Droplet-Surface Impingement Dynamics for Intelligent Spray Design

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Spray cooling has high potential in thermal management and life support systems by overcoming the deleterious effect of microgravity upon two-phase heat transfer. In particular spray cooling offers several advantages in heat flux removal that include the following:

 1. By maintaining a wetted surface, spray droplets impinge upon a thin fluid film rather than a dry solid surface
 2. Most heat transfer surfaces will not be smooth but rough. Roughness can enhance conductive cooling, aid liquid removal by flow channeling.
 3. Spray momentum can be used to a) substitute for gravity delivering fluid to the surface, b) prevent local dryout and potential thermal runaway and c) facilitate liquid and vapor removal. Yet high momentum results in high We and Re numbers characterizing the individual spray droplets. Beyond an impingement threshold, droplets splash rather than spread. Heat flux declines and spray cooling efficiency can markedly decrease.

 Accordingly we are investigating droplet impingement upon a) dry solid surfaces, b) fluid films, c) rough surfaces and determining splashing thresholds and relationships for both dry surfaces and those covered by fluid films. We are presently developing engineering correlations delineating the boundary between splashing and non-splashing regions.
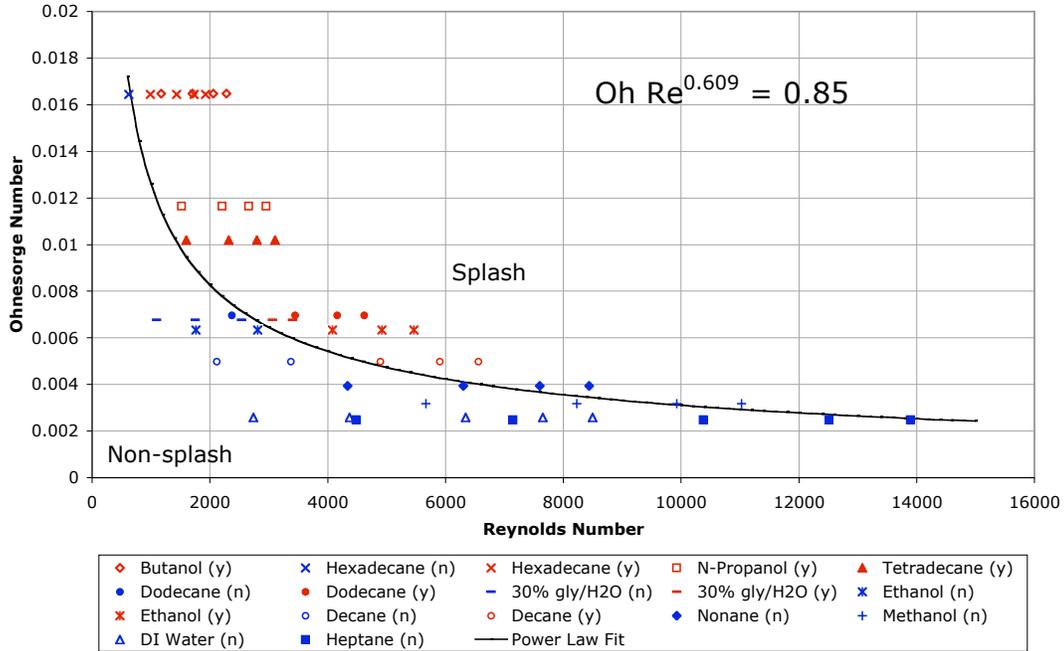
 Determining the splash/non-splash boundary is important for many practical applications. Coating and cooling processes would each benefit from near-term empirical relations and subsequent models. Such demarcations can guide theoretical development by providing definitive testing of its predictive capabilities. Thus, empirical relations describing the boundary between splash and non-splash are given for drops impinging upon a dry solid surface and upon a thin fluid film covering a similar surface. Analytical simplification of the power laws describing the boundary between the splash and non-splash regions yields insight into the engineering parameters governing the splash and non-splash outcomes of the fluid droplets.

 Figure 1 shows the power law correlation separating the splashing versus non-splashing regions as developed for droplets impinging upon a dry solid surface. Splashing upon a dry surface is reasonably described by $Ca > 0.85$, reflecting the competing roles of surface tension and viscosity. Figure 2 shows the power law correlation separating the splashing versus non-splashing regions as developed for droplets impinging upon a thin fluid film covering the solid surface. Splashing upon a thin fluid film, as described by $v (pd/s) > 63$, is governed by fluid density and surface tension, but is rather independent of viscosity. Finally, the data presented here suggests that a more direct dependence upon the surface tension and viscosity, given a better understanding of their interplay, would allow accurate description of the droplet-surface impacts for more complicated situations involving non-Newtonian fluids, specifically those exhibiting viscoelastic behavior.
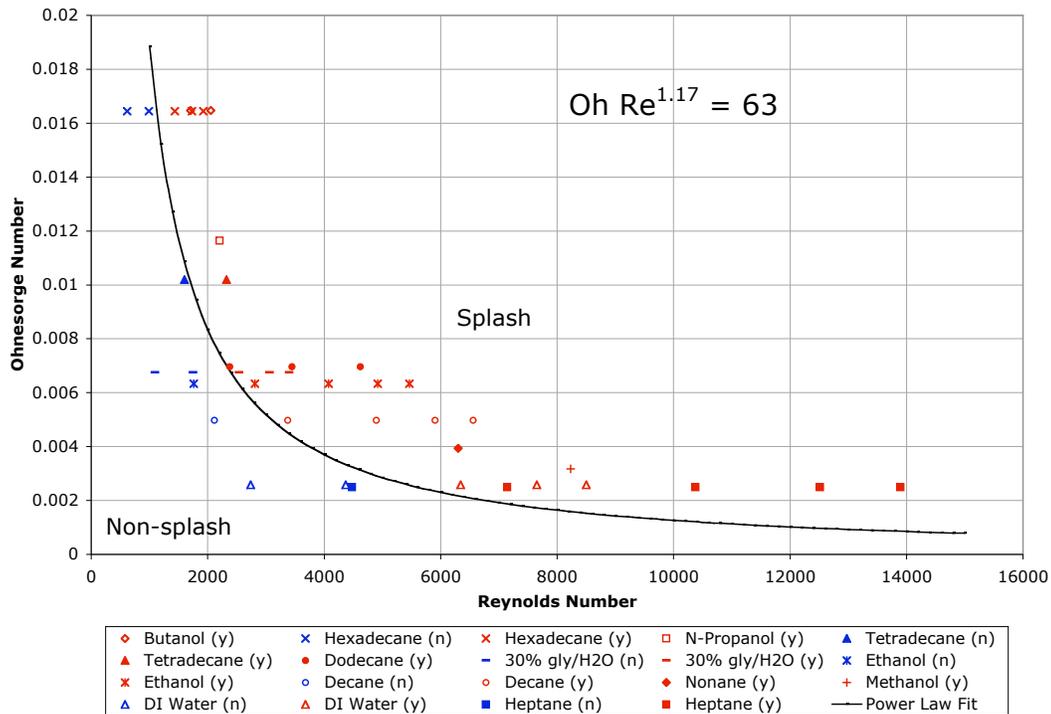
Splash/Non-Splash Boundary for Impact on a Dry Surface

$$\text{Oh Re}^{0.609} = 0.85$$

Ohnesorge Number

Splash

Non-splash

Reynolds Number

Legend:
- ◇ Butanol (y)
- × Hexadecane (n)
- ✕ Hexadecane (y)
- □ N-Propanol (y)
- ▲ Tetradecane (y)
- ● Dodecane (n)
- ● Dodecane (y)
- − 30% gly/H2O (n)
- − 30% gly/H2O (y)
- ✶ Ethanol (n)
- ✶ Ethanol (y)
- ○ Decane (n)
- ○ Decane (y)
- ◆ Nonane (n)
- + Methanol (n)
- △ DI Water (n)
- ■ Heptane (n)
- —— Power Law Fit

Splash/Non-Splash Boundary for Impact on a Thin Film

$$\text{Oh Re}^{1.17} = 63$$

Ohnesorge Number

Splash

Non-splash

Reynolds Number

Legend:
- ◇ Butanol (y)
- × Hexadecane (n)
- ✕ Hexadecane (y)
- □ N-Propanol (y)
- ▲ Tetradecane (n)
- ▲ Tetradecane (y)
- ● Dodecane (y)
- − 30% gly/H2O (n)
- − 30% gly/H2O (y)
- ✶ Ethanol (n)
- ✶ Ethanol (y)
- ○ Decane (n)
- ○ Decane (y)
- ◆ Nonane (y)
- + Methanol (y)
- △ DI Water (n)
- △ DI Water (y)
- ■ Heptane (n)
- ■ Heptane (y)
- —— Power Law Fit

Figures 1&2. Splash behavior on a dry solid surface and on covered by a thin film, respectively, each plotted with respect to Ohnesorge and Reynolds number values. Red plot marks correspond to splashing behavior and blue to non-splash. The equation for the boundary fit line is included on the graph.