EXPERIMENTAL AND NUMERICAL INVESTIGATION OF A FLAMELESS OXIDATION COMBUSTOR

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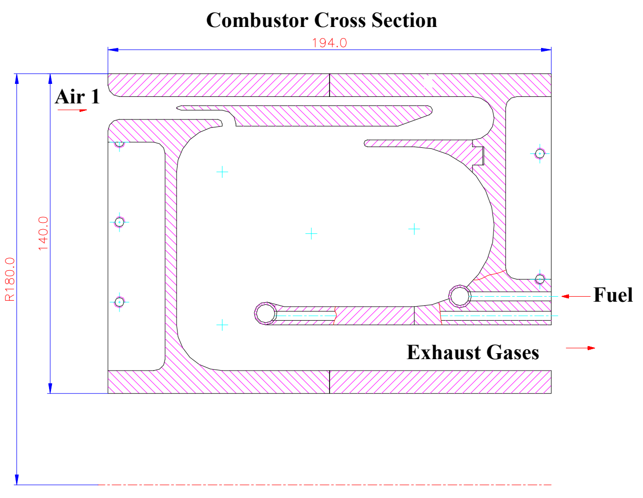
Summary The flow characteristics of a combustor model under non-reacting conditions have been experimentally and numerically investigated using LDA and the Fluent code, respectively. Data is reported for mean and turbulent velocities as a function of the air mass flow rate. The isothermal flow characterization was followed by combustion measurements at the exit of the combustor model. Measurements and predictions of gas species concentration are reported as a function of the equivalence ratio and thermal input.

INTRODUCTION

Flameless oxidation is a combustion regime identified about one decade ago and characterized by strong internal gas recirculation, relatively low temperature in the reaction zone, which occupies a large volume rather than exhibiting a flame front, no visible flame, and very low NO_x emissions and noise. This work describes an experimental and numerical investigation of a new combustor designed to operate in this combustion regime.

EXPERIMENTAL FACILITIES

Figure 1 shows a schematic of the combustor model. Prior to the combustion experiments, the isothermal flow in the combustor model was characterized by the application of Laser-Doppler Anemometry (LDA). Under reacting conditions, the gases for the measurement of the flue-gas data (O_2, CO, CO_2, hydrocarbons (HC), and NO_x concentrations) were extracted using a water-cooled stainless steel probe. The analytical instrumentation included a magnetic pressure analyzer for O_2 measurements, non dispersive infrared gas analyzers for CO_2 and CO measurements, a flame ionization detector for HC measurements, and a chemiluminescent analyzer for NO_x measurements.



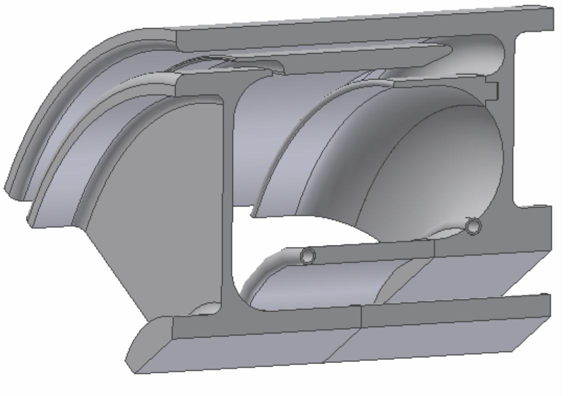


Figure 1. Schematic of the Combustor Model

MODELLING

The flow field was numerically simulated using the Fluent commercial code. Turbulence was simulated using either the k-ε model or the Reynolds stress model. In the case of a reactive flow, the laminar flamelet model along with an assumed probability density function was employed for combustion modelling. The NO emissions were predicted using a post-processor module based on the solution of a transport equation for the mass fraction of NO with the source term accounting for the thermal and prompt mechanisms of NO formation and for the turbulent fluctuations.

RESULTS AND DISCUSSION

Experiments under non-reacting conditions

Figure 2 shows the effect of the flow rate of Air 1 (see Fig. 1) on the mean flow structure and reveals that a common feature to all test conditions is the establishment of a large recirculation zone and that the mean velocities increase within the recirculation zone as the Air 1 mass flow rate increases.

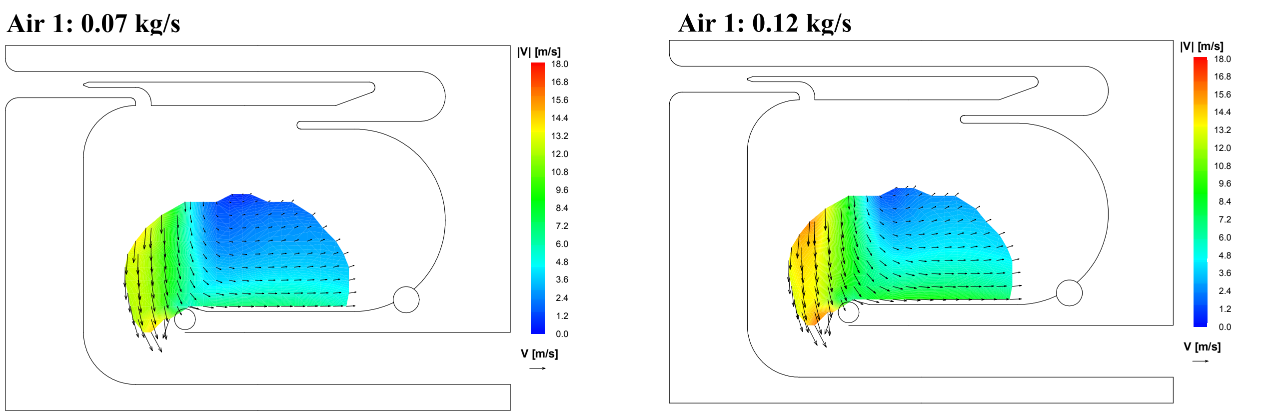


Figure 2. Effect of the Air 1 Flow Rate on the Mean Flow Structure

Experiments under reacting conditions

Figure 3 shows the measured flue-gas data for the combustor as a function of the equivalence ratio and of the thermal input. The figure reveals that combustion efficiency is highest (about 90%) for both low values of thermal input as well as of equivalence ratio. It is interesting to note that NO_x emissions are very low over a large range of the combustor operating conditions.

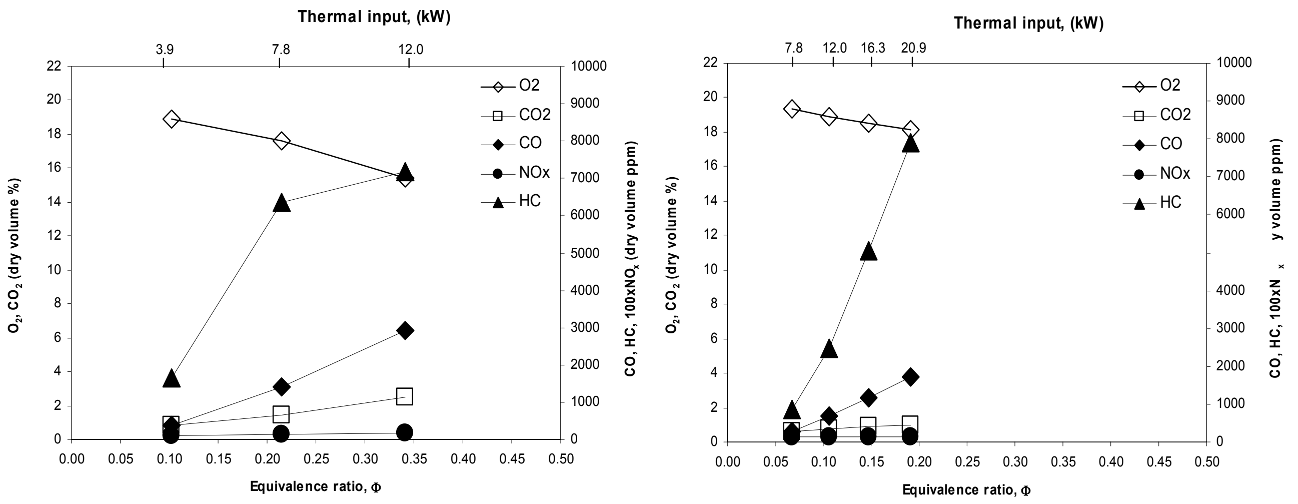


Figure 3. Measured volumetric fractions of species at the combustor exit.

CONCLUSIONS

The flow characteristics of a combustor model under non reacting conditions were investigated using Laser-Doppler Anemometry. Data is reported for mean and turbulent velocities as a function of the air mass flow rate. The main conclusions are as follows: i) a common feature to all test conditions is the establishment of a large recirculation zone and ii) mean and turbulent velocities increase within the recirculation zone as the air mass flow rate increases. The computational simulation correctly predicts these trends. The isothermal flow characterization was followed by combustion measurements at the exit of the combustor model. Measurements of mean gas species concentration (O_2, CO_2, CO, HC and NO_x) are reported as a function of the equivalence ratio and thermal input. The main conclusions are as follows: i) combustion efficiency is highest (about 90%) for both low values of thermal input and equivalence ratio, ii) NO_x emissions are very low over a large range of operating conditions and iii) the predicted concentrations of O_2, CO_2 and CO are in agreement with the experiments, but only qualitative agreement was found for the emissions of HC and NO_x.

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