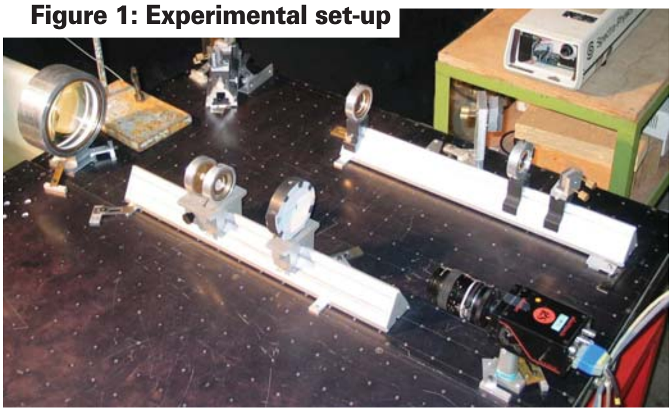
RAINBOW THERMOMETRY

Rainbow thermometry is a non-intrusive measurement technique capable of simultaneously measuring the size and the temperature of liquid droplets suspended in a liquid or gaseous bulk. This technique has already been applied to flat fan water sprays in air. Figure 1 shows the experimental set-up. An Argon laser beam ($\lambda = 514.5$Nm, $P = 2$W) is directed by means of two mirrors through two lenses in order to be expanded. Finally it is directed towards the spray by means of a couple of mirrors. The light scattered by the water droplets, is collected at an angle making ~139° with the laser beam, by a large-diameter lens (lens diameter $d = 140$mm, focal length $f = 183$mm). A pinhole of 5×10^{-3}m of diameter is used to select a volume of measurement of 10^{-6}m^3. Finally, a lens projects the scattered light on a semitransparent screen scanned by a CCD camera, which records the rainbow interference image. The spray is moved step by step vertically and horizontally in order to vary the position of the probe volume.

Figure 1: Experimental set-up



In Figure 2a, a low and high frequency component can be observed, while in Figure 2b the variation in droplet size and temperature blurs the interference structures. Fringe spacing yields droplet size, without prior knowledge of droplet temperature. The rainbow position is related to the droplet refractive index, thus droplet temperature. With the help of numerical simulations, data-inversion algorithms have been established. They allow size and temperature measurement for single droplets and mean values and dispersion factors of droplet size and temperature for multiple droplets. Using this data-inversion algorithm a flat fan water spray has been characterised. Figure 3 shows the streamwise evolution of the Sauter Mean Diameter (SMD) measured at downstream distances of 0.2m, 0.4m and 0.6m.

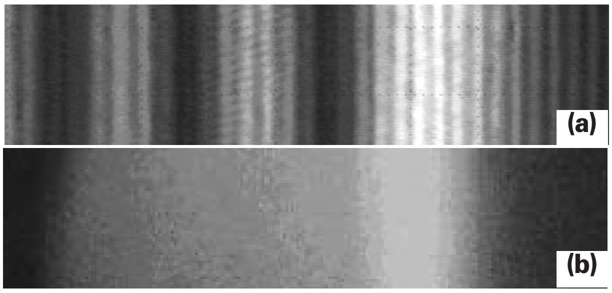


Figure 2: Rainbow pattern from (a) a single droplet and from (b) an ensemble of droplets

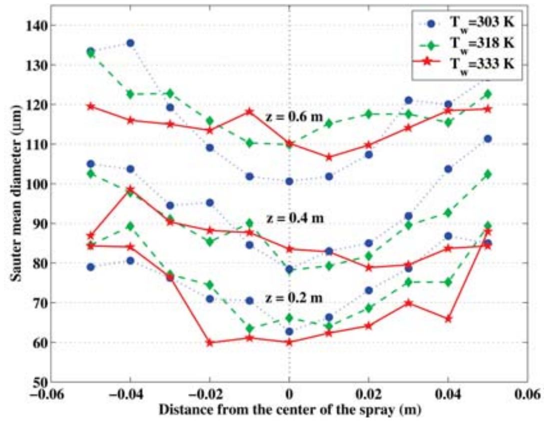


Figure 3: Sauter diameter profile at 0.2m, 0.4m and 0.6m from the nozzle

The temperature measurements obtained using the Rainbow Thermometry technique were compared to measurements performed by means of a thermocouple placed in the probe volume. Both measurement techniques indicate that droplet temperature decreases from the centre to the edges of the spray. Such a behaviour results from the entrainment of the fresh air that cools down the water droplets at the spray border.

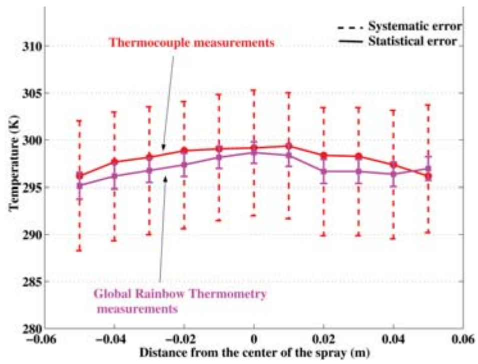


Figure 4: Temperature profile at 0.4m from the nozzle

Experimental validation of the rainbow thermometry technique has been performed through an original experiment, in which the droplet size and temperature could be independently measured. For this purpose the diameter, temperature and non-sphericity of liquid droplets suspended in a liquid bulk were measured. The experimental set-up used to perform the diameter and temperature measurements of liquid droplets suspended in a liquid bulk is shown in Figure 5, while an image of a suspension is presented in Figure 6.

The rainbow technique has been used to measure the size and the temperature of oil droplets with refractive index ranging from 1.0521 to 1.0533 at a temperature of 25°C. At the same time, the size of each droplet has been measured by direct observation with the CCD camera and its temperature is measured by means of a thermometer immersed in the water bulk. The results for the droplet size and temperature obtained with Rainbow Thermometry are in agreement with those achieved with the other techniques used. In the worst case (silicon oil of 30cSt of viscosity) the values obtained, both for size and temperature, differ from each other by about 10%. As far as the validation of Rainbow Thermometry is concerned, one of the advantages of using an oil-in-water dispersion rather than a water-in-air spray is that the variation of the rainbow scattering angle as a function of the temperature is weaker in the former case. Therefore, for a given uncertainty in the measurement of the reference angle, the error found for the temperature is 3 times smaller for the oil-in-water dispersion than for the water-in-air spray.

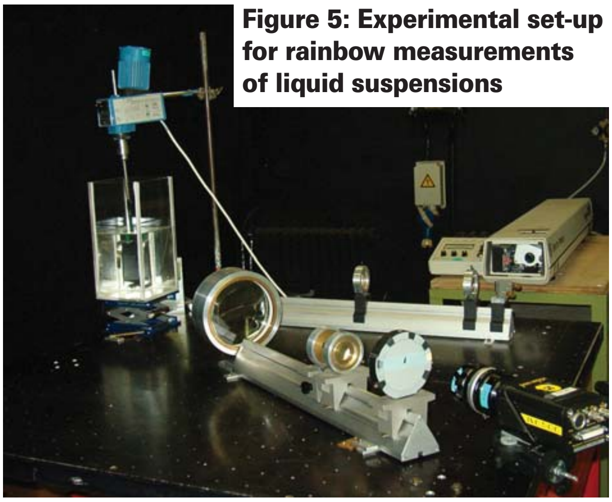


Figure 5: Experimental set-up for rainbow measurements of liquid suspensions

Up to now, the application of Rainbow Thermometry has been limited to particle systems possessing a uniform refractive index. This is mostly due to the absence of an appropriate data inversion algorithm that takes into account the presence of a refractive index gradient. Exploiting a generalization of the Airy theory, a data-inversion algorithm for a single droplet, presenting a parabolic refractive index gradient can be proposed. This data-inversion algorithm is used to compute the diameter and the refractive index at the core and at the surface of a simulated n-octane droplet burning in a standard atmosphere.

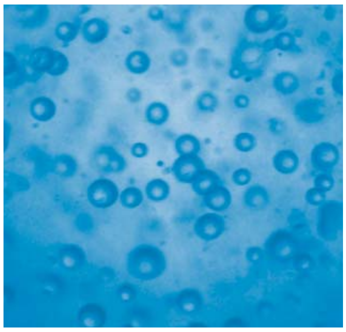


Figure 6: Silicon oil droplets suspended in water bulk

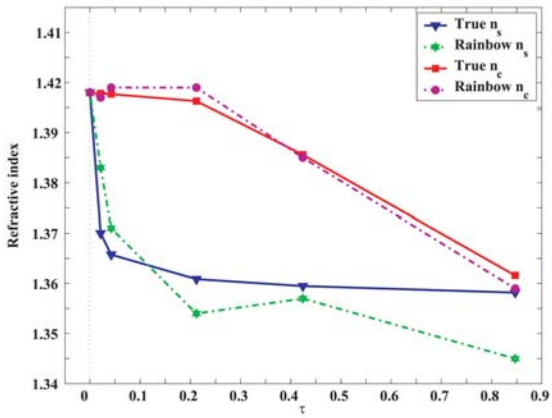


Figure 7: Comparison between the theoretical refractive index values in the core and at surface of a n-octane droplet burning in a standard atmosphere and the values obtained with the old and with the new data inversion algorithm

Figure 7 presents the comparison between the values of the refractive index numerically imposed (n_c: refractive index of the droplet core, n_s: refractive index of the droplet surface) and the corresponding values obtained using the data-inversion algorithm. The values corresponding to the core of the droplet are in better agreement [discrepancy ~ 2.7 x 10^{-3}] than those at thr surface [discrepancy ~ 1.3 x 10^{-2}]. Translated into temperature for the n-octane droplet, the disagreement for the core value is about 5.6K (~1.5%) while for the surface this value rises to 27K (~7%). Moreover the results concerning the diameter evaluations show that the discrepancy between the real value and that obtained by means of the data-inversion algorithm is, at maximum, 5%.