EXPERIMENTAL STUDY OF THE EFFECT OF THE DISTRIBUTION OF REACTANTS ON THE SUPERFICIAL TEMPERATURE OF RADIANT POROUS BURNERS

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Abstract. *In this work we present a method to control the superficial temperature of radiant porous burners by changing the distribution of reactants at the inlet surface of the porous medium. An inlet plate with a distribution of orifices is used to create a thermal and fluid dynamic mechanism of flame stabilization as described in previous works. Here, the effect of the distribution of the plate orifices on the temperature level and homogeneity at the burner surface is evaluated. Three different inlet plate were tested for equivalence ratios ranging from 0.40 to 0.60. Stable operation points with a surface temperature as low as 655ºC and radiant efficiency up to 53% were achieved.*

***Keywords**: Porous burner, temperature control, distribution plate.*

1. INTRODUCTION

Porous burners have attractive characteristics such as higher burning speeds and leaner flammability limits than open flames, low NOx emissions and high radiant efficiency (Howell *et al.*, 1996; Pereira and Oliveira, 2002). Because of these advantages, porous burners are an interesting option for industrial manufacturing processes that use low grade fuels and require low levels of pollutant emissions.

In porous radiant burner, the surface temperature is usually controlled by reducing the total reactants mass flow rate or by decreasing the equivalence ratio. However, these methods are limited by the burner stability and flammability ranges. Typical porous burners will not burn methane-air mixtures for equivalence ratios smaller than 0.40. At this equivalence ratio the surface temperature of stable flames ranges from 1100K to 1200K (Pereira *et al.*, 2005), being still too high for applications such as the cure or thermal forming of polymeric materials.

The use of a distribution plate at the inlet of porous radiant burners is a known well used strategy to evenly distribute the reactants at the burner inlet surface and to create a fluidynamic mechanism for flame stabilization (Catapan *et al.*, 2011). In these when the average velocity of the flow of reactants is decreased, maintaining the equivalence ratio constant, the flame moves upstream to a position closer to the plate orifices. In this region, the unburned gas velocity is higher and a new stable position is found where the gas velocity equals the flame propagation velocity.

The use of the distribution plate leads to an alternative choice to reduce the surface temperature and total power of radiant burners. The strategy presented here consists in reducing the number of orifices of the distribution plate while keeping a constant reactants velocity at the orifices. In this way, the total mass flow of reactants is reduced, while the burning conditions for the flame near each orifice is maintained practically unchanged.

The objective of this work is to study the temperature control of porous radiant burners by changing the distribution of reactants at the inlet surface of the porous medium. Different configurations of the inlet plate are evaluated. The results show that this strategy is adequate to improve the temperature control of radiant burners, extending the applicability of these devices to processes that require low temperatures.

2. EXPERIMENTAL SETUP

An experimental setup was built to test porous burners as illustrated in Figure 1. The combustion air is supplied by an air compressor and the fuel is provided by natural gas cylinders. The air flow rate is manually controlled by a needle valve and measured with a mass flow meter Omega FMA 776-V in a range between 0 and 500 lpm. The natural gas flow rate is also controlled by a needle valve and measured with a mass flow meter Omega FMA 773-A in a range of 0 to 50 lpm. Air and natural gas are mixed prior to enter the burner. Electrodes placed 15 mm above the burner surface provide a spark ignition to the mixture.

A schematic representation of the porous burner is presented in Figure 2. It consists in a metallic housing, an inlet plate with several orifices and a porous medium where the combustion reaction takes place. Three different inlet plates were tested. The plates are 25mm thick and are made of an isolating material based on Al_2O_3 fibers. The orifices have 1.3 mm in diameter and are distributed along the plate according to a triangular pattern, as shown in Figure 2. The distance between the orifices is the only parameter that is changed among the three plates tested. In the first plate, L is set equal to 5 mm, totalizing 297 orifices. In the second plate, L is increased to 10 mm, totalizing 78 orifices. In the third plate, L is set equal to 13 mm, totalizing 48 orifices of injection.

The porous media is made of silicon carbide with 10 ppi (porous per inch) and is manufactured by FOSECO. Six pieces of 100x50x20 mm are arranged inside the housing in two layers of 300x50x40 mm, producing a radiant area of 0,015 m^2. Alumina blanket is wrapped around the porous media providing thermal insulation and sealing, preventing gas leakage through the edges of the ceramic foam. Type R thermocouples placed inside the porous media are used to evaluate the burner performance. The thermocouples are connected to a data acquisition system and monitored by a computer interface. An infrared camera Flir ThermaCam SC 500 positioned in front of the burner is used to measure superficial temperature and to observe temperature distribution over the burner surface. An operation point is considered to be stable when the measured temperatures vary less than 5ºC in 10 minutes.

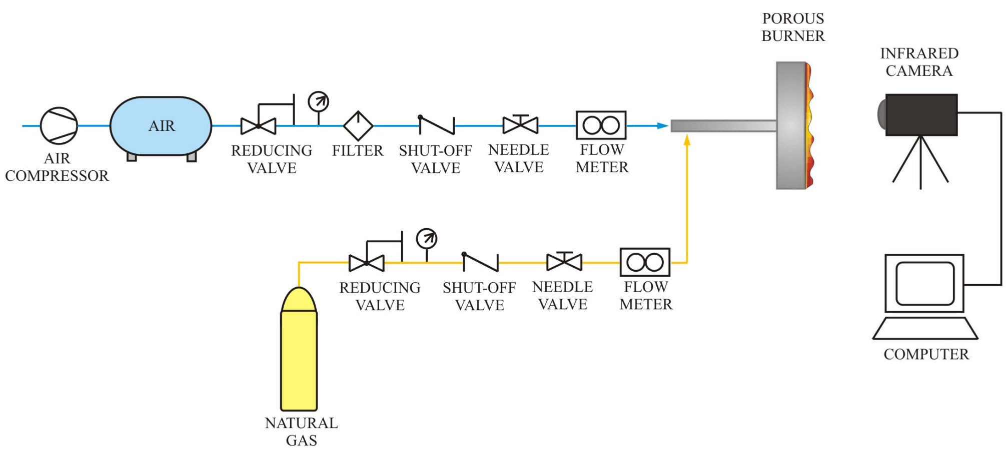


Figure 1. Diagram of the experimental apparatus.

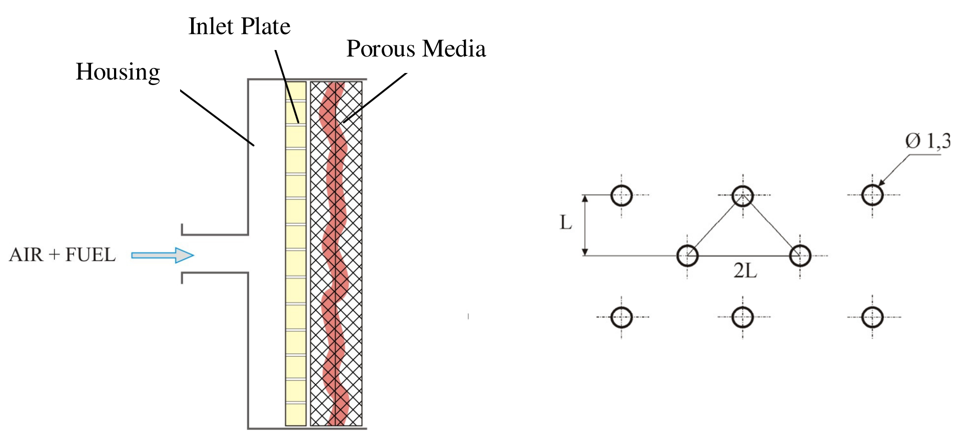


Figure 2. Schematic representation of the porous burner and the inlet plate.

Here, some of the key parameters used in this work are presented. The equivalence ratio is given by the usual definition:

$$\phi = \frac{\left(\dot{m}_F / \dot{m}_A \right)}{\left(\dot{m}_F / \dot{m}_A \right)_S} \tag{1}$$

where $\dot{m}_F$ is the fuel mass flow rate, $\dot{m}_a$ is the air mass flow rate, the subscript s stands for stoichiometric conditions.

The flame speed u_f is assumed to be equal the mean (darcyan) speed of the reactants flow:

$$u_f = \frac{\dot{V}_r}{A_b} \tag{2}$$

where $\dot{V}_r$ is the volume flow of fresh reactants and A_b is the burner area.

The total heat input $\dot{S}_r$ is determined with the equation

$$\dot{S}_r = \dot{m}_f \Delta h_{r,f} \tag{3}$$

where $\dot{m}_f$ is fuel mass flow rate and $\Delta h_{r,f}$ is the low heating value of natural gas ($\Delta h_{r,f}$ = 50050 kJ/kg) .

The energy transferred by radiation $\dot{Q}_r$ was approximated by:

$$\dot{Q}_r = A_b \varepsilon \sigma \left(T_s^4 - T_a^4 \right) \tag{4}$$

where A_b is the burner area, ε is the emissivity, σ is the Stephen Boltzman constant, T_s is the surface temperature of the burner and T_a is the ambient temperature.

The radiant efficiency is defined as the ratio between the energy transferred by radiation $\dot{Q}_r$ and the total heat input $\dot{S}_r$:

$$\eta_{rad} = \frac{\dot{Q}_r}{\dot{S}_r} \tag{5}$$

The velocity of the reactants at the orifices of the inlet plate V_o was calculated with the equation

$$V_o = \frac{\dot{V}_r}{n A_o} \tag{6}$$

where $\dot{V}_r$ is the volume flow of reactants, n is the number of orifices and A_o is the passage area of one orifice.

4. RESULTS

The tests were conducted using three different inlet plates, where the distance between the orifices adopted was: L = 5 mm, L = 10 mm and L = 13 mm. For each plate 15 operation points were tested in a range of equivalence ratio from 0.40 to 0.60. Three values for the velocity of the reactants at the orifices were tested: 925 cm/s, 1250 cm/s and 1480 cm/s. Figure 3 shows the stability diagram found for the three inlet plates tested. This shows it is possible to reduce significantly the equivalence ratio (and the flame propagation speed) maintaining the same velocity at the orifices by reducing the number of orifices at the inlet plate.

When L = 5 mm we note that for an equivalence ratio richer than 0,45 the temperature on the inlet plate reaches 1300ºC, which is the maximum temperature tolerated by the material of the inlet plate. For L = 13mm the large distance between the orifices affects the burner stability due to a reduced power input that leads to lower temperatures at the reaction region. Therefore it is necessary to set higher equivalence ratios to find stable operation points. The inlet plate with L = 10 mm presented the larger stability range. It was found stable operation points for equivalence ratios of 0,45, 0,50, 0,55 and 0,60.

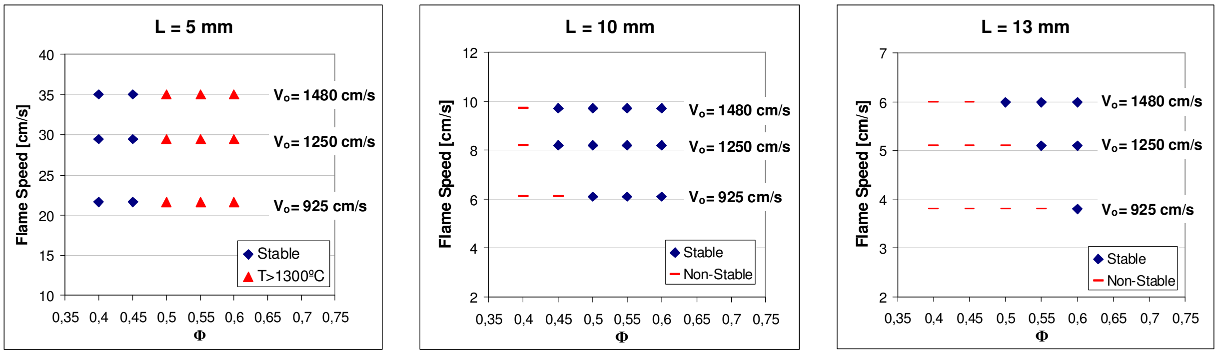
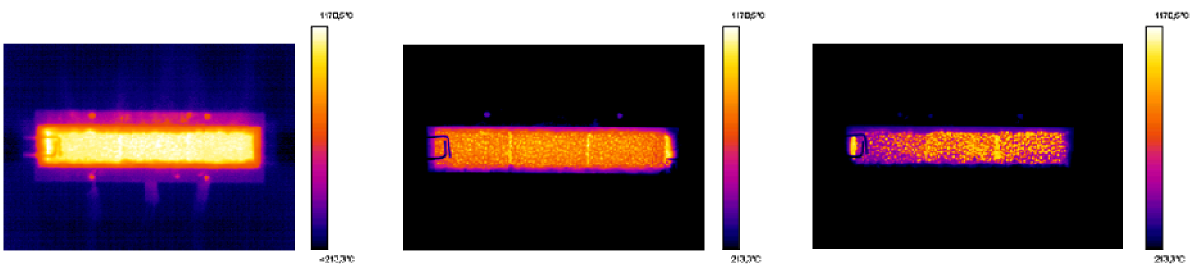


Figure 3. Stability diagram for the inlet plates tested. Premixed reactants injected at 298 K.

An infrared camera was used to evaluate the temperature distribution over the burner surface. Figure 4 presents three images taken with the camera. On the left side of the images we note two wires above the burner utilized for spark ignition. The brighter edge of the porous burner is a gap without porous media where the electrodes for flame detection and monitoring are placed.



(a) L=5 mm, V_0=1480 cm/s, φ=0.45 (b) L=10 mm, V_0=1480 cm/s, φ=0.50 (c) L=13 mm, V_0=1480 cm/s, φ=0.50

Figure 4. Infrared images for L=5mm, L=10mm and L=13mm.

We observe that the surface temperature decreases as the distance L increases while V_o and ϕ are maintained constant. Images (a) and (b) show homogenous superficial temperature around 1028ºC and 800ºC, respectively. In image (c) the average temperature is 701ºC but the left side is colder than the rest of the burner. This is due to the heat losses at the gap between the ceramic foam and the insulation. Although stable combustion was achieved inside the ceramic foam, the free flame in the gap was extinguished because the total heat input was too low sustain a free flame at this equivalence ratio.

Figure 5 presents the surface temperature of the burner for all the stable operation points tested. The temperature was measured with the infrared camera by taking the average temperature over the radiant area, with the burner emissivity set at ε = 0.95. As expected, the superficial temperature increases while the mixture becomes fuel richer and the velocity at the orifices becomes higher due to the increase in total heat input. With the same velocity at the orifices and the same equivalence ratio we observe a reduction on the surface temperature while the distance L becomes larger.

The total heat input based on the heat of combustion of natural gas is shown in Figure 6. The heat input can be altered by changing the equivalence ratio or the velocity at the orifices. For the inlet plate with the largest distance L, stable combustion was found for total heat input as low as 1,14 kW (76 kW/m^2).

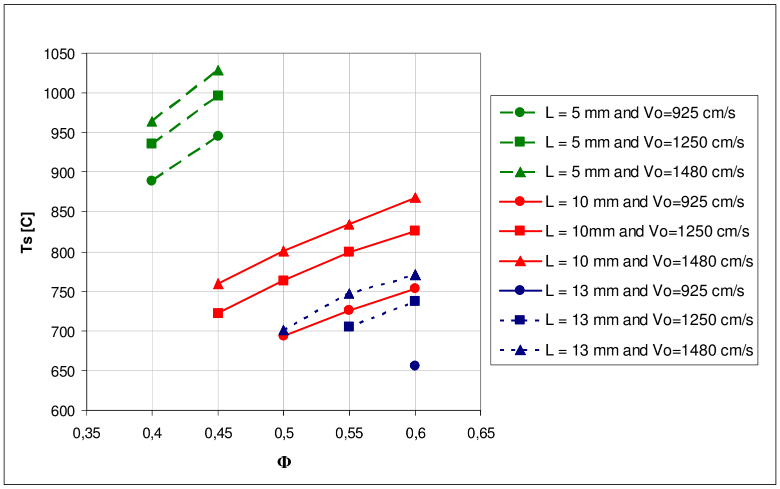


Figure 5. Surface temperature of the burner.

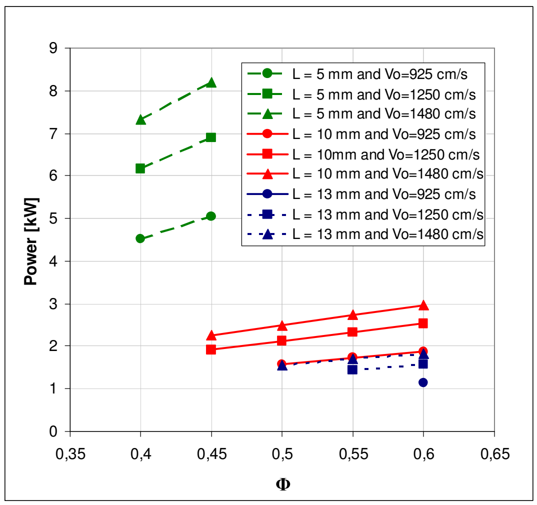


Figure 6. Total heat input.

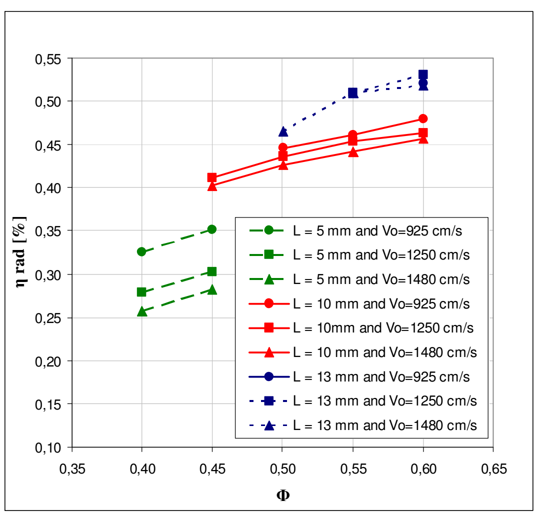


Figure 7. Radiant Efficiency.

Khanna *et al*. (1994) experimentally investigated the radiant output for methane-air combustion within a porous medium burner for various equivalence ratios and flow rates. Their results indicate that the radiant efficiency decreases with the flow rate. Figure 7 shows the same behavior described by Khanna *et al*. (1994). For the inlet plate with L=13 mm the flame speed is lower and the radiant efficiency achieved 53%.

4. CONCLUSIONS

Three porous burners with different inlet plate configurations were tested for a range of equivalence ratio and three velocities of reactants at the orifices. Superficial temperature, total heat input and radiant efficiency were measured. Based on the experimental results obtained, the following conclusions can be written:

- The superficial temperature of radiant porous burners can be reduced by increasing the distance L between the orifices of the inlet plate. It was found surface temperatures from 655ºC to 1028ºC.
- Stable operation points were found for the three inlet plate tested. The stability was limited by flashback, blow-off and elevated temperature at the inlet plate.
- The radiant efficiency decreases with the flow rate. For the inlet plate with L=13 mm, the radiant efficiency achieved 53%.
- Low surface temperatures can be achieved with an adequate distribution of orifices at the distribution plate, enhancing the temperature control of these burners and extending their applicability to low temperature processes.

5. REFERENCES

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6. RESPONSIBILITY NOTICE

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