An experimental investigation of the interaction of swirl flow with partially premixed disk stabilized propane flames

C. Xiouris, P. Koutmos

Laboratory of Applied Thermodynamics, Department of Mechanical and Aeronautical Engineering, University of Patras, Patras 26500, Greece

A R T I C L E   I N F O
Article info:
Article history:
Received 16 October 2010
Received in revised form 26 January 2011
Accepted 24 February 2011
Available online 1 March 2011

Keywords:
Turbulent propane flames
Annular jet flows
Swirl burner
Partially premixed flames
Lean combustion

A B S T R A C T
The present work describes the experimental investigation of reacting wakes established through fuel injection and staged premixing with air in an axisymmetric double cavity arrangement, formed along three concentric disks, and stabilized in the downstream vortex region of the afterbody. The burner assembly is operated with a co-flow of swirling air, aerodynamically introduced upstream of the burner exit plane, to allow for the study of the interaction between the resulting partially premixed recirculating afterbody flames with the surrounding swirl. At low swirl the primary afterbody disk stabilizes the partially premixed annular jet in the downstream reacting wake formation region. As swirl increases, a system of two successive vortices emerges along the axis of the developing wake; the primary afterbody vortex is cooperating with an adjacent, swirl induced, central recirculation zone and this combination further promotes turbulent mixing in the hot wake.

Complementary measurements of the counterpart isothermal turbulent velocity fields provided important information on the near wake aerodynamics under the interaction of the variable swirl and the double cavity produced annular jet stabilized by the afterbody. Under reacting conditions, measurements of turbulent velocities, temperatures and statistics together with an evaluation of the exhaust emissions were performed using LDV, thin digitally-compensated thermocouples and gas analyzers. A selected number of lean and ultra-lean flames were investigated by regulating the injected fuel and the air supply ratio, while the influence of the variation of the imposed swirl on wake development, flame characteristics and emission performance was documented for constant fuel injections. The differences and similarities between the present partially premixed stabilizer and other types of axisymmetric configurations are also highlighted and discussed.

1. Introduction

Recirculation regions are frequently employed within the reaction zone of combustion systems to control fuel–air mixing, promote flame stabilization and target performance over a wide range of operating conditions [1,2]. Bluff body geometries have proved popular arrangements in providing such recirculations, whereby a reaction front anchors close to a region of entraining flow with large-scale engulfment of fuel and air (in the case of non-premixed flames) or fresh mixture and hot products (premixed case) followed by fine scale mixing within reasonable residence times [1,3–6]. Challenges in bluff body combustion configurations such as the effects of organized eddy flow/flame structure interactions, fuel injection and air placement on stability, heat release and emissions have been addressed both experimentally and computationally for non-premixed [1,7,8] and fully premixed flames [6,9].

Swirling motion on the other hand is an equally relevant method traditionally employed to induce intense flow reversals and flame stabilization in practical systems. Plane swirl can be regulated to create a free standing central recirculation zone with proven aerodynamic flame holding characteristics, while in combination with a central bluff body swirl allows for further intensification in mixing rates and improvements in flame anchoring effectiveness [10–12]. A variety of swirl flame configurations have been exploited as a research tool in both experimental [10,11,13] and computational [14–16] investigations related to studies of strong turbulence/chemistry interactions, flame stability and emissions reduction, under both premixed and non-premixed conditions.

Rising environmental concerns however are placing even stricter controls on pollution from high efficiency/high intensity industrial systems leading combustion technology to its limits. Driven by regulation the exploitation of lean or partially premixed combustion [17,18] has emerged as an important and promising