Holography of Fuel Spray Breakup on Hot Surfaces

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Motivation
Characterization of fuel spray atomization during hot surface impacts is necessary for many IC engine applications.
- Single droplet breakup characterized by Weber number regime
- In realistic spray multi-drop interaction may occur
- Difficult measurement environment due to presence of multiple phases with different indices of refraction (air, fuel vapor, droplets, ...)
- Test whether single dop scaling vs. We applies to multi-drop spray environments.

Background
Drop impact on heated walls
Drop break-up, surface wetting and ultimately evaporation strongly depend on $T_{surf}$ and Weber number $We = \frac{\text{drag}\ \text{Cohesion}}{\rho u^2 D_p}$

Small droplet and particle measurement techniques
LV (Laser Doppler Velocimetry) [2] Smith et al 1995
- Particle traveling through Laser fringe create doppler shift $u \propto \nu$

PDPA (Phase Doppler Particle Analysis)
- Multiple photo detector record phase shift between doppler bursts $\propto D_{particle}$

Holography
- 3D imaging technique for particle / droplet laden flows using highly coherent Laser light source.
- Objects create diffraction pattern at distance $z$ from object plane
- Interference between coherent reference light and light diffracted by object creates hologram

$$E_z(x,y,z) = |I(x,y)E_s(x,y)| \otimes g(x,y,z)$$

- Simple setup
- Numerically refocus to particle location $f4$
- Field measurement, difficult in dense particle fields and sensitive to phase distortions (e.g. vapor, shockwave, large thermal gradients)

Objectives
Develop experiment to characterize fuel spray (multi droplet) breakup during hot wall impact.

Challenges:
- Resolve droplets ranging from 10 $- 1000 \mu m$
- Droplet velocities 1 $- 10 m/s$
- Thermal gradients in air and vapor generation
- Dense particle field containing both primary (pre-impact) and secondary (post-impact) droplets

Experimental Methods
Optical Setup:
Holography of small fast-moving droplets requires high resolution + magnification and short exposure.

- AOM (Acousto Optic Modulator) allows ultra fast shuttering ($< 10 \mu s$) of 15mW HeNe-Laser independent of Camera system.

Heated impact surface:
Insulated brass heater block with 2 $×$ 300W cartridge heaters allows even heating of 1 $×$ 3 in sapphire window up to 550°C (1000°F)

Digital Off Axis holography (DOH)
- Effect of object presence on resolution of refocusing for high velocity particles

Conclusions

Results
Numerical refocusing of droplets at varying z-depths complicated in dense particle fields even with screen.

Overlapping diffraction patterns from close and overlapping particles hinder identification.

Cluster are identified as very large drops.

Additional filtering is necessary to find particle size distributions.

Summary:
- Demonstrated highspeed micro DIH of fuel spray atomization during high super heat wall impact
- DIH reconstruction through thin heated window and vapor layer in Leidenfrost regime

Future Work:
- To enable characterization of droplet breakup at wall temperatures below Leidenfrost implement phase correction method e.g.: Digital Off Axis holography (DOH)
- Phase conjugate DIH
- Implement multi-frame particle tracking to extract velocities and Weber numbers
- Repeat and compare free spray and post impact droplet characterization using LDV+PDPA
- Implement DIH for single droplet impact at elevated pressures

Acknowledgements

References

Image sequence of vertical JP-8 spray impact on heated surface shows formation of dense secondary droplets cloud.