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Influence of reaction layer thickness on surface/submerged flame during porous media combustion of micro burner

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Abstract. Porous media combustion (PMC) possesses many unique features to effectively utilize fuel, which includes better thermal efficiency. Thus making PMC a better choice when compared to conventional free flame combustion. Present study deals with variation in thickness of reaction layer to two different thicknesses; 10 and 20mm by using dual layered micro burner. In addition, two different discrete materials; alumina and zirconia was compared with each other across various ER. Burner performance was enhanced by operating burner at equivalence ratio (ER) below 1. While optimum ER for surface flame and submerged flame was found to be 0.7 and 0.6 respectively. Maximum thermal efficiency was noted by using 20mm reaction layer, the value of which was turn out to be 79 % and 72 % by using alumina and zirconia respectively.

1. Introduction

One of the major global issue is to save fuel to the best possible extent. Since the demand to use fossil fuel is increasing massively while the supply is getting shortage day by day. The reason for poor supply is super-fast depletion of natural reservoirs. Thus any nation economy gets affects directly or indirectly with variations in fossil fuel prices. In general, burners are one of the fast consumption of fuels, which indirectly supports human daily needs. Thereby even a small amount of fuel saving in a individual burner can make a big change in global world.



Since burner are massively used in both domestic as well as industrials sector to fulfill various basic to luxury products to make life of the people to stay under comfort level [1, 2]. Porous medium burners (PMBs) have reportedly proved a better technology for combustion to take place over conventional free flame combustions due to the installation of porous media (PM) in burner housing. The key aspect of PMB popularity is due to the availability of voids to carry out combustion and the presence of excess enthalpy phenomenon [3]. Zhao et al. [4] dealt with a novel method of temperature assessment with heavy oil in-situ combustion according to the fuel availability. They indicated the pseudo-components between 420 °C and 500 °C can able to give 23% reaction heat of the oil. While, Wang et al. [5] performed with fuel-rich combustion of methane in a dual layered PMB with Al₂O₃ pellets of different diameters 5, 6.5, 7.5 and 9.5 mm. They conveyed that 50% of the methane can be transformed in to H₂ and CO at ER=1.7. On the other side two types are flame can be generated using discreet/foam type of porous media namely; surface and submerged flame [6, 7]. Surface flame refers to conventional flame but the combustion takes place on the upper region of the reaction layer, where is almost not existence of radiation effect [8, 9]. While submerged flame implies to combustion of reactants below to surface of the reaction layer, and it propagates heat transfer by pure radiation [10, 11]. In the present work highlights, the dual layered micro burner performance with two different thickens of 10 and 20mm using discreet porous media in reaction layer. In addition, comparative study was made between alumina and zirconia porous media by considering thermal efficiency.

2. Experimental setup

Figure 1 indicates burner housing by highlighting two major section reaction zone (reaction layer) and preheat zone (preheat layer). While a complete snipped overview of the burner layout is as shown in Fig. 2, finally actual photo of the setup in Fig. 3. Burner's upper region is called reaction zone while lower as preheat zone. Thickness of preheat zone was kept constant of 10mm, while reaction was replaced with 10, 20 and 30mm when necessary. Reaction layer was made by discreet spheres of 5mm radius. Supply of fuel mixture was fed from the lower portion of the housing. Preheat layer was made of porcelain foam with 8 ppcm and a porosity of 84%. Solid thermocouple of K-type was used to measure surface temperature (T1), while K type needle thermocouple was used to measure wall temprature at suitable locations (namely T2, T3, and T4). T2 and T4 was placed at mid of reaction and preheat layer, receptively. While T3 at the junction between reaction and preheat layer. All thermocouples where connected to DAQ for accurate measurements. Thermal images where captured from FLUKE thermal imager. Flow rate of air and butane was monitored by digital flow meter was set in L/min.

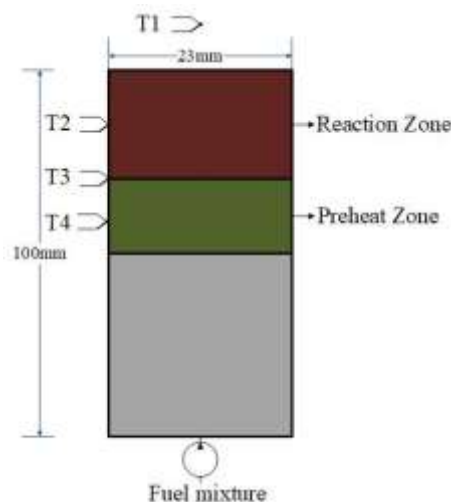


Figure 1. Typical burner housing (Not to scale)

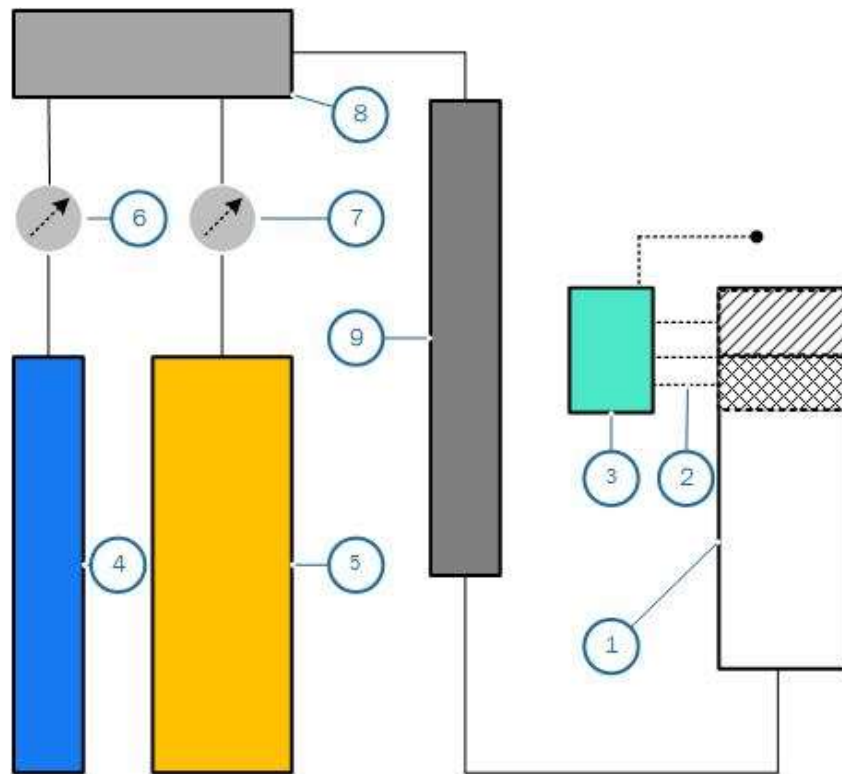


Figure 2. Layout of combustion system. (1) burner housing, (2) Thermocouples, (3) Data acquisition system (DAQ), (4) Butane unit (5) Air pump, (6) Butane flow meter, (7) Air flow meter, (8) Mixing unit, (9) Pre-mix,



Figure 3. Experimental setup

3. Analysis

A basic equation to calculate ER is as shown in Equation (1), where the actual air–fuel ratio was taken during experimental trials while stoichiometric air fuel ratio for butane gas was found out using general complete combustion of butane which was computed a value of 30.95 at room temperature [2]. The actual values of butane and air are as shown in Table 1.

$$ER = \frac{\text{Stoichiometric air fuel ratio}}{\text{Actual air– fuel ratio}} \quad (1)$$

Table 1. ER for butane and air flow rate

Butane (Lpm)	0.1				
Air (Lpm)	3.1	3.4	3.8	4.4	5.1
ER	1.0	0.9	0.8	0.7	0.6

Stable surface flame was generated by using trial and error method by using a minimum fuel of 0.1 Lpm (litre per min). Maximum surface temperature was found by using 20mm reaction layer thickness, and was noted as 631°C at 0.7 ER. While maximum average wall temperature found to be 170°C at 0.6 ER. The possible reason of burner to undergoes surface or submerged flame mainly depends on availability of oxygen and surface area to perform combustion. Furthermore Figs. 4 and 5 indicate the actual photographic images for flames with alumina and zirconia PM respectively. While Figs 6 to 9 indicate temperature profiles across considered compositions of thickness and different PM used. During surface/submerged flame combustions, alumina type of PM has shown significantly showed higher surface and average wall temperatures as compared to zirconia type of PM over various ER's. Since lean combustions give better results, hence this strategy was applied in dealing with discrete type of PM. With this heat transfer due to conduction and radiation from flame front to its upstream and downstream section increases. For a stable combustion, reaction zone transfers heat through the solid matrix to the upcoming unburned reactants. Through this process, it can be predicted to achieve temperatures higher than the adiabatic flame temperature. Another prime parameter that plays active role is the behavior of burner size, because the current burner is of the microburner category. While Figs 10 and 11 shows thermal images used to capture the temperature distribution during submerged flame conditions, which ensure the occurrence of stable combustion. Thermal images are cannot pass thought free flame so this thermal images were restricted to only submerged flame conditions. Finally, thermal efficiency for various critical ER are indicated in table 2.

Table 2. Thermal efficiency for various critical ER

Porou meida	Thickness	Thermal efficiency	
		Surface flame	Submerged flame
Alumina	10	64	33
	20	79	44
Zirconia	10	59	29
	20	72	36



(a)



(b)

Figure 4. Flame with discrete alumina in reaction zone ; (a) surface flame at $ER=0.7$ and (b) submerged flame at $ER=0.8$



(a)



(b)

Figure 5. Flame with discrete zirconia in reaction zone ; (a) surface flame at $ER=0.7$ and (b) submerged flame at $ER=0.8$

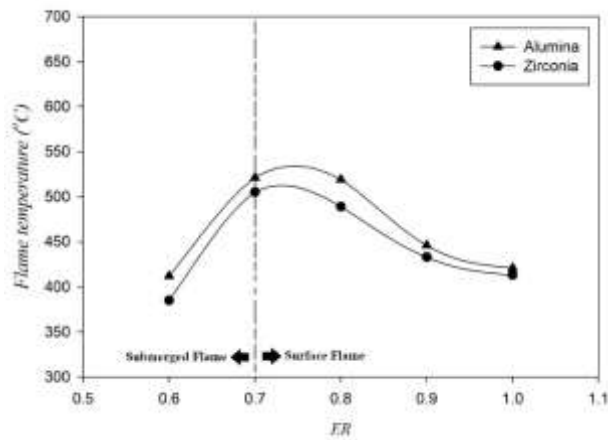


Figure 6. Temperature profile with 10mm reaction zone

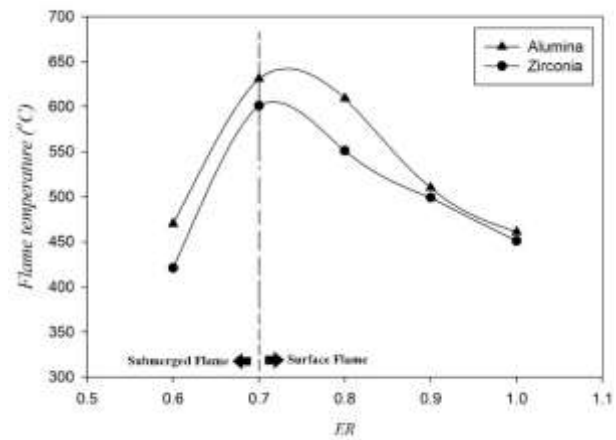


Figure 7. Temperature profile with 20mm reaction zone

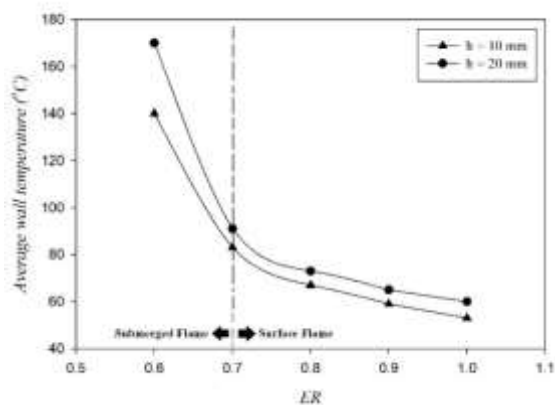


Figure 8. Average wall temperature with alumina discrete type of PM

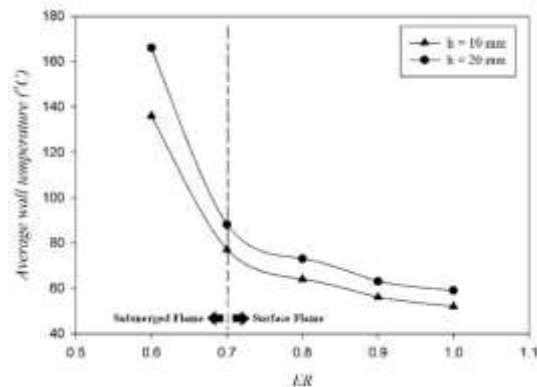


Figure 9. Average wall temperature with zirconia discrete type of PM

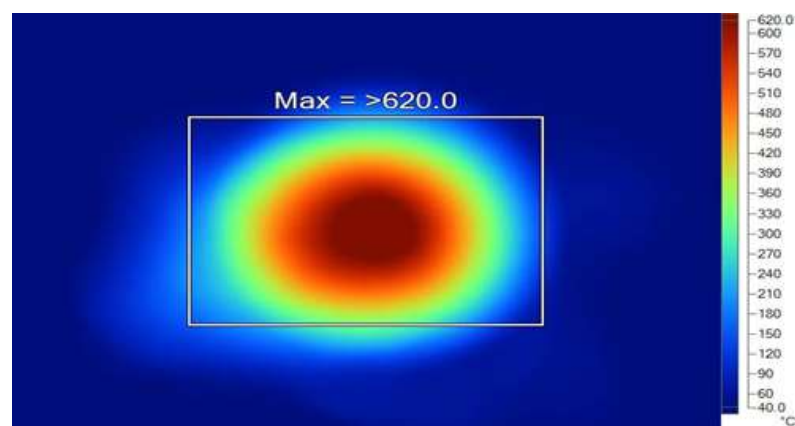


Figure 10. Thermal image (Top view).

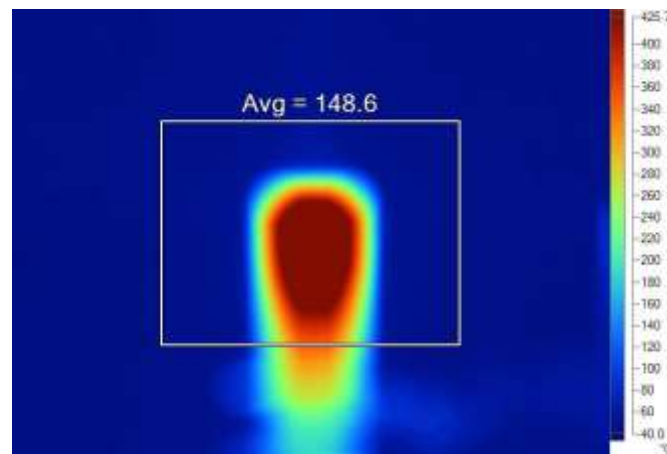


Figure 11. Thermal image (Side view).

4. Conclusions

Presented experimental work deal comparative study between alumina and zirconia porous media (PM) in reaction layer, out of two alumina showed better performance. Further, two thickness of reactions layer was tested; 10 and 20mm, out of which 20 mm is more efficient. Both PM can able to get surface and submerged flame based on ER. Optimum ER to get surface flames and submerged flame are 0.7 and 0.6 respectively. Maximum thermal efficiency recorded with alumina was 79% which was nearly 10% better than zirconia.

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