ensues just after the droplet impacts the substrate and the pressure is at the direction of the negative *z* axis.



(a) U=0 m/s (b) U=1.1 m/s (c) U=3 m/s

Fig. 2 Droplets impact spreading at low speed

Air entrainments are found at the speeds between 0.2 m/s and 3 m/s in the paper, and the air entrainment in the droplet impact spreading at the speed of 0.5 m/s that is 3.99×10^{-6}s after the impact is shown Fig. 3.

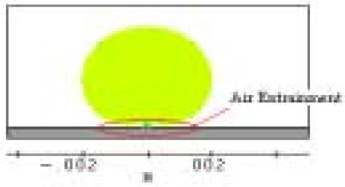
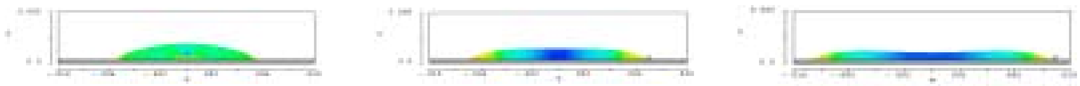


Fig.3 Air entrainment in the droplet impact spreading at the velocity of 0.5 m/s.

The most important difference between droplet spreading at high speed and low speed is that Weber number and Reynolds number are much larger than one in the status of high speed. The kinetic energy of the droplet is able to overcome the surface tension and viscosity of the liquid. The droplet can spread to a larger area and the coating layer is thin and uniform. The final shapes of three droplets impinging on the substrate at velocities 25 m/s, 40 m/s and 75 m/s are shown in Fig.4. The final shape at the impact speed of 25 m/s is a little like the top of a sphere. When the impact velocity exceeds 40 m/s, the top of the coating surface is similar to flat.



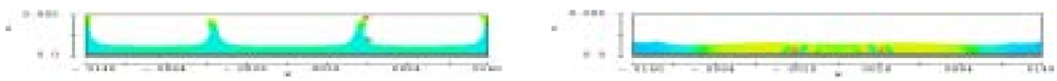
(a) U=25 m/s (b) U=40 m/s (c) U=75 m/s

Fig.4 Droplets impact spreading at high speed

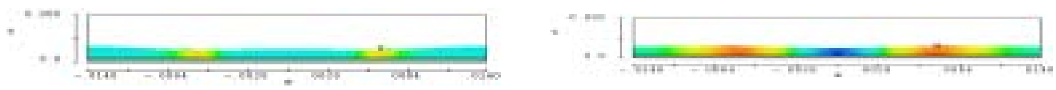
The spreading factor increases with the increasing impact velocity as expected and the coating layer becomes thinner and more uniform. However, it should also be kept in mind that very high impact speed can result in splashing as shown in Fig.5.

Fig.5 Splashing

In the actual spray coating process, there are lots of droplets impacting on the substrate simultaneously. Besides the velocities, the roughness of the substrate and properties of the liquid, the distances between the droplets also have influence on the spreading. The droplets impact spreading at L 0.01 cm and 0.0135 cm are shown in Fig.6. In each plot of Fig.6, the left plot is the shape at the moment as the droplets contact each other, and the right is the final shape. The maximum radius of one droplet impact on the substrate is R_{max}= 0.007 cm, and the static radius is R_{sta}=0.0067 cm.



(a) L=0.01cm



(b) L=0.0135cm

Fig.6 Three droplets impact on the substrate simultaneously

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