INTRODUCTION TO SPRAY COMBUSTION MODELLING

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I INTRODUCTION

The combustion of sprays takes place in many industrial devices, Diesel and rocket engines, turbojet combustion chambers, burners. Situations where a flame is propagating through a spray of fuel droplets dispersed into the air also are of interest for security problems.

The spray, which contains droplets dispersed within a gas mixture, is a random medium, not only because the droplets are usually moving around with random, turbulent, velocities, but also because there are many droplets of different sizes randomly distributed. It may be considered as a continuous medium like a mixture of gases. The first studies devoted to the modelling of such a medium have assumed a single velocity for it ; the name of "locally homogeneous spray" (LHS) has been given to this assumption (see Faeth [1]). But now the studies represent this medium with two velocities, one for the droplets and one for the gaseous medium, or with several velocities depending on the size of droplets, and even with many different velocities for each elementary class of droplet.

There are many problems connected with this modelling. The first one is the derivation of the basic balance equations, either with a purely Eulerian point of view, or with a mixed Lagrangian-Eulerian approach ; a formalism involving probability density functions or distribution functions has also been used sometimes. Further problems arise in order to precise terms in these equations that model the interactions between the two phases. The dispersion of the droplets within the gaseous medium, the influence of the liquid phase on the turbulence of the gas, are also to be modelled. Finally, the combustion of gaseous phase in the vicinity of droplets, taking into account the gases coming from the vaporization of droplets, needs very often a specific modelling, in order to take into account the small scale non homogeneities, due to the presence of droplets, that perturb the local field of temperature and concentration.

All these problems are not yet solved, and even, the state of the art cannot be described in this paper. This paper is only an introduction to the subject, and will be organized as follows :

- The first section deals with the combustion of a single droplet of fuel in an ambient oxidizing atmosphere. The simple quasi-steady theory, well-known but necessary for a basic understanding, will be given, and corrections to this theory will be described.

- The second section is a physical description of the fine structure of flames in sprays, either for a "premixed spray" (with fuel droplets and gaseous oxidant) or for a "non premixed spray flame" (between a stream of fuel droplets and vapour and a stream of gaseous oxidant).

- The third section gives the basic equations for the spray, in the Eulerian form for a "two velocities approach", or in Eulerian-Lagrangian form. The problems arising due to the interaction terms will be emphasized, and references will be given, but without any detailed discussion of the existing models. A little bit more emphasis will be put on the reaction term, that will give the volumetric rate of consumption of droplets in a given volume of spray.

- The fourth section finally presents some typical results of calculations, showing the most advanced capabilities available.

II <u>Single droplet combustion theory</u>

The first "quasi-steady theory" has been developed during the fifties, by Godsave [2] and D.B. Spalding [3]. Many experiments have been done so far, which confirm partially the relevance of such a theory (see in particular Kumagaï [4]). A departure from the basic assumption of this theory is very often necessary, and so several modifications of the basic formulae coming from the "quasi-steady theory" have been proposed and verified.

<u>II.1 The quasi-steady theory</u>

The quasi-steady theory really deals with a spherical droplet that is continuously feeded in its center in such a way that its radius remains constant while it is continuously evaporating and burning. In this case the flow and thermochemical fields around the droplet is sketched Fig. 1. The problem is specially symmetric if the gravity force is neglected, and if the gaseous medium it supposed at rest at infinity ; these basic assumptions are indeed used in the theory, and the flame around the droplet, separating the inside mixture of fuel vapours and combustion products from the outside mixture of air and products, is perfectly spherical.

Other assumptions, of less importance, are also used : - the chemical reactions, that occur in gaseous phase only, are represented by a single very fast reaction - the gas velocities are sufficienty low in such a way that the pressure can be assumed constant all around the droplet. - The temperature inside the droplet is perfectly uniform, in such a way that all the heat received by the droplet serves to the