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Performance and Stability of Flexible Porous Medium Burner (FPMB)

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Abstract

A porous medium burner is operated on the advantages of the combustion within porous medium which has high radiation efficiency and low emission of pollutant. Therefore, there is an attempt to bring the porous medium burner used in the commercial. Combustion and Engine Research Laboratory (CERL), King Mongkut's University of Technology Thonburi (KMUTT) has developed the Flexible Porous Medium burner (FPMB) that can burn liquid or gaseous fuel and operated either premixed or non-premixed combustion mode. However, the previous experiment cannot well represent the performance and the combustion stability of the FPMB. This research was focus on studying the performance and the combustion stability of the FPMB by using liquefied petroleum gas (LPG) as a fuel. The CO/CO_2 ratio measured from exhaust gas is used as criteria to determine the combustion stability. In conjunction with low pollutant emission that represent the high performance of combustion, the experiment was set up in order to identify the performance of FPMB in terms of a combustion diagram by considering the influence of equivalence ratio (Φ) and firing rate (*FR*). The results show that the FPMB has the operating range with stable combustion at FR= 8 to 11 kW and Φ = 0.4 to 0.95. The excellent performance of combustion that are at 11 kW and Φ = 0.6, the emission of CO and NO_x are relatively low at 20 and 49 ppm (at 0% O_2), respectively.

Keywords: Combustion stability, Porous medium burner.

1. Introduction

The combustion within PIM has many advantages compared with free flame combustion. Firstly, the porous, which has high surface area to volume ratio, enhances the thermal radiation and conduction though the porous matrix. For this reason, the combustion in PIM can provide a regenerative combustion, which has a peak temperature higher than the adiabatic flame temperature so-called 'excess enthalpy flame [1]. Thus, the higher burning speed and combustion intensity together with high radiant output can be achieved [2]. Secondly, the lean flammability limit is extended because of efficient internal energy recirculation. Thirdly, the heat of combustion in PIM was absorbed by porous material, thus, the peak temperature which is the causes of thermal NO_x, was reduced. Furthermore, CO and unburned hydrocarbon emission were also low due to preheating effect and the increased residence time of exhaust gases in a high temperature post combustion region. [3].

From the advantages of the combustion within PIM mentioned, research on the combustion within PIM burner has been the focus by numerous researchers. Homraruen A. and Jugjai S.[4] designed the Flexible Porous Medium Burner(FPMB) that was a two-layer porous medium burner, i.e. an upstream Porous Burner (PB) and a downstream Porous Emitter (PE). The PB was used as a fuel distributor and a fuel vaporizer, while the PE was used as combustion chamber. Moreover, the PB was movable in a telescopic manner in relation to the fixed PE. The adjustable distance between PE and PB was defined as X_{PB} (combustion mode controller, i.e., premixed and non-premixed combustion). The result shown that for non-premixed combustion, the flame zone not only moves into PE but also enlarger as compared with premixed combustion. In addition, a new design of FPMB can efficiently eliminate the thermal expansion and melting problem of the PB that occurred in the past. When the FPMB was continuously operated for a long time, the stainless steel wire mesh porous within the PB was clogged by the black carbonic like deposit affecting the reliability and performance of the burner

To improve the performance and reliability of the FPMB Sompu P. and Jugjai S. [5] designed the PB with cooling system moreover the fuel outlet port and the area of annular flow are modified. As a result, a new design of PB with a cooling system can eliminate the clogging problem at stainless steel mesh and fuel outlet of the PB. Moreover, this can improve the performance and reliability of porous burner. By using the combustion air for cooling at the bottom of PE the combustion air is also preheated with the maximum preheated air temperature of about 515˚C. The effect of the combustion mode on the burner performance has been investigated as temperature profiles of the premixed and the non-premixed mode are almost identical. CO and NO_x emissions however, are low at non-premixed combustion mode.

However, the previous experiment cannot well represent the performance and the combustion stability of the FPMB. This research was focus on studying the performance and the combustion stability of the FPMB by using liquefied petroleum gas (LPG) as a fuel.

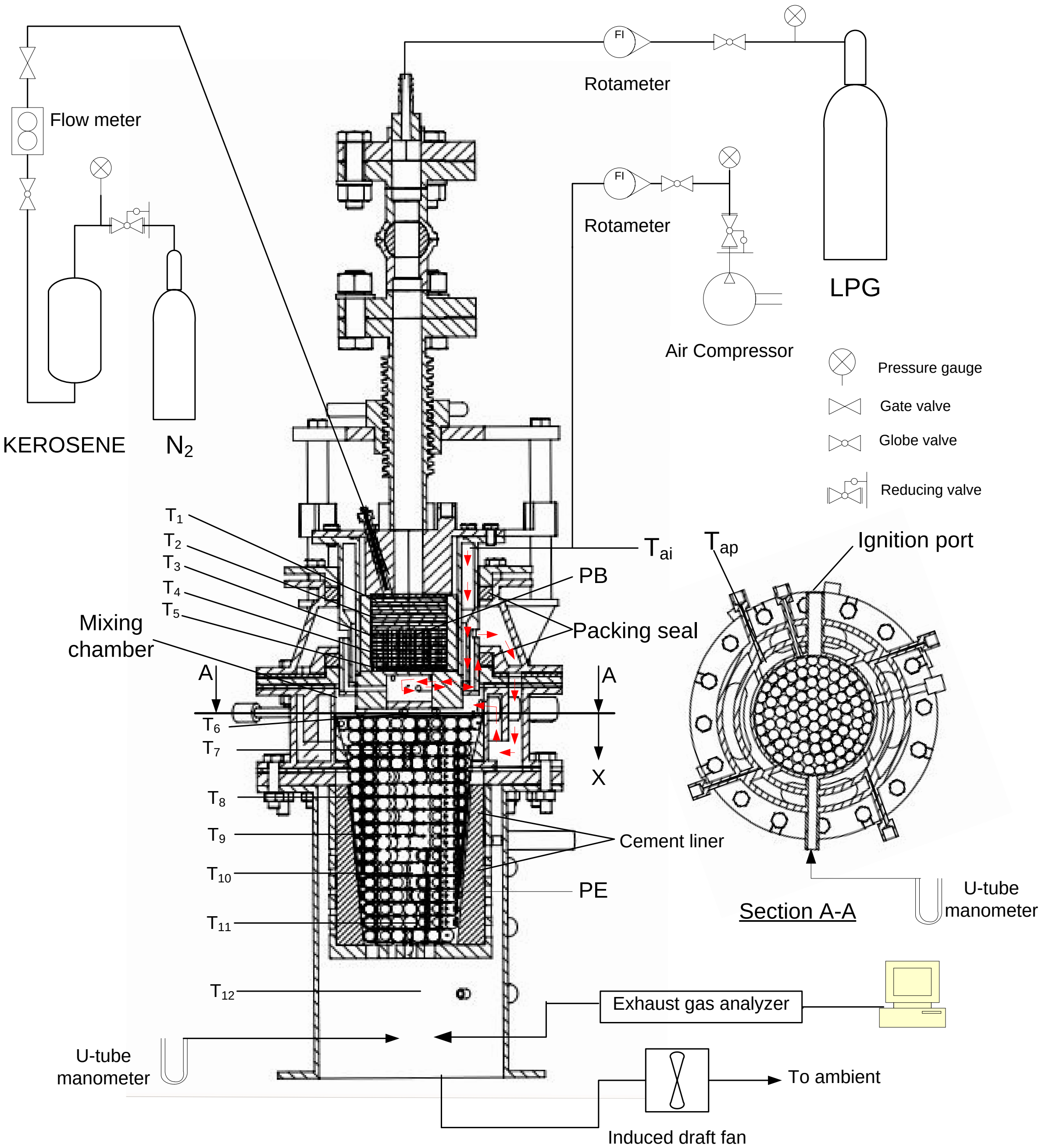

Fig. 1 Schematic diagram of the FPMB.

2. Experimental apparatus and procedure

Fig. 1 shows a schematic diagram of the FPMB including data acquisition systems, which are the same as the previous work [5]. The FPMB consists of three sections, an upstream Porous Burner (PB), a mixing chamber and a down-stream Porous Emitter(PE).

The PB is made from the 60 mm height stack of 100 mesh/inch and 53 mm diameter stainless wire mesh. The PIM packed bed within the PE is made from 10 mm diameter of alumina balls which has 160 mm of length.

Liquefied petroleum gas (LPG) was supplied directly into the PB from above (Fig.1.). The combustion air, however, was supplied into the air jacket surrounding the PB and flow into the cooling pocket at the bottom of the PB to reduce the temperature in PB. Then combustion air is fed into the mixing chamber through 4 ways tangential swirling flow outlet.

The combustion characteristics were determined from the temperature profiles within PB and PE and the composition of product gas at the FPMB exit. Induced draft fan was used to assist a down flow of the burner. The temperature measurement was done by using 14 thermocouples (T_1 to T_{12}) installed along the burner axis. The 0.1 mm diameter N-type sheath thermocouples were positioned within the PB to study the temperature inside stainless steel porous (i,e.,T_1 to T_5). The 0.5 diameter B-type bare thermocouple were positioned within the PE and the burner exit to study the combustion temperature profile within the combustion zone (i,e.,T_6 to T_{12}). Moreover, two N-type sheath thermocouples were installed at the inlet and after preheated of combustion air (T_{ai} and T_{ap}), in order to know the air preheating temperature. The thermocouple signals were recorded by Data Logger model DT-600.

The CO and NO_x emissions were analyzed by the Messtechnik Eheim exhaust gas analyzer model Visit-01L, the measuring range of which was 0–4000 ppm for the NO_x and 0–10,000 ppm for the CO with measuring accuracy of about ±5 ppm and resolution of 1 ppm for both NO_x and CO. All measured emissions were reported at 0% excess O_2 and dry-basis.

The operation of the burner was started using LPG as a fuel. The startup condition is X_{PB} = -20 mm equivalence ratio (Φ) = 0.6 and firing rate (*FR*) = 5 kW. The pilot flame (oxy-acetylene burner) was used as an igniter by inserting it through the ignition port. Then the X_{PB} was increased from -20 to 0 to obtain a non-premixed combustion mode. After steady state combustion is reached, the variation of Φ was started by changing the airflow rate at constant *FR*. Next increase the *FR* each 1 kW and changing Φ to find out the combustion stability region and the optimum Φ (lowest CO emission).

3. Results and discussions

3.1 Combustion stability region

In this experiment the values of [CO]/[CO_2] ratio as the basis for determining the burner can operate stable and more efficiently. The burner should have low [CO]/[CO_2] ratio due to the product of the complete combustion is CO_2 and H_2O without CO. The stable combustion region was defined as the state where [CO]/[CO2] is lower than 0.004 [6]. [CO] and [CO_2] are volume fraction in flue gas on O_2 0% base.

Fig. 2 show stable combustion region of FPMB which this represent the proper functioning to provide the stable combustion. The blue mark in Fig. 2 is the state that the [CO]/[CO_2] ratio <0.004, which the burner can operate stable. And the red cross mark in Fig. 2 is the state that the [CO]/[CO_2] ratio> 0.004, which the burner operate at unstable condition. The stable combustion region at low firing rate (*FR* = 5,6 kW) is a narrow operation range because of the less mixing of fuel and combustion air. At the middle firing rate (*FR* = 7-11 kW) the burner have wider operation range due to the firing rate increase the flow rate of fuel and combustion air is increase, making the mixing much better. And at high firing rate (*FR* = 12 kW) the operation range is begin to narrow down again because of the speed and volume of fuel and combustion air is too high, there is shot time to mixing. The Stable combustion region show that the burners have the proper operation range at *FR* = 7-11 kW and Φ = 0.38-0.95 and at *FR* = 11 kW the burner has widest operation range.

Fig.3 shows the stable combustion region of three types of burner. The operation range (port loading) of FPMB is wider than free flame burner [7] and surface

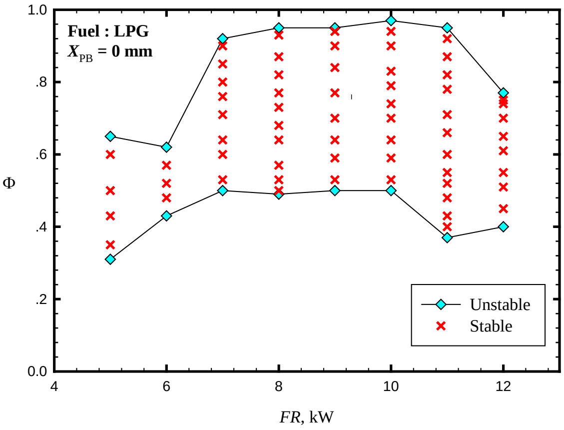

Fig. 2 Stable combustion region of FPMB

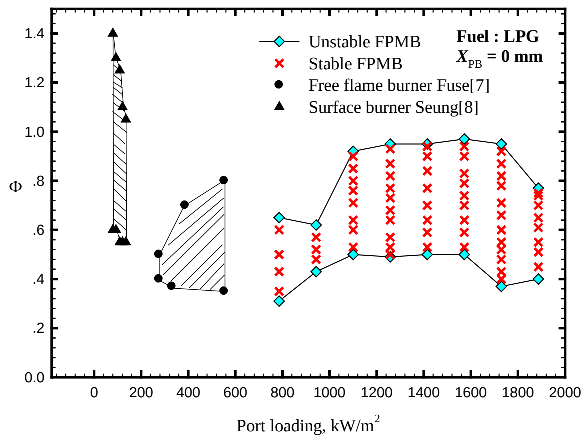

Fig. 3 Comparison of Stable combustion region

burner[8] due to the combustion with in PIM as mentioned above.

3.2 The influence of Φ on CO and NO_x emission.

Fig. 4 shows the influence of Φ on the amount of CO at various *FR*. The appearance of the graph is generally U-shaped which the range of Φ that the CO concentration is relatively low and amount unchanged. Out of this range the trend of CO emission is increase due to incomplete combustion. The influence of Φ can divided in three parts. First part, *FR* = 5-6 kW the range of Φ which low CO emission is narrow (Φ=0.35-0.57) because at the low *FR* the less mixing of fuel and combustion air. Second part, *FR* = 7-11 kW the range of Φ which low CO emission is widened (Φ=0.40-0.95) due to the speed of the fuel and combustion air is in order to make a proper mixing.
Third part, *FR* = 12 kW the range of Φ which low CO emission is begin to narrow down again (Φ=0.75-0.75) because of the speed and volume of fuel and combustion air is too high.

Fig. 5 shows the influence of Φ on the amount of NO_x at various *FR*. The appearance of the NO_x graph is opposite of CO graph while the range of Φ that the

CO concentration is relatively low, the NO_x concentration is high due to the high temperature and complete combustion. Out of this range the trend of NO_x emission is decrease due to incomplete combustion and low temperature. Form Fig. 4 and 5 show that at the Φ = 0.40-0.95 is the proper operation condition of FPMB by complete combustion is take place.

3.3 The influence of *FR* on CO and NO_x emission

Fig. 6 shows the influence of FR on the amount of CO at various Φ. As *FR* increase the CO emission is decrease due to the high fuel and combustion air flow rate promote the well mixing and complete combustion take place. At low *FR* (5-6 kW) the CO concentration is relatively high because of incomplete combustion due to the poor mixing of fuel and combustion air. So the proper operation range of FPMB is *FR* between 8 to 11 kW

Fig. 7 shows the influence of FR on the amount of NO_x at various Φ. As *FR* increase the NO_x emission is increase due to the complete combustion that is high temperature which is the source of Thermal-NO_x.

Form the influence of the *FR* and Φ on CO and NO_x emission in the exhaust gas the optimum condition of FPMB is FR = 11 kW and Φ = 0.6, the emission of CO and NO_x are relatively low at 20 and 49 ppm (at 0% O_2), respectively.

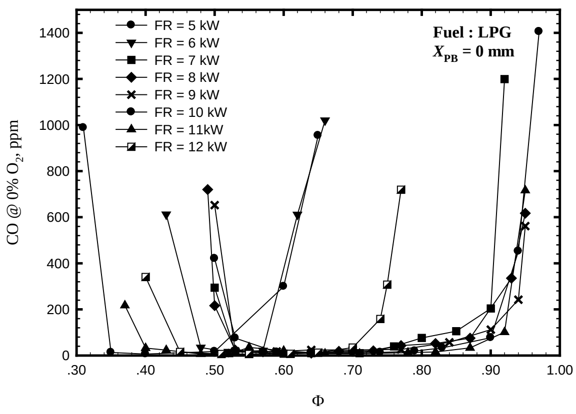

Fig. 4 influence of Φ on CO emission

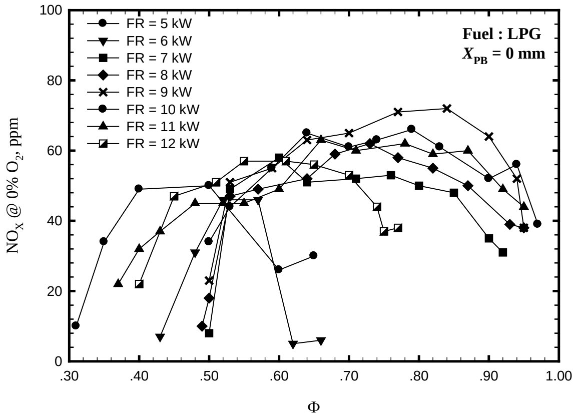

Fig. 5 influence of Φ on NO_x emission

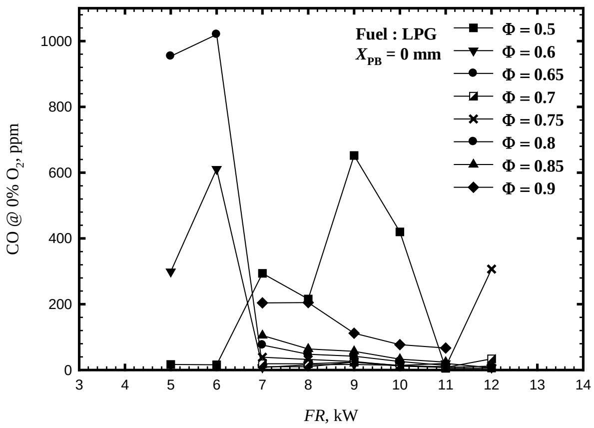

Fig. 6 influence of *FR* on CO emission

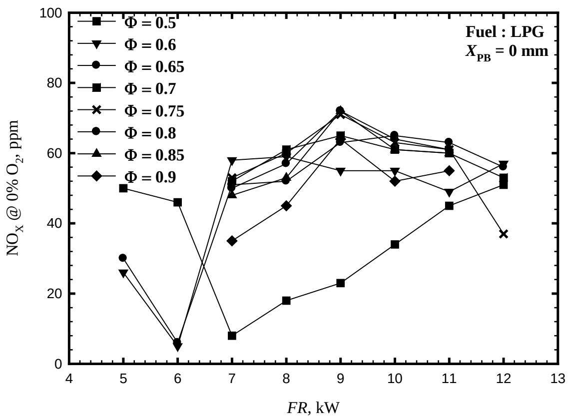

Fig. 7 influence of *FR* on NO_x emission

4. Conclusions

The FPMB is a burner that not only can operate with gas and liquid fuel but it also can change the combustion mode (premixed or non-premixed) easily. The non-premixed mode is the combustion mode that low emission especially NO_x emission when compare with premixed mode [5]. In this experiment focus on the operation range of FPMB that operate with stable combustion condition. Moreover, the condition that has the excellent performance of FPMB is finding. As a result, the FPMB has the operating range with stable combustion at X_{PB} = 0 mm, FR= 8 to 11 kW and Φ = 0.4 to 0.95. The excellent performance of combustion that are at 11 kW and Φ = 0.6, the emission of CO and NO_x are relatively low at 20 and 49 ppm (at 0% O_2), respectively.

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6. References

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