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Multi-component droplet heating and evaporation: Numerical simulation versus experimental data

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ABSTRACT

The earlier reported simplified model for multi-component droplet heating and evaporation is generalised to take into account the coupling between droplets and the ambient gas. The effects of interaction between droplets are also considered. The size of the gas volume, where the interaction between droplets and gas needs to be taken into account, is estimated based on the characteristic thermal and mass diffusion scales. The model is applied to the analysis of the experimentally observed heating and evaporation of monodispersed n-decane/3-pentanone mixture droplets at atmospheric pressure. It is pointed out that the effect of coupling leads to noticeably better agreement between the predictions of the model and the experimentally observed average droplet temperatures. In most cases, the observed droplet temperatures lie between the average and central temperatures, predicted by the coupled solution. For the cases reported in this study, the observed time evolution of droplet radii cannot be used for the validation of the model. It is pointed out that the number of terms in the series in the expressions for droplet temperature and species mass fraction can be reduced to just three, with possible errors less than about 0.5%. In this case, the model can be recommended for the implementation into computational fluid dynamics (CFD) codes and used for various engineering applications, including those in internal combustion engines.

1. Introduction

The problem of modelling multi-component droplet heating and evaporation is a long-standing one, and has been widely discussed in the literature (e.g. [1–8]). A new simplified model for bi-component droplet heating and evaporation was suggested in [9]. This model is based on the analytical solutions for heat conduction and species diffusion equations inside droplets, which are incorporated into a numerical code. The results of calculations were validated against experimental data obtained at the University of Nancy (France).

Although the model, suggested in [9], was recommended for incorporation into computational fluid dynamics (CFD) codes, there are still a number of issues which need to be addressed. The original model of [9], took into account the effect of ambient gas on droplets but ignored the effects of droplets on gas. Furthermore, the issue of optimisation of the code was not addressed in [9]. The choice of the number of terms in the analytical solution was based exclusively on the numerical values of the ignored terms, without taking into account the computational cost. These two issues will be addressed in this paper. Also, the model suggested in [9] will be generalised to arbitrary number of species and validated against experimental data different from those used in [9]. The new analytical solution for species was given in [9], without showing the details of the derivation. Since these details are not trivial, they are reproduced in this paper.

As in [9], we will assume that the surface of the droplet remains spherical (see [10–12] for modelling the time evolution of the droplet surface using the Volume of Fluid methodology), and its radius remains constant during the time step (this assumption was relaxed in the most recent papers [13,14]).

Basic equations and approximations are briefly summarised in Section 2. Our approach to the coupled solution and the numerical algorithm are described in Sections 3 and 4. Section 5 is focused on

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