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Effect of Porous Materials on Unconfined Porous Burner Performance

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Abstract

The performance assessment on different porous materials, SiC and Al₂O₃, applied on unconfined LPG porous burner was presented in this work. Unlike previous literatures, our porous domain was studied without insulated wrapping so that the heat transfer characteristics was different. Three different heat capacities with fully premixed were performed by maintaining at 0.7 of equivalence ratio. Axial distribution of flue gas temperature measuring was separated into C (X/D=0) and R (X/D=2.6) axes to investigate heat transfer characteristics in combustion chamber. Emission was also considered as combustion performance. On both materials, the axial distribution of temperature along symmetry axis (C) was less uniform than those on surrounding axis (R). This was because of two effects of heat transfer mode, convection and radiation, beyond the burner. Al₂O₃ burner gave higher axial temperature of 20% and 8% increment beyond burner axis and surrounding, respectively, than those on SiC burner. It corresponded to the greater degree of local extinction observed in SiC matrix. The partially burnt product was then appeared in form of CO which was relatively high in case of SiC. High level of NO_x was measured.

Keywords: Porous burner, Combustion, Porous material, Gas burner

1. Introduction

Porous inert media combustion has been an effective technology which serves flame stability, as well as, pollutant reduction. It is due to tortuous structure that can slow down unburnt and promote recirculating of heat within the domain. Once a premixed fuel/air is trapped within the solid cavities, capability on three modes of heat transfer leads to higher flame speed than those encountered in free flame [1], [2].

As the porous burner has been an available commercially technology, there are several productive materials were selected by regarding their combustion characteristics and also durability life. The most commonly based materials, for instant Al₂O₃, SiC and ZrO₂ has been adopted for many applications. In 1999, Pickeacker et al. [3] informed that among these materials, SiC had highest performance for supporting thermal shock due to the low thermal expansion coefficient as seen in Tab.1. Gao et al [4] selected those three types of ceramic to comparatively investigate the combustion performance of two layers porous burners. Results indicated that flame stability limitation was expanded with increased conductivity of solid. When focused on SiC, the hydrocarbon in combustion products was found decreased with increasing flame speed. On numerical study, Al-Hamamre and Trimis [5] investigated the partial oxidation of methane comparing between Al₂O₃ fiber static mixer and SiC foam porous

reactor. They found that the soot formation for SiC porous reactor was occurred at lower air ratio as compared with Al₂O₃. Moreover, the investigation on porous material was also conducted for hydrogen production where the equivalence ratio was larger than 1.9. Results showed that, comparing with Al₂O₃, the longer resident time was served in SiSiC porous domain due to better thermal properties. And the tendency of soot formation was lower also [6]. Apart from ceramics based porous media, metal work has been adopted as porous burner as well. Yu et al. [7] conducted the experiment to compare the combustion characteristics of metal fiber, ceramic and stainless steel fin. The findings reported that metal fiber burner gave highest thermal efficiency and NO_x, while stainless steel one performed lowest of both.

Our main scope is to improve the combustion characteristics on the burner using for ceramics production process where the high and uniformed distribution of temperature in baking chamber are importantly required. The porous inert media has been an interested technique for this work. Due to high thermal properties of inert media, the high and homogenous temperature of flue gas in combustion chamber has been expected.

On current work, a part of the improvement is presented. The performance assessment on different porous materials, SiC and Al₂O₃, applied on unconfined LPG premixed burner was performed. Once, the porous

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domain was served without insulated wrapping or any enforcement, unlike aforementioned literatures, the heat from solid matrix could transfer to the surrounding including axial and radial directions. As far as the combustion performance was concerned, axial temperature distribution of flue gas including along symmetry and adjacent axes were contributed to consider the heat transfer characteristics. CO and NO_x were also monitored as pollutant emission.

Table 1 Thermal properties of porous materials [2C]

Property	Al ₂ O ₃	SiC	ZrO ₂
Thermal expansion coefficient (10 ⁶ 1/K)	8	4-5	10-13
Maximum usage temperature in air (°C)	1900	1600	1800
Thermal conductivity at 1000 °C (W/m K)	5-6	20-50	2-4
Total emissivity at 2000K	0.28	0.9	0.31
Thermal shock resistance, hard shock (K)	100	230	230

2. Methodology

The experimental apparatus is consisted with 2 parts, burner and combustion chamber, as shown in Fig.1. LPG, containing with 70% of propane and 30% of butane, was fed through an injector corresponding to heat capacity of 615, 923 and 1231 kW/m². To investigate the performance under premixed condition, combustion air was fed with fuel at 0.7 of equivalence ratio (30% of excess air).

To represent the combustion performance without major retrofit of a conventional burner, a burner tip was modified such that it was replaceable with the same diameter of porous cylinder. Porous foams with 20 ppi, as claimed by the vendor, made of alumina (Al₂O₃) and silicon carbide (SiC) were carved into cylinder geometry of 52mm and 56mm in diameter and height, respectively. Porous media are illustrated in Fig.2. The thermal properties at reaction temperature are shown in Table1.

Concerning experiment set up, temperature distribution of flue gas was monitored along height of chamber corresponding with $0 \leq Z / D \leq 11$. There are two alignments as shown in Fig.1 with C and R alphabets. The locations with an R alphabet are at $X / D = 2.6$, located between the boundary of testing chamber and the axis of symmetry. These sensing positions are meant to investigate not only the magnitude of temperature, but also the distribution

along axial distance of the two distinctive radial positions. Thermocouple type K connected with YOKOGAWA MW100 data logger was implemented (accuracy including thermocouple is $\pm 1^\circ\text{C}$). Emission in flue gas was considered as ppm of CO and NO_x by Testo 350XL flue gas analyzer (accuracy of $\pm 5 \text{ ppm}$ and $\pm 4 \text{ ppm}$, respectively). Percentage of oxygen was also measured (accuracy by volume fraction of $\pm 0.1\%$) in order to verify the combustion air inlet. Oxygen percentage in flue gas can be converted to amount of air following to the relationship:

$$0.7C_3H_8 + 0.3C_4H_{10} + a(O_2 + 3.76N_2) \rightarrow (3.3 - y)CO_2 + 4.3H_2O + yCO + xO_2 + 3.76aN_2 \quad (1)$$

x and y are moles of O₂ and CO, respectively, obtaining from flue gas analyzer. In this case, equivalence ratio of 0.7 is associated with 6% by volume of oxygen. This value was used as a cross-reference with the reading obtained from a rotameter.

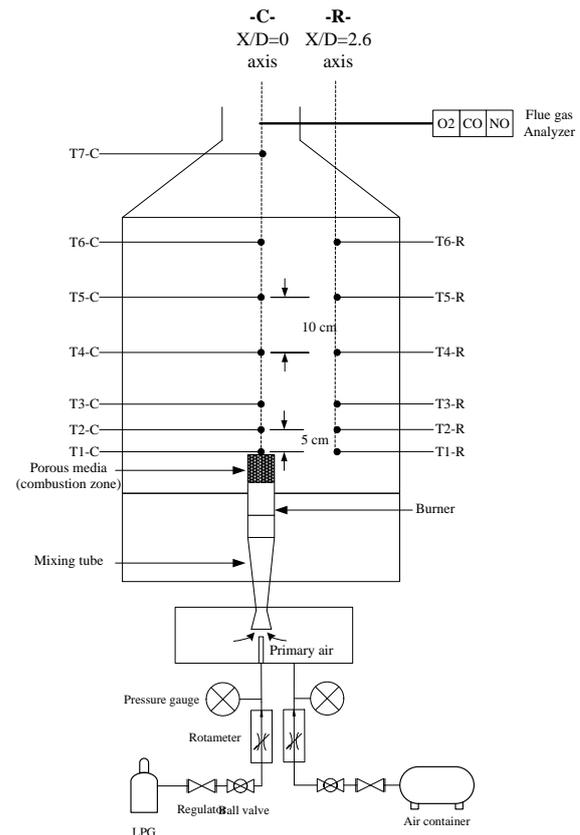


Fig.1 Experiment set-up

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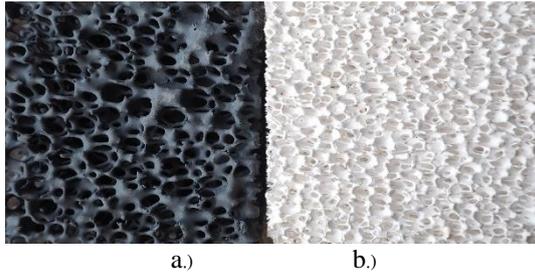


Fig.2 Porous media a.) SiC b.) Al₂O₃

3. Results and discussion

Fig.3 shows the temperature distribution on both C and R axes when using Al₂O₃ as a medium. Results indicate that flue gas temperature was gained when increasing heat capacity. It is due to relative heat loss at high capacity is lower than at low one. When considering axial distribution of temperature, the distribution along the axis of symmetry (given with "C" alphabet) was less uniform than those measured along the locations with "R" alphabet. This was because there were two effects of heat transfer mode, convection and radiation, along axial distance of "C" location beyond the burner. While the effect of heat radiation was dominant at T1-R. At this location relatively higher temperature was observed. At T2-R through to T6-R however, the hot flue gas was drifted along the axial distance of symmetry axis and diffused into the monitoring points along R locations.

The comparison of flue gas temperature between Al₂O₃ and SiC was indicated in Fig.4. It was evident that Al₂O₃ porous burner could provide higher temperature magnitude than applied with SiC at the same rate of heat capacity. Approximately, 20% and 8% increment were observed in order for C and R axes. Considering the material's properties in Tab.1 as SiC has higher thermal conductivity and emissivity than those of Al₂O₃, it was expected that the heat generated from the reaction site was better transferred away by means of conduction and radiation. This could result in greater quenching effect and greater probability of local extinction in SiC material. In addition, as investigation was performed further on pore structure of the material, significant difference was observed as seen in Fig.2. Bigger pore size was observed for SiC foam. This is expected to play an important role on temperature distribution and emission. The results will be discussed in the next paragraph.

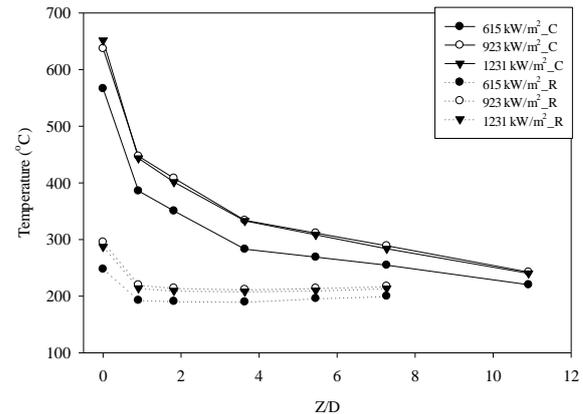


Fig.3 Flue gas temperature distribution on both C (solid line) and R (dot line) axes with heat capacity variation of Al₂O₃ burner

When considering visual flame propagation in Fig.5, intense illuminated solid matrix was observed in case of Al₂O₃ burner. However, SiC exhibited less intensity of illumination indicating greater degree of local flame extinction at the outer region of the porous domain. There were some locations in the matrix that has not been heated up to the illuminating temperature of the material itself. The partially burnt product was then appeared in form of CO, see the comparison from different material in Fig. 6. Nevertheless increasing heat capacity could increase the degree of illumination of the porous domain of both materials. Therefore, less flame extinction was expected. The decreasing in CO with increasing heat capacity agreed with reduction in flame quenching area.

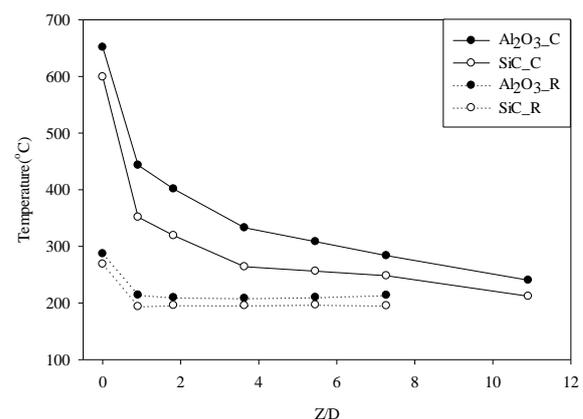


Fig.4 Comparison of flue gas temperature distribution on both C (solid line) and R (dot line) axes at 1231 kW/m² between Al₂O₃ and SiC

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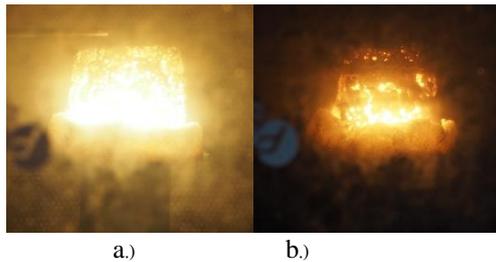


Fig.5 visual flame propagation at 1231kW/m² of heat capacity of a.) Al₂O₃ and b.) SiC

As far as NO emission was concerned, the burner was operated under near stoichiometric condition with excess air of 30%. Arguably, ones may deduce that an increase in NO with increasing heat capacity could relate with thermal NO_x due to an increase in temperature inside the porous domain. However, this statement does not justify a decrease in NO_x with increasing heat capacity for the case of Al₂O₃ foam.

Residence time is also another important factor affecting NO_x formation especially Thermal NO_x since the characteristic time scale of Zeldovich's reaction is relatively longer than the oxidation rate of hydrocarbon. Increasing heat capacity would certainly affect the residence time for NO_x formation. When considering NO emission of Al₂O₃ shorter residence time could result in lower NO_x emission. However, this is not the case when considering the emission of SiC.

From the above statement, it is obvious that only one pathway of NO formation, such as thermal NO_x could not thoroughly describe its total emission. It is still unclear what is the dominant factor leading to an increase in NO_x emission with increasing heat capacity when firing with SiC foam.

NO_x formation due to reaction of intermediate species with oxygen known as prompt NO_x is another source of formation which is strongly related to the amount of unburned hydrocarbon in the cavity of porous domain. Due to limitation of measuring device, it is not appropriate to discuss how Fenimore's mechanism play the role in NO_x formation.

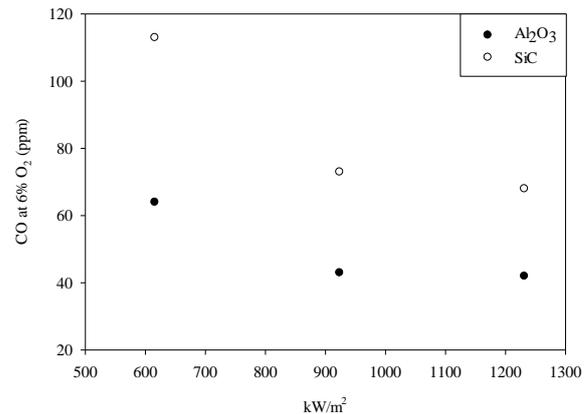


Fig.6 CO emission

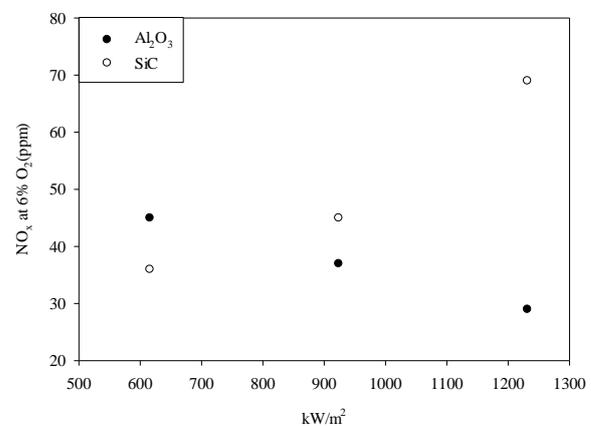


Fig.7 NO_x emission

4. Conclusion

The performance assessment on different porous materials, SiC and Al₂O₃, applied on unconfined LPG premixed burner was performed. As far as the combustion performance was concerned, axial temperature distribution of flue gas including along symmetry and adjacent axes were contributed to consider the heat transfer characteristics. CO and NO_x were also monitored as pollutant emission.

Less uniformed of axial temperature distribution on symmetry axis of combustion chamber than axis's surrounding was observed. This was due to convective and radiative heat transfer characteristic beyond the burner. Comparing two materials, SiC burner performed lower axial temperature distribution than those measuring on Al₂O₃ one. This lower temperature associated with the local extinction area which was observed greater. The partially burnt product from local extinction area was then indicated in form of CO emission. However, the high level of NO_x emission could not explain properly in this paper, since many probabilities of formation path way was related.

5. Nomenclature

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- C denotes $X/D=0$ axis
- D diameter of the burner, m
- R denotes $X/D=2.6$ axis
- X radial distance from symmetrical axis of burner, m
- Z axial distance from burner rim, m

6. Acknowledgement

The authors are grateful to the financial support from Thailand Research Fund under a Royal Golden Jubilee Ph.D. Scholarship, jointly funded by King Mongkut's Institute of Technology Ladkrabang.

7. References

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