

# Laser Doppler and optical techniques applied to multiple drops impact on solid hot dry surfaces

by

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## ABSTRACT

Drop impact onto solid heated surfaces is a phenomenon encountered in many industrial applications such as the metal surface cooling in the steel industry and in the nuclear power plants, the hot coating of surfaces, the thermal control of electronic devices, the fuel drop impact on cylinder walls in diesel and gasoline direct injection engines. The study of single and multiple drop impact on heated surface represents the unavoidable intermediate step toward a better comprehension of the spray-wall interaction. One of the aims of this work is an attempt to bridge such a gap, by studying experimentally the impact of single and multiple water drops of millimetric size onto a heated surface. A large difference between single droplet and multiple droplet impingement outcomes is indeed expected to exist, as drop-drop interaction on the surface is expected to produce liquid fingers than may break-up in secondary drops.

To study the effects of interaction among drops impacting simultaneously on a heated surface, a drop generator was developed and assembled, capable to produce on demand an array of drops with diameter ranging between 2 to 4 mm. The drop generator uses a pressure pulse to detach droplets from needles, the initial velocity of such drops is usually different from zero and the impact velocity was then measured by means of multiple exposed pictures taken by a CCD camera. For the present study, three needles positioned on a line were used to produce three identical drops at a distance of 8mm from each others. The impact of liquid drops on the heated surface is investigated by different techniques: Phase Doppler Anemometry (PDA), Image Analysis Technique (IAT) and Particle Image Velocimetry (PIV). A Dantec PDA (Phase Doppler Anemometer) was used to measure simultaneously the secondary drop velocity (one component) and size. The focused probe volume is  $0.119 \times 0.119 \times 0.516$  mm (x,y,z). The transmitting optics uses an Ar-Ion, air cooled, mid-power laser (300mW) at the wavelength of 514.5nm (green light). The receiving optic is covered with mask type A. Due to the unknown liquid temperature of the secondary droplets, an off-side angle of  $70^\circ$  was chosen, since it reduces to a minimum the sensitivity of the measurements to the refractive index. Because this angle is very near to the Brewster angle ( $73.7^\circ$  for water), also the polarization plane must be perfectly aligned to the vertical axis in order to measure the real velocity component with a reasonable accuracy. The set-up allows measuring the drop size from  $5.5\mu\text{m}$  to  $250\mu\text{m}$  and this overlaps partially the range allowed by using the CCD camera (from  $40\mu\text{m}$  to few mm), allowing to reconstruct the entire drop size PDF from few mm to millimetres. Only the vertical drop velocity was acquired. The acquisitions were triggered by the same system used for the CCD camera. Hi-resolution CCD B&W image analysis is used mainly to study the morphology of impact and to extract the size and position of the secondary droplets generated after impact in a diameter range from  $20\mu\text{m}$  up to few  $\mu\text{m}$ .

Finally a Particle Image Velocimetry (PIV) technique was developed to be applied to the images acquired with the color CCD camera, and used to detect the whole secondary drop velocity field at different times after impact. The idea of the technique is to acquire and use the real (physical) images at 12bits with back-light of different colours (red and blue) in order to split it into 2 frames and analyse red and blue channel separately. The average movement of secondary droplets is determined by the direct cross-correlation technique applied to an interrogation area of any size. The back light is generated by a matrix of a new type of high power (1W) LED. An intensity calibration is made to get the same light flux between the 2 colours.

To point out peculiar characteristics of the impact process when the surface is heated above the liquid ( $\text{H}_2\text{O}$ ) boiling point, different wall temperatures were chosen. Two main regimes were observed as a function of wall temperature: bubble boiling regime ( $T_w=145^\circ\text{C}$ ) and film boiling regime ( $T_w=260^\circ\text{C}$ ).

The paper deals also in accuracy of the presented measurement techniques. Data reduction procedures adopted are also described and commented.