QUENCHING DISTANCE AND LAMINAR FLAME SPEED IN A BINARY SUSPENSION OF SOLID FUEL PARTICLES

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Abstract — A mathematical combustion model of non-adiabatic dust flame is developed for a suspension of two monosize metal powders. Depending on the combustion properties of particles at different concentrations, the flame structure may display either an overlapping or a separated configuration. In the present study the heat loss term, which is assumed to be linearly proportional to temperature difference, is added to the energy conservation equation. The laminar flame speed and quenching distance are obtained by solving the energy equation in each zone and matching the temperature and heat flux at the interfacial boundaries. Calculated values of flame speed adequately agree with experimental data.

Keywords — Dust Combustion – Binary Suspension – Non-Volatile Solid – Laminar Flame Speed – Quenching Distance.

Nomenclature

\( a \) — thermal conductivity of gas, \( m^2s^{-1} \)
\( B \) — dust concentration
\( c_p \) — specific heat of gas
\( c_s \) — specific heat of solid
\( d \) — diameter of the quenching channel
\( m \) — mass of particle
\( p \) — combustion time ratio of the second dust to the first dust
\( Q \) — heat of reaction per unit mass of fuel
\( Nu \) — Nusselt number, \( \alpha d / a \)
\( r \) — particle radius
\( T \) — temperature
\( v \) — flame speed
\( W_f \) — heat source term
\( x' \) — spatial coordinate
\( x \) — independent variable that is related to the spatial coordinate \( x' \) as \( x' = \int_0^x (\rho / \rho_s)dx \)
\( y \) — nondimensional coordinate
\( Z \) — distance between two combustion zones

Greek Symbols

\( \alpha \) — heat transfer coefficient between gas and channel walls
\( \phi \) — equivalence ratio
\( \eta \) — heat loss parameter
\( \kappa \) — nondimensional flame speed
\( \lambda \) — heat transfer coefficient, \( a.\rho.c_p \)
\( \mu \) — nondimensional dust concentration
\( \theta \) — nondimensional temperature, \( T / T_u \)
\( \rho \) — density
\( \tau_c \) — combustion time of individual separated particle at initial oxygen concentration
\( \xi \) — ratio of the characteristic particle heat exchange time and combustion time of the particle

Subscripts

\( g \) — gas
\( i \) — conditions at ignition points
\( st \) — stoichiometric
\( s \) — solid fuel particles
\( u \) — characteristics of unburned mixture at \( x = -\infty \)

I. INTRODUCTION

Because of their high combustion enthalpy, metal powders are often used as additives in propellants, explosives, or pyrotechnics. The combustion stability in rocket engines has also been improved by the addition of metal powders to propellants (Markstain, 1963; Gordon et al., 1968). Natural and industrial combustible dusts mostly have a wide domain of particle size distribution. Given that the ignition temperature and combustion rate of an individual dust particle are functions of particle size, real dust suspensions have a complex, multistage flame structure. Research on multistage dust combustion was initiated by Goroshin et al. (2000) who theoretically and experimentally investigated the combustion of a suspension of two monosize powder. They developed a simple analytical model for the adiabatic flame in a fuel-lean binary suspension, which permits the analysis of flame speed and structure as a function of the dust composition and combustion properties of individual particles. In the experimental section of the study, the flame speed in a binary suspension of aluminum and manganese powders was investigated by observing the laminar stage of flame propagation in a semi-open vertical tube. Their proposed model correctly predicted dependence of the flame speed on mixture composition (mass ratio of manganese and aluminum dusts in suspension) and the mixture composition at the limit of flame propagation (Goroshin et al., 2000). This