

## Experimental study of foam layout effects on NO emission inside a porous burner with three porous media layers

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The effect of foam layout on NO emission inside a porous burner with three porous media layers has been experimentally studied. The experimental set-up included two zones, combustion and preheating. At the combustion zone, there are five layers of porous media with different pore densities; at the preheating zone, there are alumina spheres as porous media. Numerical solutions show that permutation of porous foams with different pore densities has an effect on emission rates. The purpose of this experimental study is to investigate effect of porous media permutation and equivalence on emission rates. Results indicate that when the foam density is decreased from combustion zone to exit, NO emission is declined.

**Keywords:** Porous burner, Experimental study, Porosity, Low emission combustion

Considering the effects of combustion pollutant gases on the environment, it is desired to develop low emission burners. Restrictive policies to reduce emissions were determined by institutions, and burners must have emission rates below the limits defined by these policies. It is also important to have higher power density as far as the compactness is concerned. It is possible to reduce emissions with better preheating of the incoming air and fuel. Since thermophysical properties of gases are not satisfactory conventional burners have poor preheating. In conventional burners, dominating heat transfer mode is convection, yet in porous media burners with the installation of solid matrix three modes of the heat transfer can be achieved in the burner. This increases preheating and causes temperature distribution to be homogenous in any direction which results in drop of emissions<sup>1</sup>. Also better preheating provides higher burning velocity and stability in combustion.

There are several studies about porous media combustion to examine its performance in terms of the emissions, efficiency and power density. Weinberg<sup>2</sup> is the first researcher to suggest better preheating to reduce the emissions. In his study, in order to improve pre-heating, recirculation of flue gases into the inlet gas stream was proposed. Takeno and Sato<sup>3</sup>, improved this idea by installing a solid matrix into the combustion zone. With better heat transfer characteristics of the solid phase compared to

the gaseous phase, heat can be better transferred to the preheating zone. Trimis and Durst<sup>4</sup>, conducted experiments in a two-sectioned porous media combustor which include different diameter spheres in each section. They reported emission values for different sphere diameters inside the burner. The results showed that emissions are lower in the porous burners with respect to conventional ones. Trimis *et al.*<sup>5</sup>, compared the free flame burners with porous media burners in terms of stability range, power density and emission. According to this comparison, it was stated the porous media burners are superior to the conventional burners.

Shakiba *et al.*<sup>1</sup> investigated the effect of the material from which porous media was manufactured. In this study, porous medium produced from Al<sub>2</sub>O<sub>3</sub> and SiC were compared in terms of emission rates and flame temperature. It was stated, SiC is better at lower excess air ratios according to these comparisons because of its better heat transfer characteristics.

Even though many experimental studies were conducted on the porous burner and its effects on emission, this study is carried out to find the effects of the arrangement of porous medium with different pore densities at different combustion powers and excess air ratios Table 1. In porous media combustion, it is important to control flame location which depends on Peclet number, given in Eq. 1, that is the ratio of released energy from a pore and absorbed energy by

the surface of the pore<sup>1</sup>. Flame must be located at the intersection of preheating and combustion zones. Mixture of air and fuel inside the porous burner can be ignited when Pecklet number is higher than 65 and it can be given as,

$$Pe = \frac{S_l d C_p \rho_f}{\lambda_f} \quad \dots (1)$$

where  $S_l$  is laminar flame velocity,  $d$  is equivalent pore diameter,  $C_p$  is specific heat capacity of themixture,  $\rho_f$  is the density of mixture and  $\lambda_f$  is heat conductivity coefficient of the mixture. Calculation of the  $Pe$  in the preheating zone is crucial since porous media is heated with combustion energy and if it reaches above 65 it can cause ignition at preheating zone.

### Experimental Section

A schematic of the combustor is represented in Fig. 1 and it illustrates the three main sections of the

Table 1 — Porous media arrangement cases.

Case	First Section	Second Section	Third Section
1	8 PPI	8 PPI	8 PPI
2	30 PPI	20 PPI	8 PPI
3	30 PPI	8 PPI	20 PPI
4	8 PPI	20 PPI	30 PPI
5	8 PPI	30 PPI	20 PPI
6	30 PPI	30 PPI	30 PPI

burner with the boiler section. Air and methane are premixed at the mixer before directed to the preheating zone of the burner and temperature of the mixture is raised in this section. Preheating zone of the burner is a rectangular prism cavity which is 8 cm wide, 6 cm long and 9 cm high and includes 2 mm diameter alumina balls inside. The reason of usage of alumina balls at this section instead of the continuous matrix as in combustion zone is to decrease heat conduction to preheating zone and prevent flame propagation. Since alumina balls provides discrete matrix porous media, heat conduction is decreased from combustion zone. Size of the balls was chosen according to  $Pe$  as defined in Eq. 1.

Combustion zone of the burner is 10 cm wide, 15 cm long and 30 cm high. Around the combustion zone, there is a water boiler to simulate the household applications. During the experiments, five SiC porous media are used with different arrangements. Porous media layers are divided into three sections; the first section has a layer of porous media, second and third section have two layers of porous media with same pore density or Porosity Per Inch (PPI).

In the combustion zone, three different sections were used and measurements were done for 6 cases. Each case was tested at 3, 4 and 5 kW power at three different equivalence ratios. The pore density arrangements for each case were

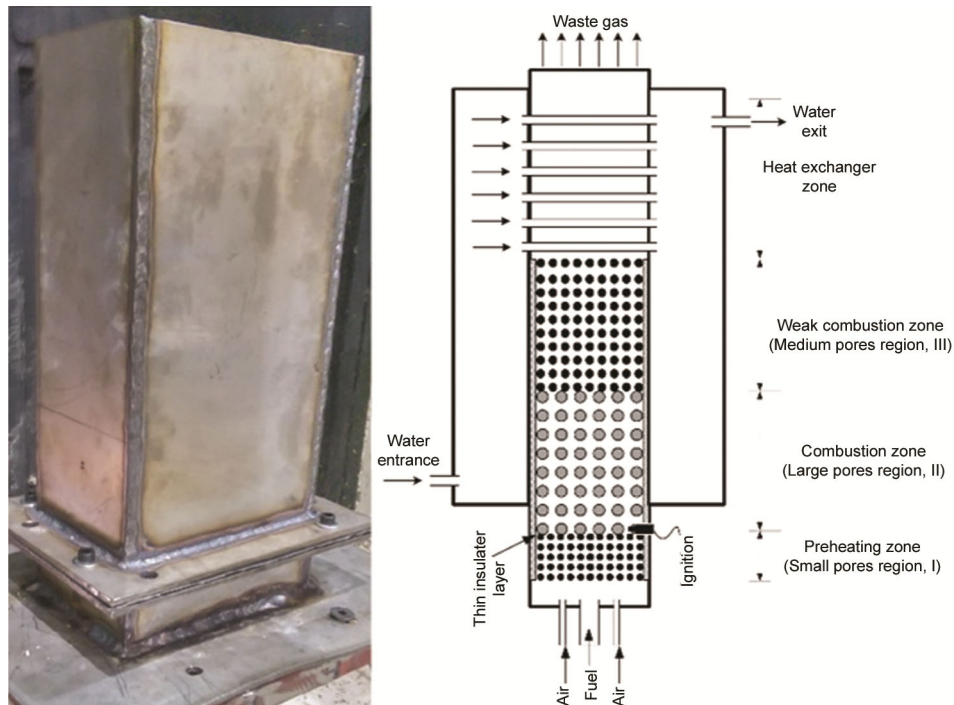


Fig. 1 — Real and schematic view of experimental setup

Table 2 — NO emissions in ppm.

Power (kW)	EQ.	Case I	Case II	Case III	Case IV	Case V	Case VI
5	0.7	45	54	58	49	46	54
	0.8	47	56	68	64	53	71
	0.9	27	58	49	31	34	27
4	0.7	35	49	70	55	56	58
	0.8	43	44	68	62	53	65
	0.9	30	14	24	30	7	42
3	0.7	33	38	62	37	46	50
	0.8	32	21	58	25	29	40
	0.9	25	9	11	11	5	19

listed in Table 1. Emission measurement for each case was made with VARIO plus SE MRU Air emission monitoring system. For each case NO values were recorded.

## Results and Discussion

### NO concentration

Decreasing NO concentration of exhaust gas of the burner is one of the main goals of the porous burner. It is known that NO is released from high-temperature zones in combustion. Therefore, either higher burning temperatures and poor heat transfer from the combustion zone causes the NO concentration to be higher. Table 2 shows the results obtained for each measurement for different equivalence ratios (EQ). Values are consistent with the literature<sup>1,4</sup>.

For all powers, highest values of NO emissions were measured for case 3. It is known that for each case, combustion takes place at the lower foam, which is 30 PPI foam for case 3 and it is connected to an 8 PPI foam. Since the 8 PPI foam has poor heat conduction as a result of its cavities inside, 30 PPI foam cannot transfer combustion heat to 8 PPI foam well. This causes temperature rise inside the combustion area and increases NO emission. In conclusion, lower pore density foams next to high pore density foams in the combustion zone is not preferred as far as NO concentration is concerned.

The lowest NO emission was obtained with the powers of 3 and 4 kW at case 2, while with the power of 5 kW the best emission rate was obtained with case 1. The flow rate of air and fuel for 5 kW were higher, therefore dominating heat transfer mode for

this power is convection. At case 1 pore size of the foams were larger which means they can be cooled better which drops the NO emission. For powers of 3 and 4 kW, conduction heat transfer mode needed to be enhanced and case 2 provided that. Case 2 provided better results compared to case 6 because after combustion area lower pore density foams were placed and they provide convectional heat transfer. Also at case 6, heat transfer with conduction and radiation to the preheating zone were much better than other cases and this caused the combustion temperature rise.

### Error analysis

Uncertainty of all measurement devices was given in this section. Volumetric flow of air was measured with rotameter with a precision of 5% of full scale, and volumetric flow of fuel was measured with a digital mass flow meter which has the precision of 1%. Also emission values were measured with MRU AIR Fair emission monitoring system and its accuracy is 5 ppm for NO concentration.

## Conclusion

In this study, it is obtained that permutation of foams inside the burner has a critical role on NO emission for various powers since it affects the heat absorption inside the burner. Also, foam arrangement inside the burner alters temperature distribution which has an effect on emission values. According to the results of this study, denser foams should be placed in the combustion zone and above these section less dense foams should be placed to obtain lower NO emission.

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