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Development of foam porous media to undergo surface and submerged flame during premixed combustion

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Abstract. Behaviour of porous media combustion is mainly relay of material used in reaction and preheat zone to possesses high thermal efficiency. Present study deals development of porcelain foam porous media which shall acts as preheat zone to obey peclet number. While in reaction zone consist of alumina foam. In a dual layered micro burner the thickness of reaction and preheat zone was kept at 15 and 10 mm respectively. Burner was developed to achieve not just conventional free flame but also generate submerged flame, varying equivalence ratio (ER). Further, premixed combustion performance was enhanced by running ER below 1, which is lean condition. While optimum ER for surface flame and submerged flame was found to be 0.7 and 0.5 respectively. Maximum thermal efficiency during for surface and submerged flame was turn out to be 90 % and 38 % respectively.

1. Introduction

Saving of fuel to the best possible extent is global issue and nations keep this agenda on high priority, since it directly affects economy of the country. Hence status of “fuel stock” is in an alarming stage due to super-fast depletion of fossil fuels. To take this problem in best possible way is to identify the major fuel consumption devices and improvise it based on available new technology. Out of major fuel consumption systems to fulfill human needs directly or indirectly, burner rank in top category. Since burner are massively used in domestic as well as industrials sector to supply various basic to luxury products to make sure people



stay at almost comfort level [1, 2]. Porous medium burners (PMBs) have consistently proved a better technology for combustion to take place over conventional free flame combustions due to the presence of porous media (PM) in reaction layer. The major features that make PMB as best candidate are availability of large voids to carry out combustion and the phenomenon of excess enthalpy [3], hence the materials preset in reaction and preheat zone directly affect the burner performance. Zhao et al. [4] worked with new technique to predict temperature variation using in situ combustion. They conveyed pseudo-components between 420 °C and 500 °C can able to give more than 20% better performance. Wang et al. [5] worked with rich combustion of with methane as fuel in a dual layered PMB with alumina sphere of different diameters 5, 6.5, 7.5 and 9.5 mm. They found out that 50% of the methane can be transformed in to H₂ and CO at ER=1.7. On the other side two types of flame can be generated using discrete/foam type of porous media, which generally named as convectional free flame (surface flame) 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, foam porous media was developed and used in preheat zone along with alumina (reaction zone), by ensuring peclet number. Further the dual layered micro burner performance was tested for various ER under lean conditions to get best equivalence ratio during porous media combustion (PMC). Finally, comparative study was made between surface and submerged flame by considering thermal efficiency.

2. Experimental setup

Fig. 1 indicate burner configuration with two-layer zone. The two major section are reaction zone (reaction layer) and preheat zone (preheat layer). While a complete snippet overview of the burner layout is as indicated in Fig. 2. Real picture of the setup is shown in Fig. 3. Thickness of preheat zone was kept constant of 10mm, while reaction was replaced trimmed to be 15mm. Alumina foam was having 8 ppcm and porosity of 84%, while developed porcelain foam was 26 ppcm and porosity of 86%. Supply of fuel mixture was allowed from lower portion of the burner. Preheat layer (8 ppcm and 84% porosity) was made up of porcelain material. Thermocouple (K-type) was used to detect surface temperature, and noted as T1. While needle thermocouple (K-type) was used to detect wall temperature at T2, T3 and T4. T2 and T4 was placed at center position of reaction and preheat zone respectively. While T3 at the junction between two layer. All thermocouples were fused into DAQ for accurate measurements. Thermal images were captured using digital thermal imager. Flue mixture was controlled and monitored by advanced digital flow meter.

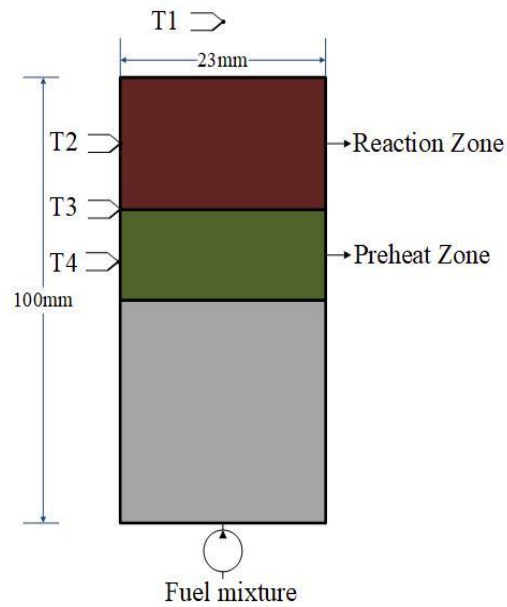


Figure 1. Burner setup

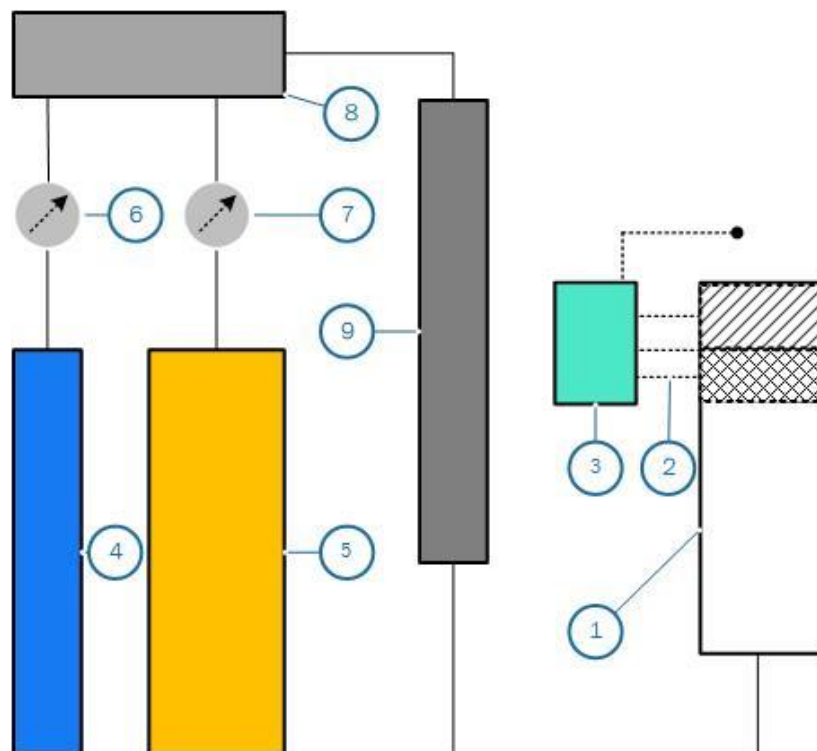


Figure 2. Setup for combustion system. (1) burner unit, (2) Thermocouples, (3) Data acquisition system (DAQ), (4) Butane unit (5) Air pump, (6) Fuel meter, (7) Air meter, (8) Mixing unit, (9) Pre mixing unit.



Figure 3. Experimental setup

Manufacturing of porcelain porous media was carried out at in-house facility from school of materials & mineral resources engineering, Universiti Sains Malaysia. A typical flow chart is as shown in Fig.4 to highlight important tasks.

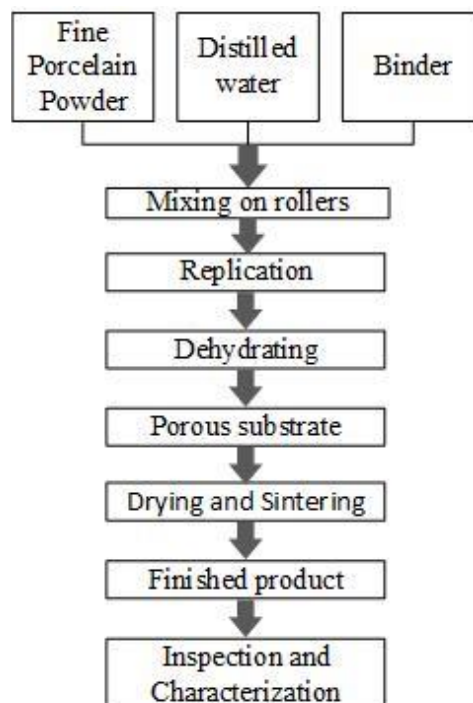


Figure 4. Typical flow chart for making of porcelain foam porous media

The key devices used to carry out the manufacturing process involved hotplate, oven, sponge and furnace. Firstly, slurry was made by mixing porcelain (powdered) along with water and binder. Bender used here is Polyvinyl alcohol (PVA). Generally, 5 to 6% of water added is based in the amount of binder [12], as shown in Fig 5(a). Water (distilled) of 0.5 Kg was gradually heated up to 50°C, and on the other hand to binder are added in continuously to get stable slurry. Mixed slurry temperature was reduced to room temperature and then subjected to mixing action using miller for 24 to 48 hrs., as shown in Fig. 5(b). Obtained slurry was used for replication process with the help of 18ppcm template. Sponge was twisted in sigmoid manner to force out air inside the sponge, thus allowing slurry to occupy the space during contraction/expansion. Further, using parallel roller excess slurry was removed as shown in Fig. 5(c). This process was repeated three to five times to ensure uniform distribution of slurry across the template. Next, a process called dehydration was performed where in template was subjected to dry atmosphere for 24 to 48hrs then kept at oven for 24hrs at 85 °C. The actual view of porous media developed is as shown in Fig. 5(d). Next, sintering process was enabled by using different temperatures as per Jamaludin et al. [12].



(a)



(b)



(c)



(d)

Figure 5. Preparation of foam porous media; (a) mixing of binder with distilled water, (b) mixing of slurry, (c) pre-set rollers to remove excess slurry and (d) final template

3. Analysis

Peclet number (Pe) plays vital role in arrangement of reaction and preheat zone, thus If Pe is >65 , selected PM can be used in reaction zone, else if <65 should be placed in preheating zone. The equation for Pe is as shown in Equation 1. By obeying Pe burner can bale to get better performance[13]. In addition, dual layer arrangement is much preferred over single layer due to the property of flame stabilization [14].

$$Pe = \frac{FD\rho C_p}{k} \quad (1)$$

Where, F and D are flame speed and equivalent diameter selected porous material receptively. C_p and ρ implies to specific heat of the flue mixture and density of the flue mixture, receptively. Next, k refers to thermal conductivity coefficient. Thus the value of Pe for reaction and preheat zone was 76 and 26 respectively. ER equation was calculated using Equation (2). With air-fuel combination, stoichiometric ratio for fuel was found out to be 30.95 at room temperature [2].

$$ER = \frac{\text{Stoichiometric ratio}}{\text{Actual ratio}} \quad (2)$$

Stable surface flame was generated by using trial and error method by using a minimum fuel usage. Thus a minimum fuel of 0.1 Lpm (litre per min) was shortlisted. Maximum surface temperature was found to be 703 °C and 401 °C at ER = 0.7 and 0.5 receptively. Presence of oxygen during PMC is a major factor to initiate surface or submerged flame across various ER. Thus whit the help of Fig. 6 temperature profiles across various ER during surface/submerged flame combustions are highlighted.

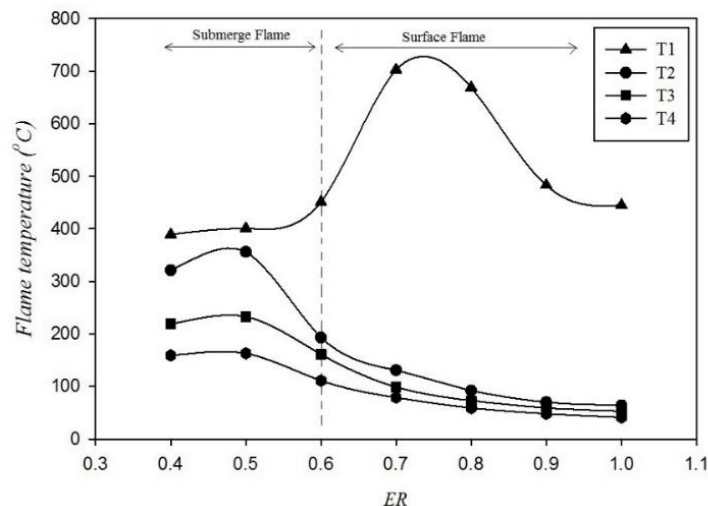


Figure 6. Temperature distribution with $t=10\text{mm}$

Since lean combustions is much preferred over rich due to better results [3], hence this technique was used in the present research work. Since submerged flame emits energy transfer based in radiations hence complete internal recirculation happens in reaction zone alone. Thus this phenomenon is commonly known as excess enthalpy which is the key feature of PMB. Size of the burner is another critical issue with effects

the PMC and flame type. Thus thermal efficiency noted was 90 % for surface flame, while submerged flame can only able to get around 38 %.

4. Conclusions

Presented work deal with development of foam porous media for preheat zone to generate stable combustions. Arrangement of porous media in reaction and preheat zone was ensured to obey peclet number. Fabricated micro sized burner was capable to get surface as well as submerged type of flame by varying only ER to 0.7 and 0.5 respectively. Maximum thermal efficiency that can be achieved was 90 % with surface flame condition, while 38% with submerged flame.

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