Flame stabilization in a porous burner at the interface of two sections of alumina spheres

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Abstract: - Development of porous burners has been encouraged by lower emissions standards as well as highly efficient characteristics. In this work, a method of flame stabilization in a porous media burner with a double section of alumina spheres is reported. The stable operating limits are predicted for a range of gas velocity and equivalence ratio. These limits allow the creation of the porous media permanent combustor by two different zone distinguished by the diameter of the alumina spheres. Temperature profiles and chemical products compositions were measured whose results confirm the hypothesis of the front combustion stabilization in the interface between two sections of alumina spheres.

Key-Words: - Flame stabilization, Combustion in porous media, Porous burner

1 Introduction

In the last few decades, porous media burners have shown lot of promise over the conventional burners. The advantages of porous media burners are high power density, reduced NO_X and CO emissions, very wide power range, combustion stability over wide range of equivalence ratio and high thermal efficiency. All the arguments mentioned above are driving the current development of these kinds of burners which have already found several important industrial applications [1,2]. The problem of gas combustion in inert porous media has been studies intensively both theoretically and experimentally, and the most important results have been summarized [3,4].

One of the more important problems of porous media burners is flame stabilization in a specific zone of the inert porous medium. It is also important for the static combustion flame have some characteristics to be able to maximize the efficiency of the burner and minimize CO and NO_X emissions [1]. For that purpose four different flame controls method have been developments. One method considers the formation of two layers of the porous medium in which the modified Peclet number is less than (first layer) or greater than (second layer) 65 [1,5]. The second method considers cooling of the second layer [6]. The third method allows retaining the flame in a specific zone of the porous medium by means of a periodic exchange of the mixture inlet and the exhaust of the combustion gases [7, 8]. Finally, the fourth method of flame stabilization employs a porous body with non-constant cross sectional area [9].

There is no doubt that two-layer porous media burners are progressing most rapidly in their development and industrial application [7-9]. They were formed by two layers of: a) two reticulated ceramics with different pore sizes [5] or b) one reticulated ceramic and one layer of alumina balls [7]. Hence, these layers have different physical properties, including porosity. In [5] performed a numerical study of the effects of material properties (ceramic foams) on flame stabilization in a two-section porous burner. They examined the effects of solid conductivity, volumetric heat transfer coefficient, and radiative extinction coefficient. They concluded that the material properties of the solid matrix significantly affect the stable operating range. However, the material employed for simulation in the present work was alumina spheres, in contrast with ceramic foams which in practice suffer thermal and mechanical shock in these types of burners, implying the need for their periodic replacement.

The present study investigates gas velocity and equivalence ratio stability ranges of an adiabatic combustion wave in a porous media burner composed of two sections of alumina spheres with diameters of 2.5 and 5.6 mm, and the estimation of the optimum operating conditions, for the resulting permanent burner, as a function of the reduction of NO_X and CO emissions.

2 Experimental apparatus

Fig. 1 shows the experimental apparatus able to work with both 2.5 mm (downstream of the porous solid) and 5.6 mm (upstream of the porous solid) diameters of alumina spheres. It consists of four main components: porous heating burner, a fuel and air supply system, a temperature measurement system, and gas emission analyzers. Burner is a quartz tube with internal diameter of 38 mm and wall thickness of 2 mm. The methane/air mixture was prepared by a continuous flow method where the concentrations were monitored using Omega mass flow controllers. The quartz tube is filled with a randomly packed of spherical alumina pellets, it had a porosity of approximately 40%. The inner surface of the combustion tube was covered with a 2 mm layer of Kaowool insulation. To minimize heat losses additional 30 mm thick high-temperature insulation was applied on the external diameter of the reactor.

Premixed methane/air mixtures were introduced into the reactor through the distribution grid at the reactor bottom. During the experiments, the combustion was started at the reactor outlet with 6 l/min for ϕ=1.0. Then upstream propagation was recorder. As the wave reached the interface between two sections of alumina spheres the experimental conditions where adjusted to find experimental stabilization ranges for compositions of ϕ=0.6 and ϕ=0.7.

Running axially in the centre of the quartz tube was a ceramic shell of 0.32 cm outer diameter and 56 cm long. The shell contained six holes of 0.08 cm diameter each holding an S-type (platinum/rhodium) thermocouple. Temperature measurements from these thermocouples were transferred to a PC where they were digitized using a personal data acquisition DAQ/56. The thermocouple junctions were equally spaced along the length of the shell, with the bottom one being 13 cm away from the gas inlet. The completely covered by ceramic material junctions recorded temperatures very close to the temperatures of the solid phase.

CO and NO_X emissions were measurement by the gas analyzer Horiba PG 250 at the exit zone of the reactor.

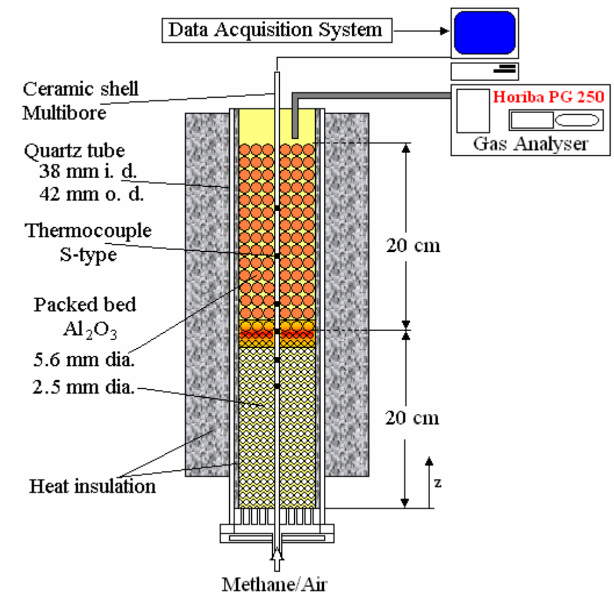

Fig. 1. Schematic of the experimental setup.

3 Results and discussion

Data were collected at equivalence ratio of ϕ=0.6 and ϕ=0.7, and flow ranging from 6.91 l/min to 19 l/min. Solid phase temperatures as well as CO and NO_X product emissions were measured and the flame stabilization was obtained considering 20 min without evolution change of temperature profiles.

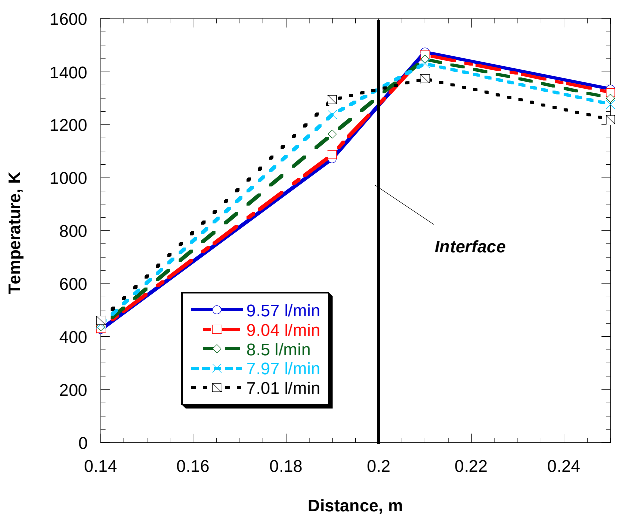

Fig. 2. Static temperature profiles for ϕ=0.6.

3.1 Temperature profiles

The solid temperatures of a flame stabilized in a porous burner are shown in Fig. 2 for different volumetric flow rates and an equivalence ratio of ϕ=0.6. The flame is located at the interface between the two sections of alumina spheres. Downstream from the reaction, a moderate increase in the maxima temperatures without considerable modifications in the shape of the profiles. The maximum temperature reach in average for the case ϕ=0.6, 1474 K. Downstream from the reaction, the solid temperature decreased with increased of volumetric flow rates.

For the case of ϕ=0.7, maximum and minimum stable volumetric flow rates were identified. The solid temperature profiles at the minimum and maximum stable volumetric flow rate at an equivalence ratio of 0.7 are shown in Fig. 3. At the minimum stable volumetric flow rate (Q_{min} = 12.88 l/min), the flame stabilizes slightly upstream of the interface of the two sections of alumina spheres. At volumetric flow rate lower than 12.88 l/min, the flame propagates through the upstream sections. At the maximum stable volumetric flow rate (Q_{max} = 19 l/min), the flame stabilizes slightly downstream of the interface. At volumetric flow rate higher than 19 l/min the flame propagates downstream and out of the burner. For all the case with ϕ=0.7 the maximum temperature in the reactor reaches to 1675 K.

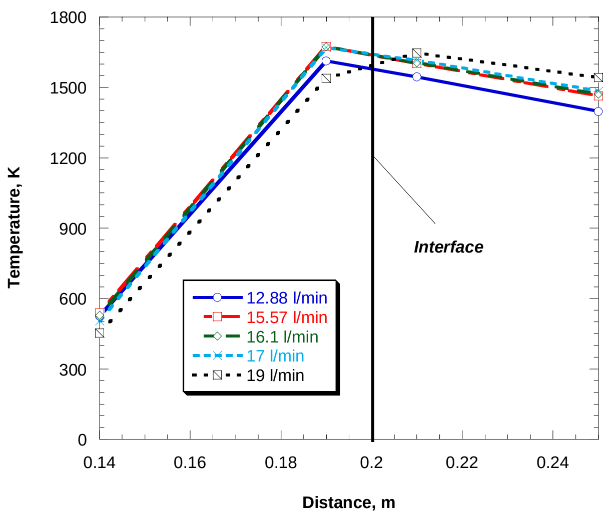

Fig. 3. Static temperature profiles for ϕ=0.7.

3.2 CO and NO_X emissions

The measurement compositions at the burner's outlet are presented in Table 1. With an increase in the flow rate emissions for CO increased and emissions for NO_X decreased, both level of emissions increased with equivalence ratio. For references is shows measured of O_2 concentrations.

Table 1. Pollutants emissions at burner's outlet.

ϕ	Q (l/min)	CO (ppm)	NO_X (ppm)	O_2 (ppm)
0.6	6.91	0	7	9.23
0.6	12.76	0	4	9.23
0.7	15.57	0.3	12.5	6.9
0.7	18.95	1	8.4	7.43

4 Conclusions

In this study, experiments of a flame stabilized at the interface of two sections of alumina spheres were presented. The result for equivalence ratio of ϕ = 0.6 and ϕ = 0.7 showed that flame stabilization occurs for a range of volumetric flow rates. Virtually constant thermal levels of 1470 K and 1670 K for stabilization regions corresponding to ϕ = 0.6 and ϕ = 0.7 respectively, were obtained. Pollutants emissions found were in all cases below 15 ppm for NOx and below 1 ppm for CO.

Acknowledgements: The support of CONICYT – Chile under FONDECYT Project 1050241, and of the Academia Politécnica Aeronáutica de la FACH, Chile, is gratefully acknowledged.

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