สำนักงานวิทยทรัพยากร จุฬาลงกรณ์มหาวิทยาลัย

CHAPTER II
LITERATURE REVIEW

The liquid droplet impact on a solid surface was first studied by Worthington (1876), he investigated the impact patterns of the various liquid droplets falling onto horizontal smoked glass plates. With using the simple flash technique, it was revealed that the splashing patterns were mainly governed by the falling velocity of liquid droplets. A liquid splash occurred when the falling velocity of liquid droplets increase up to a certain level.

Fukai *et al* (1993), used the finite element method to simulate drop impact. The effect of gravity, viscosity, surface tension and inertia force were investigated. Later studies accounted for wetting effect on the spreading of the liquid droplet on the substrate following impact. The studies demonstrated the importance of Weber number on the dynamic of the drop upon impact. Furthermore, it showed the role of advancing and receding contact angle on the maximum and final values so-called "splat".

Most experiments were performed using average speed cameras (i.e. 50 to 60 frames per sec) which cannot observe clearly the spreading, splashing, or rebound phenomena of liquid droplet impact since these phenomena occur in just a few millisecond range of time. Recently high speed cameras are available for taking image with high shutter speeds more than 1000 frame per sec or less than 0.001 sec per image.

The key experimental parameters that control the spreading are the impact velocity (V), the droplet diameter (D), the liquid physical properties such as surface tension (σ), viscosity (μ), and the properties of solid substrate itself. Schiaffino and Sonin (1995) proposed relevant dimensionless parameters to characterize drop impact and spreading which were the Weber number (We $= \rho D V^2 / \sigma$) and the Ohnesorge number (Oh $= \mu / \sqrt{\rho D \sigma}$), where ρ is the liquid velocity, We is the ratio of inertial force to the surface tension (σ) and Oh is the ratio between the intrinsic time for inertial oscillations and for their decay by viscous diffusion.

Rioboo *et al* (2001) investigated the outcomes of the droplet impact phenomena. Figure 2.1 shows 6 different outcomes from the droplet impact on solid surface, *deposition, prompt splash, corona splash, receding break-up, rebound*, and *partial rebound.* For the deposition, after contacting solid surface a liquid droplet only deforms during the entire process and at finally the liquid droplet become flat and adheres on the solid surface. For the prompt splash, a liquid droplet with high energy collides intensely and so it splash with a large number of tiny water droplets. For corona splash after collide the solid surface, a corona is forms during the spreading phase and eventually breaks up into tiny droplets. The Receding break-up is droplets are left on the surface during the receding phase after it reaches maximum spreading. The Rebound is the entire drop rebound on the surface. The Partial rebound is the partial part of the liquid droplet adheres on the surface while some part rebound.

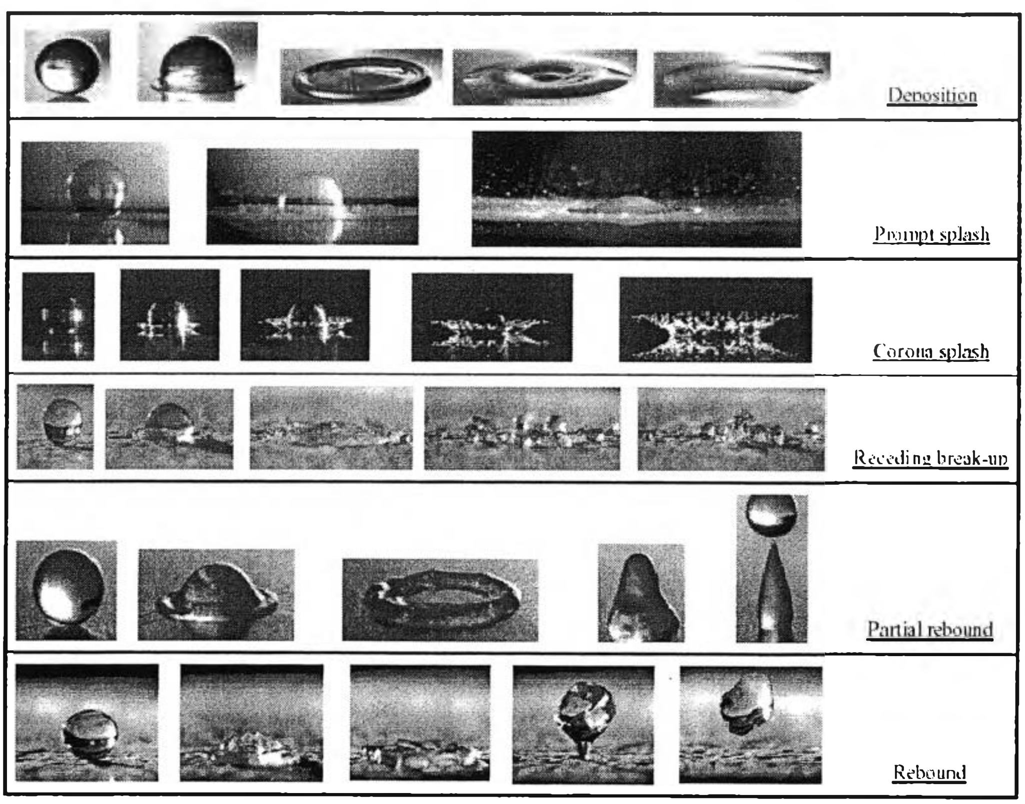

Figure 2.1: 6 Types of outcomes of water droplet impact (Rioboo *et at*, 2001)

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They explained the results by relating to process parameters; roughness wavelength (Rw), roughness amplitude (Ra), impact velocity, drop size, viscosity, and surface tension with decreasing the surface tension of liquid, leading to increasing wettability or increasing the surface roughness, the hysteresis between advancing and receding contact angle increased. Moreover they proposed the time evolution of the spreading phase after the impact which was divided into three main phases: (1) the propagation of and internal shock wave at the very beginning of the impact; (2) the generation of the spreading lamella and (3) the drop deformation into pancake shape. To quantify the various outcomes of the impact, the dimensionless parameters of Reynold number (Re), Weber number (We), and the Ornesorge number (Oh) were used. However, the uses of dimensionless parameters were usually limited to the splash and deposition, or sometimes combination. It was pointed out that both and roughness of the surface were not be taken into these dimensionless numbers, resulting in the limitation of these method.

The rebound process was first proposed by Mao *et al* (1997), As shown in Figure 2.2, the proposed impact process consists of 4 stages 1) *stage a: before impact;* at this stage the droplet impact energy consists of kinetic energy, surface energy, and potential energy, 2) *stage b: maximum spreading*; at this point at which the liquid flow changes direction from spreading outward to recoiling inwards. At this stage the surface energy is maximum while kinetic energy is zero, 3) *stage c: maximum recoil/rebound;* the droplet changes it direction of motion from up to down under the influence of gravity. The droplet possesses the potential and surface energy without the kinetic energy, 4) the last *stage d: equilibrium;* the droplet possesses a minimum energy that is equal to the static surface energy. The results indicated that the liquid viscosity and the impact velocity were found to be the most important parameters affecting especially *stage b*. The viscosity and static contact angle play a dominant role in determining the tendency of a droplet to rebound after the impact. A semiempercal model was developed to predict the maximum spreading as a function of the Reynold number (Re), the Weber number (We), and the static contact angle. The rebound model was developed to predict the tendency of the droplet to rebound upon the impact as a function of the maximum spread and the static contact angle.

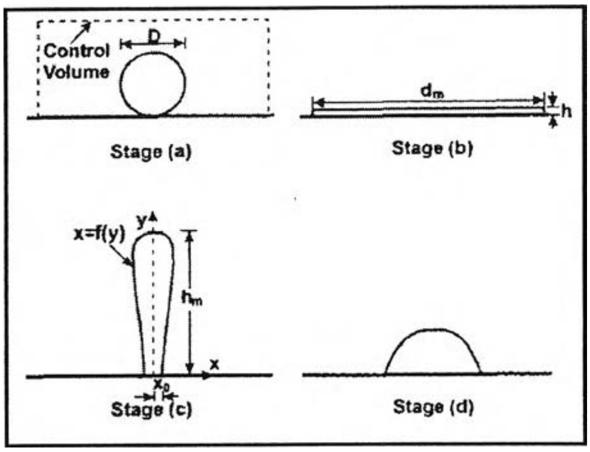

Figure 2.2: Four stages of the proposed impact process (Mao *et al*, 1997)

A number of research works investigated the effect of adding of surface active agent (surfactant) in which a fluid interface undergoes very large deformation. Zhang.*et al* (1996) reported that the dynamic surface tension (DST) radically altered the dynamic of the impact process compared to the situation in which the fluid interface was clean. They investigated that the impact on a solid substrate of a Newtonian liquid droplet containing two surfactants of SDS and Triton X-100. The presence of surfactant was found to cause a large deformation of the liquid droplet with a large amplitude oscillation that happened upon impacting and spreading on the substrate. A major consequence of the presence of surfactant was that surfactant accumulates on the fluid interface cause the reduction of the surface tension.As a results, it enhances the spreading of the droplet across the substrate. On the other hand, the non uniform distribution of surfactant along the fluid interface gives raised a Marangoni stress that inhibits the spreading effect.

Sikalo *et al.* (2005) investigated the glycerin droplet impact on an inclined plate with different degrees. The results showed that droplet rebound appeared only on the dry smooth glass surface and wetted surfaces, the rebound did not occur because the droplet sliped during the recoiling phase. Interestingly, the droplets rebound was observed on wetted surfaces with larger impact angles than the dry smooth glass.

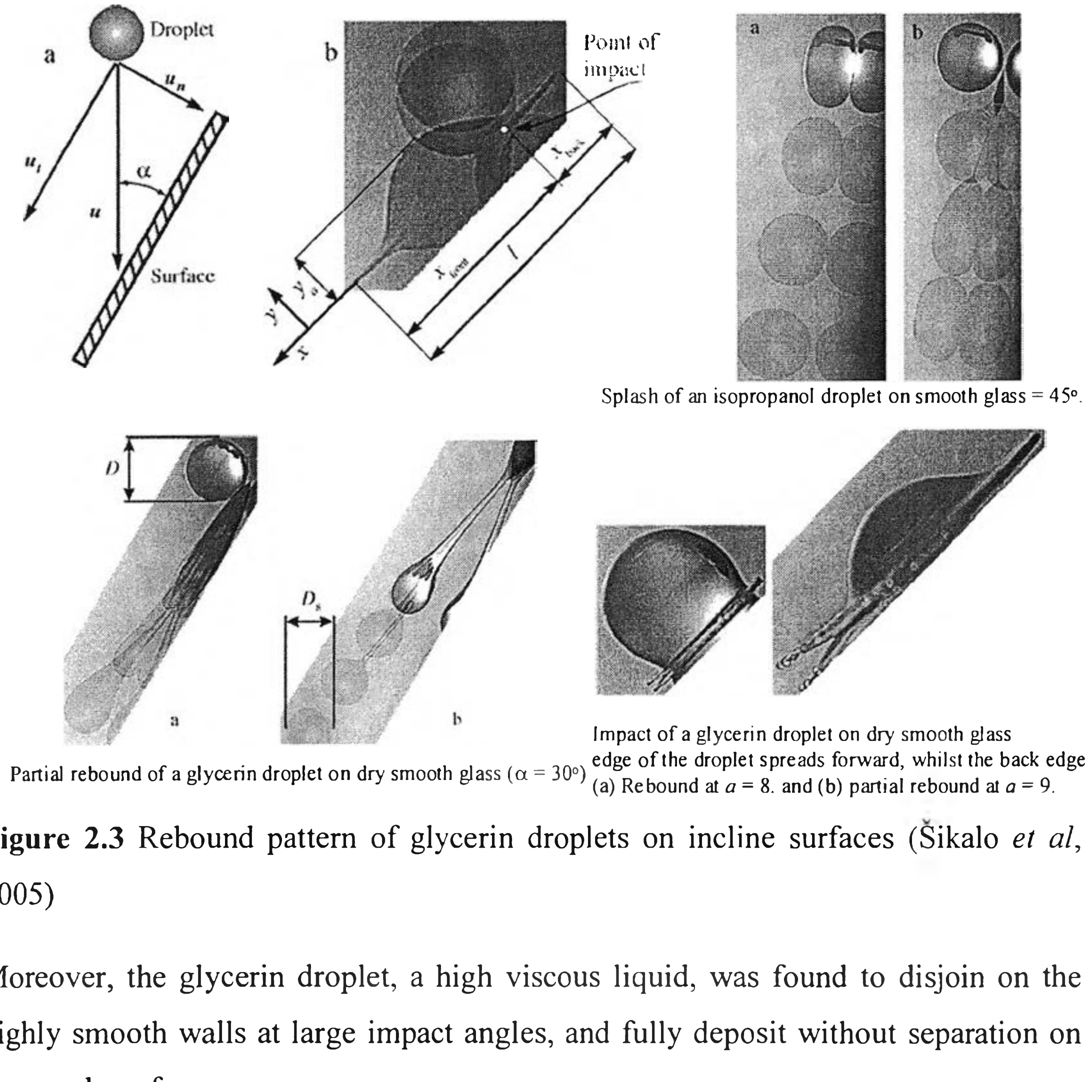

Figure 2.3 Rebound pattern of glycerin droplets on incline surfaces (Šikalo *et al*, 2005)

Moreover, the glycerin droplet, a high viscous liquid, was found to disjoin on the highly smooth walls at large impact angles, and fully deposit without separation on the rough surface.

A number of research works were rarely carried out to investigate the effect of temperature on the impact phenomena of liquid. Wachters and Westering (1996) studied a water droplet in collision with a gold surface above the Leidenfrost temperature. Leidenfrost temperature is the temperature above liquid boiling temperature once a liquid droplet reaches a solid surface, some part of the liquid droplet has already evaporated to create the air insulation between liquid droplet and solid surface. The Weber number was found to be an important effect on the dynamic parameter of the droplet. Depending on the Weber number, the droplet would either rebound without disintegration or splash on the surface after impact, depending on the Webber number. Groendes and Mesler (1982) studied the saturation film boiling impact of the water droplet on quartz surface of 460°C. They used a fast-response thermometer to measure the fluctuation of the surface temperature, and the maximal temperature drop on the solid surface during the impact was recoded to be about 20°C. Hatta *et al.* (1997) conducted a series of experiments to study the film-boiling impact of water droplets on different metallic surfaces. Experimental results on such properties as the deformation and the rebound height of the droplet during the impact, and the residence time of the droplet on the surface were found to depend on droplet size and impacting velocity.