STABILIZATION OF TURBULENT PREMIXED FLAMES IN POROUS INERT MEDIA

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Abstract. *In the present work, a new stabilization scheme is proposed for premixed flames within porous media. The stabilization mechanism is based on a pilot flame at the center of the inlet surface of the burner that continuouslly ignites the mais flow of reactants. The objective of this device is to produce high power densities at temperatures required by Low-NOx gas turbines. A porous burner was build with an integrated pilot flame to test this concept. The blow-off limit of the burner was extended in more than 25%. The temperature field inside the porous medium was measured with and without the pilot flame, revealing the flame position for each condition. Emissions of CO and NOx were negligible.*

Keywords: *combustion; porous media; flame stabilization*

1 – INTRODUCTION

Porous burners are equipments used as heat sources for industrial and domestic applications. The mixture of fuel and air is injected inside a porous ceramic matrix, where the combustion reactions occur. The porous matrix promotes the pre-heating of the reactants by radiation and conduction, which brings advantages such as low pollutants emission, high radiant efficiency, higher burning speeds and wider flammability limits when compared to laminar premixed freely propagating flames, (Howell *et al.*, 1996 and Pereira and Oliveira, 2002).

In the present work, a stabilization scheme is proposed to stabilize high power densities flames within porous media. The stabilization mechanism is based on a pilot flame positioned at the center of the inlet surface of the burner. This pilot flame is controlled to work in the laminar regime, with good stabilization characteristics, while the main flow of reactants is controlled to achieve the turbulent regime. The pilot flame aims to promote a continuous ignition of the main flow, anchoring the flame. Therefore, this concept differs from previous works on filtration combustion, where the flame front is not stationary and an ignition system is used to re-ignite the burner when blow-off occurs.

For evaluating the proposed stabilization scheme a porous burner has been build with an integrated pilot flame. Tests were made with and without the pilot flame to evaluate the capability of the device to extend the blow-off limit of the burner. The main objective of this configuration is to allow the production of high power densities at temperatures required by Low-NOx gas turbines. The thermal NOx is avoided by operating the system with lean mixtures, $\Phi = 0.5$, which presents low flame temperatures. The burner is characterized in terms of power density (kW/m^2), turn-down ratio and CO and NOx emissions.

2 – EXPERIMENT

2.1 – Experimental setup

The burner used in the experiments is shown in Fig. 1. The housing consists of a stainless steel tube with flanges connecting it to the feed lines. The porous matrix is formed by four layers of ceramic foams made of Al_2O_3 with 70 mm in diameter, 20 mm thick and 10 ppi (pores per inch). A distribution plate positioned upstream the porous matrix is used to homogenously distribute the reactants flow and to prevent flashback This plate is 25 mm thick and made of an isolating material based on alumina fibers. An alumina blanket wrapped around the porous matrix provides thermal insulation and sealing, preventing gas leakage through the edges of the porous medium. The distinct characteristic of this burner is that it has two different flows of reactants at its inlet surface. The flow in the inner tube corresponds to the pilot flame while the flow in the other tube corresponds to the main flow of reactants.

A schematic representation of the experimental setup is presented in Figure 2. As shown in the figure, the reactants at the pilot flame and at the main flow are premixed before they reach the distribution plate. The combustion air is supplied by an air compressor line and the fuel is provided by natural gas cylinders. The air and gas flows are manually controlled by needle valves and four different flow meters are used to measured the flow of each line. For measuring the two streams of reactants it is utilized four different flow meters as shown in Table 1. For measuring the temperature field inside the burner, R type thermocouples are attached on a support device with radial mobility. This device allows the radial displacement of the thermocouples inside the porous medium. For a CO and NOx exhaust gas analysis, a cooled probe is used with a Motorscan EuroGas 8020 analyzer.

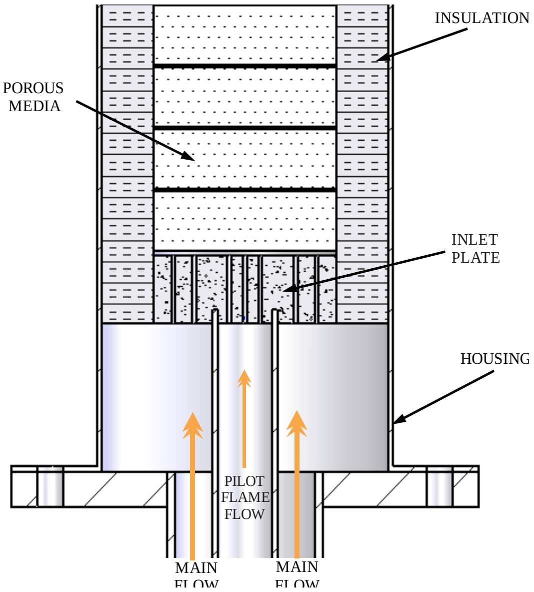

Figure 1 – Porous burner with integrated pilot flame.

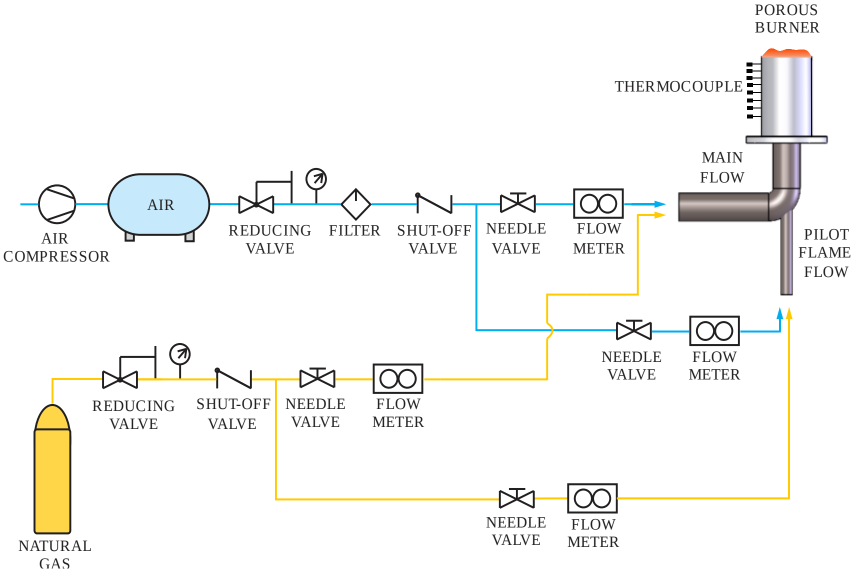

Figure 2 – Experimental set up.

Table 1 – Flow meters.

	Manufacturer	Model	Range (lpm)
Main air flow	OMEGA	FMA – 776-V	0-500
Main fuel flow	OMEGA	FMA – 773A-V	0-50
Pilot flame air flow	OMEGA	FMA 1824	0-20
Pilot flame fuel flow	OMEGA	FMA 5520	0-10

2.2 – Method

The main flow is ignited at the outlet surface of the burner. The flame is made to submerge in the porous matrix and a stable condition is maintained until the burner reaches steady-state. Then, the test condition is imposed and the flame is monitored by the thermocouples. A flame is considered stable if the thermocouples do not show oscillations higher then 10 ºC for more than 20 minutes. The flame blow off is identified when part of the flame gets out of the upper surface of the burner. Flame flash back is assumed when the distribution plate temperature exceeds 1250 ºC, which is the maximum temperature supported by the material of the inlet plate. The equivalence ratio was kept constant equal to 0.5 through the tests. The total flow of reactants was varied to find the stabilization limits of the burner.

Tests with and without pilot flame were made. For the tests with the pilot flame, first, the main flow of the burner is ignited. After achieving a stabilization point, the pilot flame flow is turned on and the pilot flame is stabilized. The pilot flame equivalence ratio and total flow were kept constant equal to 0.8 and 8.31 lpm, respectively. The flue gases at the surface of the burner are analyzed for each stable point. The temperature field inside the burner is measured by radially displacing the thermocouples.

3 – RESULTS

Figure 3 shows the stability range of the burner with and without the pilot flame (PF). It is clear that the pilot flame stabilized higher surface power densities than the standard burner. This means that the proposed stabilization scheme was able to sustain flame conditions that would not be stable otherwise. The maximum power density of the burner with the pilot flame (1234 kW/m2) is more than 25% higher than the maximum power density of the burner without pilot flame (974 kW/m2). On the other hand, the lower stability limit of the burner was increased by the pilot flame. This happens because the pilot flame increases the temperature at the bottom of the burner, reaching the maximum operational temperature of the inlet plate (1250 ºC). The stability range of the burner with the pilot flame is 16% wider then that without the pilot flame.

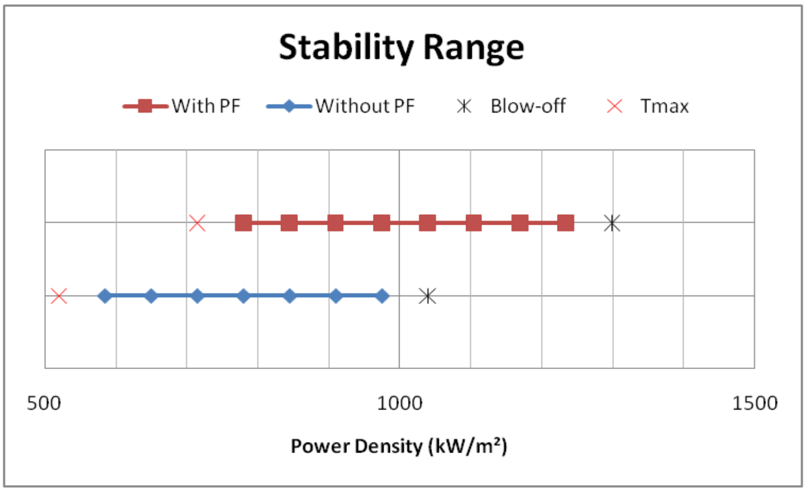

Figure 3 - Stability range of the burner with and without the pilor flame.

Figures 4 and 5 show approximate temperature fields inside the burner for a surface power density of 910 kW/m2 without pilot flame and for 1170 kW/m² with pilot flame. Figure 4 shows a planar flame located near the interface between the first and the second layer of porous ceramic (about 20 mm in height). The heat losses by radiation at the upper surface and by conduction at the insulation layer interface reduce the flue gas temperature at the top and at the side of the porous medium.

Figure 5 shows that for a flame stabilized by the pilot flame higher temperatures are found at the center of the burner as a result of the presence of the pilot flame at the bottom of the burner. On the other hand, for the main stream of reactants the maximum temperature is found at increasing radial distances from the center of the burner, showing that the flame assumes an inverted cone configuration. In this case, the stabilization of the flame is due to the continuous ignition of the main stream of reactants by the pilot flame.

The pollutants measurements did not show differences between the two operational conditions. CO and NOx emissions were not detected in both cases, which mean that their concentrations were below the resolution of the gas analyzer. Low CO emission is a characteristic of porous burners. This is due to the heat recirculation induced by the solid matrix, which increases the flame temperature and enhance the reaction rate. Low NOx emissions are also expected since the low equivalence ratio used in the tests still results in flame temperatures that are low enough to provide negligible thermal NOx formation.

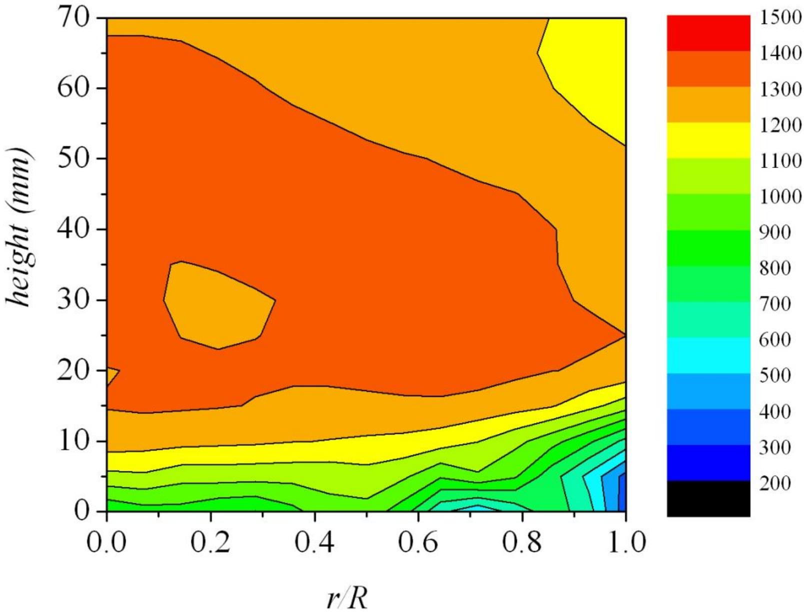

Figure 4 - Temperature field inside the burner without pilot flame

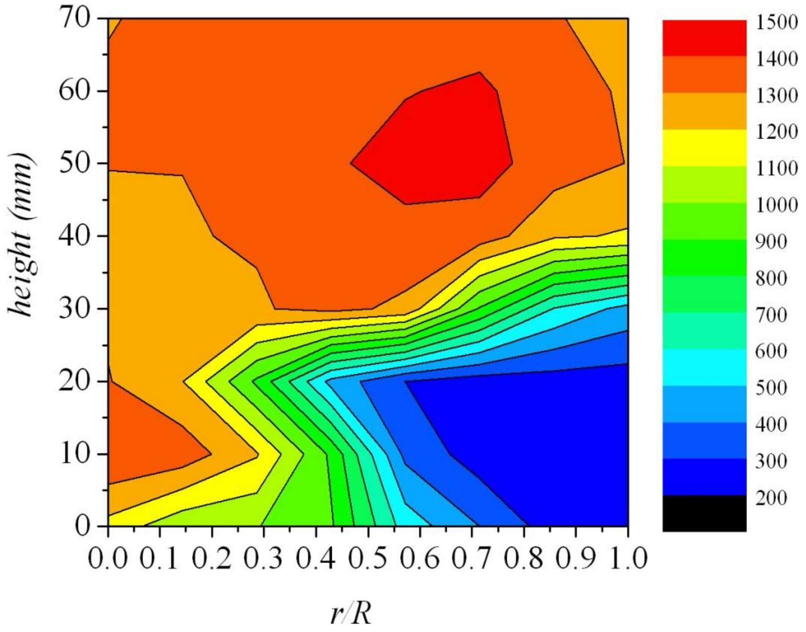

Figure 5 – Temperature field inside the burner with pilot flame

The flow in porous media is characterized by Reynolds numbers Re_p based on the pore characteristic length-scale l_p. For $Re_p < 150$, the flow is laminar, (Kaviany, 2002). The mean (darcyan) flame velocities obtained with the pilot flame ranged from 47 to 75 cm/s, corresponding to 780 kW/m^2 and 1235 kW/m^2 respectively. The respective pore level flame velocities are 58.8 and 93.7 cm/s, taking into account the matrix porosity of 80%. The pore level Reynolds number at the inlet conditions of the flow ranged from 111 to 178. Then, near the inlet surface of the burner the flow may reach the turbulent regime. On the other hand, the pore level Reynolds number at the flame conditions of the flow ranged from 36 to 58. Then, the effect of the flame is to stabilize the flow to a laminar regime. This effect is due to the increase of the gas phase viscosity in the higher temperatures found at the flame.

4 – CONCLUSIONS

This work presented an experimental study of the stabilization of premixed flames within an inert porous medium by a pilot flame. The main results obtained are listed below:

- A significant increase of the blow off limit of the burner (25%) and a wider stability range (16%) were obtained, showing that the pilot flame stabilized flames that would not burn otherwise. Then, the use of a pilot flame allowed the burner to reach higher power densities;
- Emissions of CO and NOx were negligible;
- The measurement of the temperature field inside the solid matrix shows that high power density flames, stabilized by the pilot flame, assumed an inverted cone configuration. This means that the pilot flame promoted a continuous ignition of the main stream of reactants;
- At the cold regions of the burner the flow may reach a turbulent regime and at the hot regions the flow tends to stabilize to a laminar regime.

5 – REFERENCES

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