Measurement of bi-component droplet vaporization using Global Rainbow Refractometry.

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Abstract

It is well known that, for a bi-component droplet, both the composition and the temperature modify the refractive index of the liquid. Therefore, the rainbow angle can't be used accurately to determine the temperature of the droplets as long as the composition is unknown.

We propose to improve the measurement accuracy by coupling the experimental and computational approaches. Firstly, Global Rainbow Refractometry technique is used to measure the mean refractive index of the droplets. Secondly, the droplet's composition is estimated by numerical simulation. Finally, the application of the Lorentz-Lorenz mixture law for refractive index yields the droplets mean temperature.

Introduction.

Rainbow phenomenon appears when droplets cross an incident parallel laser beam. Global Rainbow Refractometry technique consists of analyzing the interference patterns diffused by such a lighted cloud of droplets. The rainbow optical signal is acquired with a CCD sensor placed at the specific rainbow angle. The value of this scattering angle (Figure 1) is function of the droplets refractive index. From the optical signal, the droplets mean refractive index is determined using an inversion code.

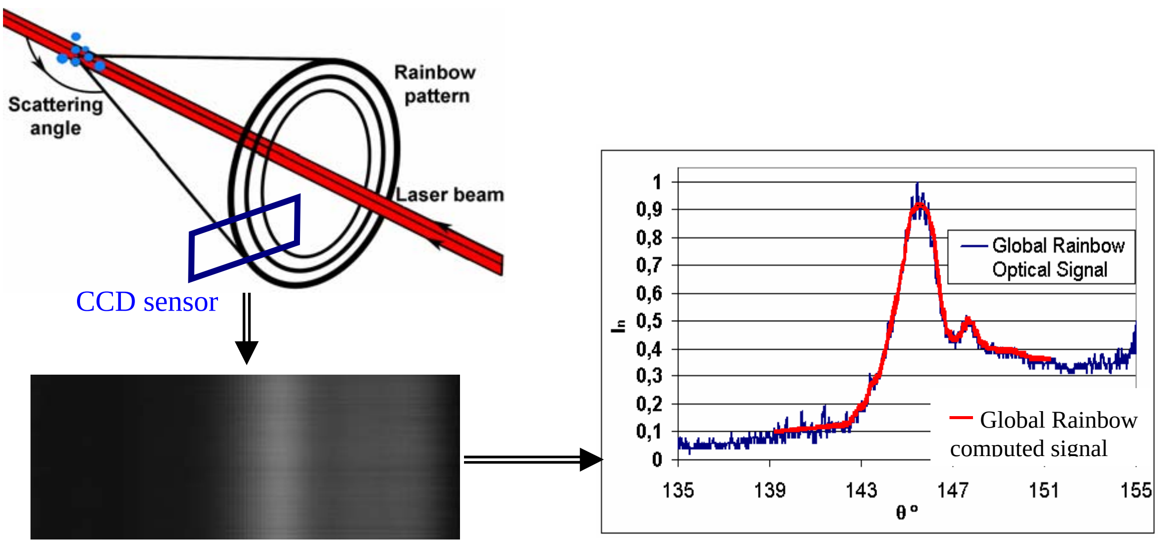

Figure 1. Global Rainbow Refractometry principals.

The accuracy of this measurement technique was largely proved for monocomponent liquids both for non-volatile and volatile liquids [1]. However, there are practical limitations and concerns with such a refractometer system. During the heating or cooling phases, the presence of thermal gradient inside the droplet involves important measurement errors [2,3]. Besides, the sensor can be only sensitive to droplets greater than a certain diameter if the intensity of the laser beam is too weak. To fix this problem, the light intensity of the rainbow signal and the influence of the receiving optical system need to be estimated [4].

Additional limitations appear when multi-component droplets are investigated. During the vaporization process, the mass fraction could change significantly because of the different components volatility. In this case, the measurement of the droplet temperature is difficult to be achieved with a Rainbow Refractometry Technique because the droplet composition is unknown. Up to now, two hypothesis were considered to overcome this problem. The first one assumes that, for a high evaporating droplet, the vaporization rate is much greater then the mass diffusion inside the droplet [5]. Thus, the mass fractions of components will remain unchanged during the

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whole vaporization process, equal to the initial one. The second hypothesis concerns the components properties. In order to avoid the refractive index variation with the mass fraction, the liquids are supposed to have the same refractive index. Of course, such an assumption is valid for liquids with close refractive index.

Materials and Methods

The goal is to measure the temperature of the bi-component droplets in an evaporating spray in stagnant air. This is carried out using the Global Rainbow Refractometry technique. Additional information about the droplets (size and velocity) is obtained with a PDA system. An experimental setup was developed and it was largely described in previous communications [1,6].

The main idea is to use a numerical simulation of the spray to estimate the variation of the droplet composition. This is performed with the multi-physical code CEDRE developed at ONERA. Two-dimensional RANS simulations are performed using a Lagrangian approach.

Results and Discussion

A mixture of n-octane and 3-pentanone is used. For pure n-octane and a mixture of n-octane with 15% 3-pentanone, the refractive index was measured with a multispectral refractometer available in the laboratory. For different other concentrations, the relationship between the temperature and the refractive index is obtained with Lorentz-Lorenz correlation [7].

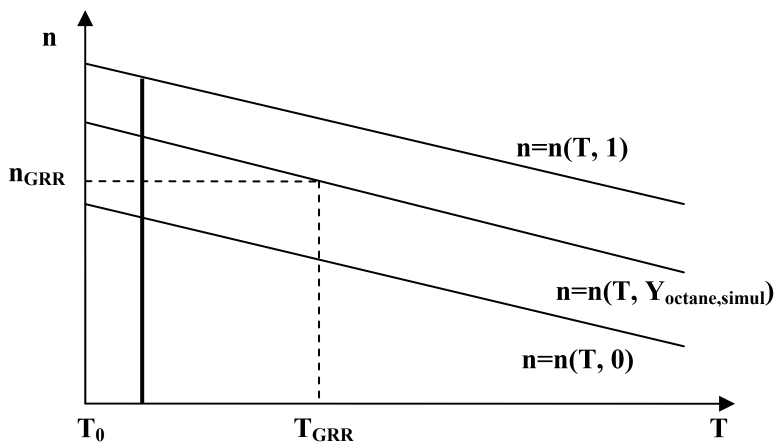

Figure 2. Refractive index evolution as a function of the temperature for different composition of the droplets.

To improve the GRR technique precision the following method is proposed. Since the refractive index $\mathbf{n_{GRR}}$ is measured with the GRR technique and the mass fraction of the n-octane ($\mathbf{Y_{octane,simul}}$) is computed, the graph directly gives the temperature of the bi-component droplets, without considering the two previous hypothesis.

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Nomenclature

GRR Global Rainbow Refractometry
PDA Phase Doppler Anemometry

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