International Journal of Thermal Sciences 50 (2011) 1181–1190

Contents lists available at ScienceDirect

International Journal of Thermal Sciences

journal homepage: www.elsevier.com/locate/ijts

Internal temperature distributions of interacting and vaporizing droplets

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ARTICLE INFO

Article history:
Received 2 July 2010
Received in revised form
6 January 2011
Accepted 6 February 2011
Available online 15 March 2011

Keywords:
Droplets
Evaporation
Combustion
Temperature measurements
Convection

ABSTRACT

A line of mono-sized and periodically spaced droplets is moving in the diffusion flame sustained by the droplet fuel evaporation. The temperature field within the droplets is measured with the help of the two-color laser-induced fluorescence technique. Experiments are undertaken on droplets made of different fuels including acetone, ethanol, 3-pentanone, *n*-heptane, *n*-decane and *n*-dodecane which have different physical properties such as their volatility and their viscosity. In some cases, the isotherms appear circular and concentric suggesting that only thermal conduction occurs in the droplet. In other cases, measurements show rather significant temperature differences between the leading and the trailing edges of the moving droplets. A simplified model of the heat transfer within the droplet is developed, taking into account both heat conduction and heat advection by the droplet internal fluid circulation. Heat and mass transfer are described in a quasi-steady approach within the framework of the film theory. The internal velocity field is assumed to correspond to the spherical Hill vortex solution, so that the velocity can be related to the stress exerted on the droplet surface. Comparisons between the measurements and the simulations reveal that the heat convection inside interacting droplets is strongly reduced, compared to the model of the isolated droplet.

1. Introduction

The importance of spray combustion in many industrial applications like turbojets, or direct injection Diesel engines is well-known. Modeling of spray evaporation is required to optimize combustion chambers performances and to reduce pollutant emissions. As a fuel droplet enters in the overheated environment of the combustion chamber, the droplet is heated and evaporates. The fuel vapor mixes with the atmospheric dioxide, burns and finally heat is released. The accuracy of the simulation tools in this field is highly related to the level of knowledge placed in the description of the elementary phenomena. Spray evaporation has been studied for several decades. In many studies, simplified models for the transient heating of the droplets are used in which the droplet is considered as isolated with uniform transfer coefficients and surface temperature, i.e. spherical symmetry is assumed. Widely used models include [1–3]:

- The 'rapid mixing limit' model which considers that the temperature is uniform in the whole droplet although it may vary in time.
- The 'conduction limit' model which assumes that the heat is transferred in the droplet solely by thermal conduction and that the surface temperature is uniform.

These models are two extremes. In fact, the temperature field within a droplet is not systematically a pure radial one. It results from combined conduction and advection by internal liquid circulation due to the friction at the droplet surface [4,5].

A more physical but still simplified model, is the 'Hill vortex' model, which supposes that the velocity field inside the droplet is given by a Hill vortex. This approach first introduced by Kronig and Brink [6] was used successfully in many research works to describe heat and mass transfers in moving droplets [7–10]. The velocity in the vortex can be related to the friction drag coefficient [7]. However, in the presence of evaporation and wake effects induced by neighboring droplets, no model is currently able to predict accurately the friction force acting on the surface of droplets and very few experimental data are also available in the literature. In an experimental study, Castanet and Lemoine [11] recently measured the temperature field within the ethanol droplets of a monodisperse stream in combustion. They compared experimental temperature distributions with numerical simulations in terms of friction drag coefficient. They found that this latter was significantly reduced (by approximately 90%) compared to the case of an isolated droplet. However, their analysis was based on a very limited number of experimental cases (only three). This paper is a continuation of this early work.

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doi:10.1016/j.ijthermalsci.2011.02.001