Experiment and modeling of Spray Impingement from Multi-hole DISI Injectors

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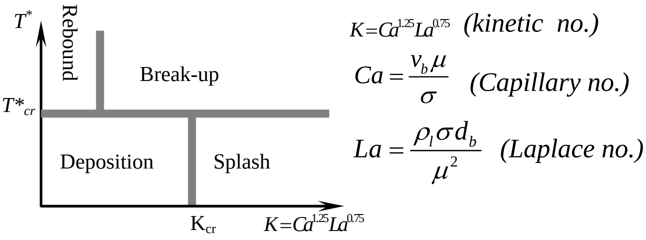
Abstract: The characteristics of the impingement spray from a six-hole direct injection spark ignition engine (DISI) injector inside a constant volume optical chamber on a hot surface have been identified by direct visualisation and PDA system for different operating conditions. The results have been analyzed respected to post-impingement characteristics and employed to validate an impingement model which takes into account the effect of surface temperature, gas phase pressure, incident droplet velocity, incident angle and surface roughness. The impingement model provides a reasonable estimation of the post impingements droplets with respect to the post droplet size and direction trends for different operating conditions but overestimates the magnitude of velocity and mean diameter.

Introduction and Experimental conditions: The fact that impingement of spray on the hot piston/cylinder is one of the major sources of HC emissions with a considerable percentage during the engine cold start drives the researcher to carry out more investigation on the impingement process. In this study, the impingement spray from a DISI six-hole injector has been characterized using CCD camera and PDA (Phase Doppler Anemometry) system. One spray plume out of the six sprays has been chosen to be characterized before and after impingement on a heated plate located 31 mm away from the nozzle exit inside a constant volume optical chamber. The plate was tilted so that its normal vector forms 60 or 30 degree with the nozzle orifice center line. The spray droplet sizes and velocities were measured simultaneously using the PDA system parallel to the wall surface with a step of 2mm at 1mm above the plate up to 8mm in front of the impingement point and of 2mm behind the impingement point. More details about the experimental setup and results have been published by Abo-Serie et al. (2003).

Impingement model: When a droplet or a spray impinges on a solid surface, different phenomena can be observed depending on the impact condition. In general, these phenomena are described as different impingement regimes such as stick, spread, rebound, splash, breakup, etc. Which regime the droplet belongs to depends on incident droplet kinetics and properties and also on the wall surface characteristics, as reviewed by Lindgren and Denbratt (2000). In the current study, four regimes are assumed to be dominating the DISI spray impingement conditions; deposition, rebound, splash and break-up. The transition from one regime to another has been found to be mainly depends on the thermal number T^* and the kinetic number K as presented in Figure 1. u, v and d are the droplet tangential and normal velocities and diameter; ρ, σ and μ are density, surface tension and dynamic viscosity; T_w and T_{sat} are surface temperature and fuel saturation temperature. The subscript b denotes before impingements. The value of T_c^* is found to be 1.18 from analysing the data of single and chain droplet impingement on a hot surface. The kinetic transition number K_{cr} depends on further parameters and also on wall temperature. For temperatures below the saturation temperature, i.e. the correlation considered by Han et al. (2000) is used while for $1 < T^* \le T_{cr}^*$, the experimental data have been analyzed and a correlation that fits the data is deduced as follow:

$$K_{cr} = 16.5 * \left[ln(\frac{2.432}{T^* - 0.993}) \right]^{1.25} .$$

For $T^* > T_{cr}^*$, the critical $K - number$ is assumed to be constant and equal to 50.0.



$$K = Ca^{1.25} La^{0.75} \quad \textit{(kinetic no.)}$$

$$Ca = \frac{v_b \mu}{\sigma} \quad \textit{(Capillary no.)}$$

$$La = \frac{\rho_l \sigma d_b}{\mu^2} \quad \textit{(Laplace no.)}$$

***Figure 1**. Overview of impingement regimes and transition criteria.*

During the deposition regime, the arriving droplets are supposed to coalesce to form a local film. Therefore, there are no secondary droplets. In the rebound regime the approach proposed by Park and Watkins (1996) based on experimental results on a single drop impinges upon a hot plate was used to calculate the droplet velocity after impingement. For splash event, the total energy is always conserved. The splash mass ratio has been calculated for a cold wall by Bai and Gosman (1995). For $T^* > T_{cr}^*$ complete splash of the impinging droplet mass occurs and thus splash mass ratio is supposed to be unity. A linear equation from cold wall model to hot wall model on splash mass is derived for temperatures $T_{cold}^* < T^* \le T_{cr}^*$. The secondary droplet size and velocity were fitted with experimental of a single droplet impingement using a Weibull distribution according to Stanton and Rutland's (1996). The description of break-up regime is almost the same as that of splash regime except that the splash mass ratio in break-up regime is always set to unity and also the secondary tangential velocity is assumed equal to the tangential value before impingement because there is no direct contact between impinging droplet and wall surface at higher temperatures, and therefore friction loss is very little.

Results and Discussions: Figures 2 a and b show the calculated and measured frequency distribution of post impingement droplet diameters under two wall surface temperatures 381K and 489K for 60^{o} plate angle. The figures show that both the calculation and experiments showed that surface temperature has slight influence on secondary diameter distribution. Although the calculated droplet diameter distribution shows reasonable agreement with the measured PDA data with regard to the maximum diameter as well as the width of distribution, the model over predicts the Sauter mean diameter due to existence of a higher occurrence probability of large droplets within the impinging spray. Similar results are obtained for the 30 degree plate angle but the Sauster mean diameter was almost similar as shown in Figure 2d. Increasing the chamber pressure causes the secondary diameter distribution to become wider, as shown in Figure 2c. The peak value decreases and the distribution is shifted rightward towards the larger sizes. The calculated results showed similar trends except that the mean value of secondary diameter is consistently overestimated.

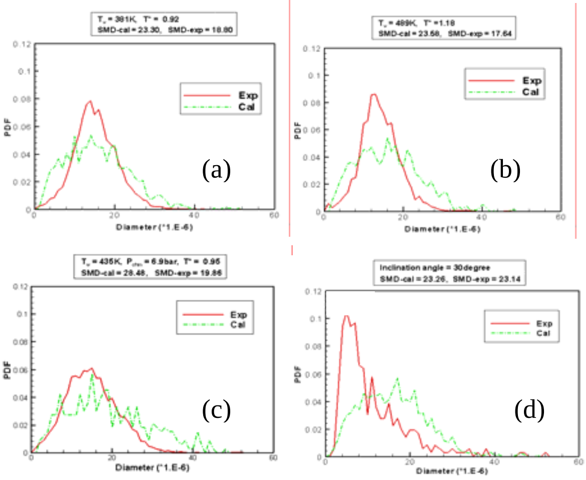


Figure 2. *Droplet size distribution of DISI spray after impingement at different operating conditions.*

The comparison for total velocity distribution for 60 degree plate angle is shown in Figure 3 which shows that the shape and tendency of the distribution could be compared qualitatively. However, the calculated results showed a wider distribution and a lower peak value with an obvious rightward shift towards higher velocity. The directions of movements of droplets after impingement described by the ejected angle showed narrow distribution in comparison with the experimental measurements. This wider distribution could be attributed to the effect of air flow which pushes some droplets upward away from the plate surface. It is believed that air flow has great influence on droplet direction. In conclusion, for all cases the calculated results showed reasonable agreement with the measured data qualitatively. However, there is a clear need for further improvement in the model by taking into account the mutual interaction of spray and air flow to have a quantitative comparison.

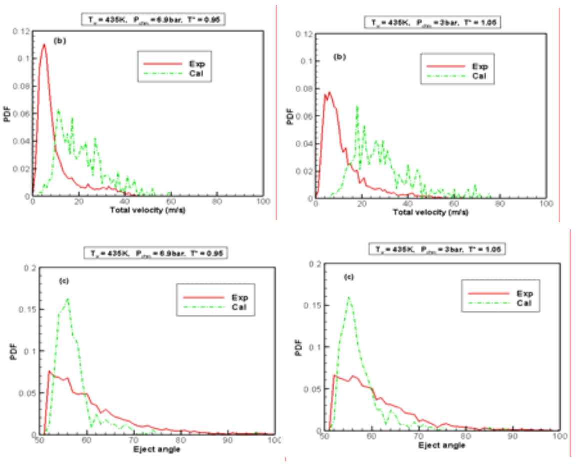


Figure 3 *Droplet velocity and ejected angle distribution of DISI spray after impingement at different operating conditions*

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