GAS INFLUENCE IN DROP IMPACT ON A DRY SOLID SURFACE

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Summary Drop impact performs different behaviors by changing the density or viscosity of surrounding gas. At $Re = 9350$,$We = 1668$,for a contact angle of 90°, the splash can be suppressed for small gas density or viscosity, a frontier exists between splash and non-splash. Whereas for 180°, a splash can always be observed and the drop "floats" over the gas layer. For both 90° and 180°, a jet is already formed over the gas layer before "contact" which originates the splash. Gas is essential to splash formation.

INTRODUCTION

Drop impact onto a solid surface is a complex three-phase dynamics. In a wide range of conditions, a splash can be observed. Most mechanism studies for splash formation were focused on liquid or solid effects, but recent experiments show that surrounding gas is also essential to splash formation[1]. In this article, we try to investigate the gas influence on drop impact. A liquid drop of diameter D, density ρ_l and viscosity μ_l falls from a height h without initial velocity but under gravity g impacts on a dry plane solid surface. The surrounding gas has a density ρ_g, a viscosity μ_g and a gas/liquid surface tension σ. The Navier-Stokes equation considering gravity and surface tension is set:

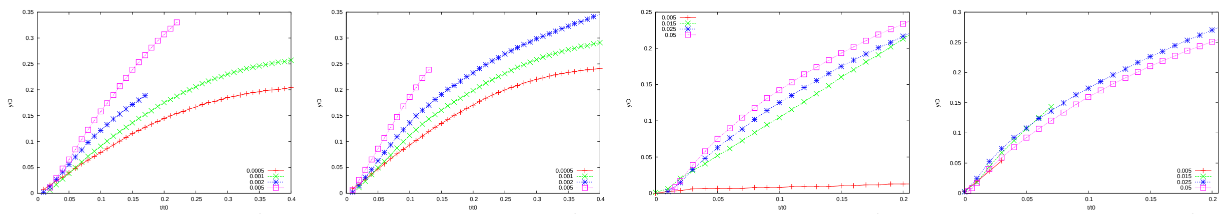
$$\rho \frac{d\mathbf{u}}{dt} = -\nabla p + \mu \triangle \mathbf{u} + \rho \mathbf{g} + \sigma \kappa \delta \mathbf{n} \tag{1}$$

The problem is solved in axisymmetric and dimensionless form by a code-Gerris, which is a partial differential equation solver based on finite-volume discretisation and an adaptive quadtree/octree mesh arrangement as an open source software[2]. The interface is tracked by a volume-of-fluid(VOF)/piecewise linear interface calculation method[3]. The Reynolds number and Weber number of liquid are defined as $Re = \frac{\rho_l U D}{\mu_l}$,$We = \frac{\rho_l U^2 D}{\sigma}$. To describe gas influence,two dimensionless numbers are introduced: density ratio $\alpha = \frac{\rho_g}{\rho_l}$ and viscosity ratio $\beta = \frac{\mu_g}{\mu_l}$. Here,two types of solid surface, whose corresponding contact angles θ are 90° and 180 °, are investigated.

GAS INFLUENCE

Influence of gas density and viscosity

To study gas effect to splash formation,we keep liquid properties constant and vary only gas density or viscosity. For gas density,we fix viscosity ratio β at 0.05 and consider density ratios $\alpha = 0.0005, 0.001, 0.002, 0.005$. As shown in Fig.1(a)&(b), as gas density decreases,the jet gets lower,but the difference between 90° and 180 ° is small. In Xu et al's experiments[1], the gas viscosity remains nearly constant,the splash can be suppressed by decreasing gas pressure. Our simulations reproduce the experimental observation which implies a decreasing gas density can make the splash disappear. For gas viscosity, we fix density ratio α at 0.001 and consider viscosity ratios $\beta = 0.005, 0.015, 0.025, 0.05$. For $\theta = 90°$, a transition from splash to non-splash is observed as gas viscosity decreases(see Fig.1(c)), whereas for $\theta = 180°$, the influence of gas viscosity is relatively small, a splash always exists(see Fig.1(d)).



(a) different α at $\theta = 90°$ (b) different α at $\theta = 180°$ (c) different β at $\theta = 90°$ (d) different β at $\theta = 180°$

Figure 1. Evolution of height of head of jet at $Re = 9350$,$We = 1668$.

In order to study gas influence for different impact behaviors,three simulations are executed at $\alpha = 0.001$, $Re = 9350$ and $We = 1668$. As the drop approaches the substrate, the gas layer decelerates and deforms the interface, a gas bubble will be entrapped under the drop. For $\theta = 90°$ and a small viscosity ratio β, no jet is formed and the drop will contact the substrate very quickly. The liquid sheet does not detach from but spreads on the substrate (see Fig.2(a)). Whereas,for a big viscosity ratio β,as shown in the inset of Fig.2(b), before the contact with substrate, a jet is already ejected. And then the drop contacts the surface, a series of small gas bubbles are formed and advance towards outside. For $\theta = 180°$,if we look

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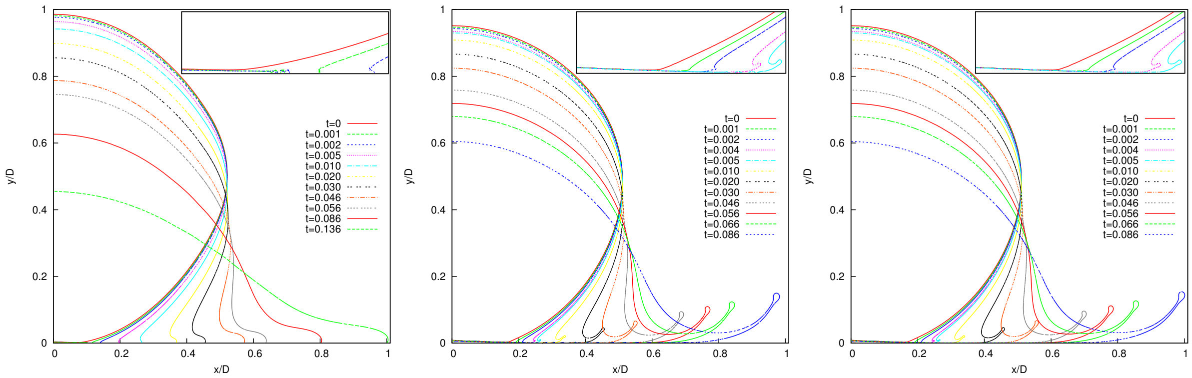
at the inset of Fig.2(c), the drop does not contact the hydrophobic surface, it will "float" over the gas layer and a splash is formed. These three cases imply that the gas layer is essential to splash formation, the lubrication effect dominates in gas layer and causes the jet ejection which originates the splash formation.

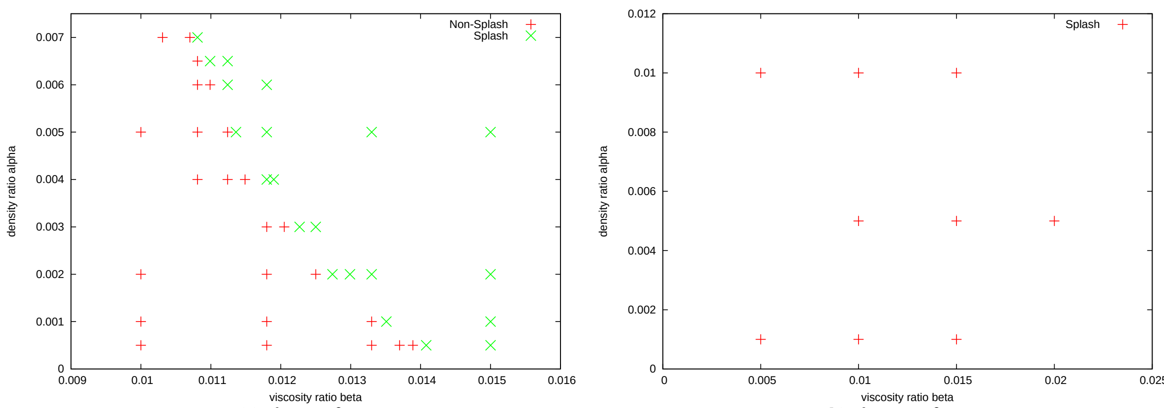


(a) $\theta = 90°, \alpha = 0.001, \beta = 0.005$ (b) $\theta = 90°, \alpha = 0.001, \beta = 0.05$ (c) $\theta = 180°, \alpha = 0.001, \beta = 0.05$

Figure 2. Evolution of drop interface at $Re = 9350, We = 1668$.

Frontier between splash and non-splash

Here, after a series of simulations, it is found that for $\theta = 90°$, A frontier exists between splash and non-splash(see Fig.3(a)), a transition between the two impact states is observed by changing gas density or viscosity. Whereas, for $\theta = 180°$, a splash always forms, the drop does not contact the substrate and a thin gas layer always exists(see Fig.3(b)).



(a) $\theta = 90°$ (b) $\theta = 180°$

Figure 3. Density ratio α versus viscosity ratio β at $Re = 9350, We = 1668$.

CONCLUSIONS

In this article, we investigate the gas influence on drop impact. We find that drop impact can perform different behaviors through varying gas properties and the splash can be suppressed by reducing gas density or viscosity. If there is a splash,for both 90° and 180° contact angles, a jet is already formed over the gas layer before the "contact". The thin gas layer between drop and solid surface is essential to splash formation. For $\theta = 90°$, a frontier exists between splash and non-splash, whereas for $\theta = 180°$, the drop "floats" over the gas layer, the variation of gas properties can influence the profile of splash but a splash is always observed. We could conclude that the surrounding gas plays an important role in drop impact issue.

References

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