Thermally Induced Breakup of Levitated Droplet

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Abstract

In this work we experimentally study the thermal effects that lead to instability and break up in acoustically levitated vaporizing fuel droplets. We report two kinds of instabilities: 1. Short wavelength (Kelvin-Helmholtz) instability for diesel and bio-diesel inducing secondary atomization near the droplet equator and 2.Bulk deformation results in wide fluctuations in droplet aspect ratio analogous to a spring mass system with low damping coefficient that ultimately leads to catastrophic breakup involving bag type and capillary wave induced atomization. Temperature dependent fuel properties and external heating rate are responsible for the inception and relative strength of these instabilities. If breakup occurs, it is always preceded by secondary atomization when droplet Weber number exceeds a critical value. Catastrophic breakup is induced in deformed droplets when the Bernoulli pressure due to the levitator pressure field is significantly high and surface tension and viscous damping is comparatively low so that the highest energy containing frequency of aspect ratio vibration leads to bag type instability.

The experimental setup consists of an ultrasonic levitator (100 kHz, 154dB) and a 30W tunable CO2 laser (wavelength 10.6 µm) to irradiate 500 micron droplets. The heating event was recorded simultaneously by a high speed (Phantom V12) camera whose images were processed to obtain instantaneous diameter, aspect ratio and shape changes, and an infra-red (IR) camera to obtain the surface temperature of the droplet. Both cameras used microscopic lenses to increase the spatial resolution. The resolution was nearly 2 µm in every pixel.

This work reports and explains that secondary atomization in levitated fuel droplets is primarily due to thermal effects. We showed that the properties such as vapor pressure, latent heat and specific heat govern the vaporization rate and temperature history. This in turn affects the surface tension gradient and gas phase density, ultimately dictating the onset of KH instability. We laid down a criterion for the inception of this instability in terms of Weber number. Low vapor pressure and latent heat leading to high surface temperatures achieved in diesel, bio-diesel and kerosene favor small scale atomization through KH instability. The temperatures for fuels having high vapor pressure and high latent heat will remain rather low and they tend to be more stable like ethanol due to lower surface tension gradient.

A second type of instability occurs in kerosene droplet due to a decrease in surface tension and viscosity with temperature. The change in surface tension causes the droplet to flatten due to increased Bernoulli pressure at the poles resulting in an increase in aspect ratio. The imbalance in pressure force and surface tension force near the equator creates shape oscillation. If the viscous damping of this oscillation is not strong enough, the droplet goes through unbounded stretching morphing into a disk-like shape, followed by bag type catastrophic breakup.