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Design of a self-aspirating annular porous medium burner

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Abstract

A self-aspirating conventional gas burner (CB) is widely used in industries in Thailand because of their simple construction, low cost, rapid heating and easy operation. As the implied name of a self-aspirating burner; the combustion air is naturally entrained by momentum transfer between the high velocity of fuel jet and the ambient air. In order to increase the amount of secondary air for more complete combustion; this research aims to propose a new design for gas burner (LPG) using an annular porous medium. A self-aspirating annular porous medium burner (APMB) is proposed and characterized by an adjustable central secondary air inlet. The APMB is formed by a packed bed of alumina spheres. Firing rate (*FR*) was varied from 21 – 44 kW at constant burner to loading vessel distance (*H*) of 125 mm because it gives low CO emission. In addition, the effect of *FR* and the existence of secondary air inlet on thermal efficiency and combustion characteristics were studied based on European testing standard (*EN*-203). The results show that flame can be stabilized within packed bed for all of *FR*. APMB with secondary air inlet can significantly further reduce CO emission and increase thermal efficiency as compared with APMB without secondary air inlet and CB. An energy saving of APMB is 30.3% as compared with CB. Although the thermal efficiency and energy saving of APMB are higher than CB, the level of CO is relatively high as compared with CB.

Keywords: A self-aspirating annular porous medium burner

1. Introduction

As Thailand industrial development has rapidly increased in recent years, the problems of excessive energy consumption and environmental pollution have become an important social issue. A self–aspirating conventional gas burners (CB) as shown in Fig. 1. are widely used in small and medium scale enterprise in Thailand (SMEs), especially in food and household sector [1] because of their simple construction, low cost and easy to operation. Although the CB has more advantages but it has a low thermal efficiency, which indicates that it has a low energy saving. Therefore many techniques were presented such as using a heat–recirculating burner [2-3], swirl burner [4] to solve these problems. But in this research, porous medium burner (PMB) technology was selected to achieve the purpose. Since the PMB is advantageous over the CB as shown in previous researches [2-3], a self-aspirating porous medium burner (SPMB) [5] with cylidrical

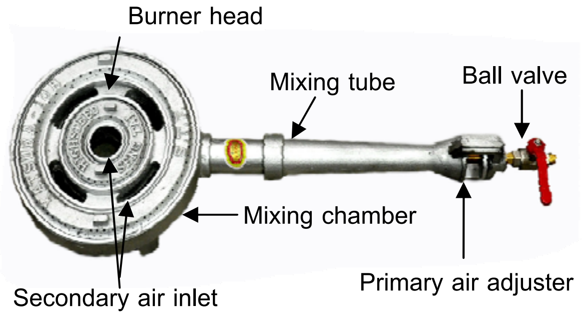


Fig 1. Self-aspirating conventional gas burner

packed bed shape was designed and developed to compare with CB. The results show that the thermal efficiency of SPMB is higher than CB. However, the amount of CO emission also increase because of a lack of secondary air entrainment due to burner geometry. Thus, porous burner with annular packed bed shape was proposed to solve this problem.

This paper aims to present a new innovative burner, self-aspirating annular porous medium burner (APMB), which was developed from CB. The concept of design for this burner was based on the important characteristics of CB such as using the same pressure drop, same mixing tube, same nozzle diameter. Flow area of APMB was kept equal to flow area of SPMB [5]. This work presents the burner performance, which was tested by European standard En-203 [6] to compare with CB.

2.Methodology

2.1. APMB design method

Pressure drop across the burner of the CB is an important parameter which was used to design the APMB because it has highly affected to primary air entrainment and flame stabilization. Thus, the Sodre and Parise equation [7] as shown by Eq.(1), which was developed from ergun Equation, is used to calculate the burner length (*L*). Here, ΔP is a pressure drop across the CB from the experiment and is a function of volume flow rate of mixture or the firing rate (*FR*). $\bar{\varepsilon}$ is average porosity, and it can be estimated from Sodre and Parise method [7]. Once the porous diameter (d) and the packed bed diameter are selected. correction factor (*C*) can be calculated by Eq(2), Where $\bar{v}_c$ is corrected total average flow velocity thought the packed bed, $\bar{v}$ is single region average flow velocity thought the packed bed, v_{wi} and A_{wi} are average velocity and area of internal region, v_t and A_t are average velocity and area of transition region, v_{we} and A_{we} are average velocity and area of external region, A_b is single region area.

$$\frac{\Delta P}{L} = 150\frac{(1-\bar{\varepsilon})^2}{\bar{\varepsilon}^3}\mu\frac{(C\bar{v})}{d^2} + 1.75\frac{(1-\bar{\varepsilon})}{\bar{\varepsilon}^3}\rho\frac{(C\bar{v})^2}{d} \quad (1)$$

$$C = \frac{\bar{v}_c}{\bar{v}} = \frac{v_{wi}}{\bar{v}}\frac{A_{wi}}{A_b} + \frac{v_t}{\bar{v}}\frac{A_t}{A_b} + \frac{v_{we}}{\bar{v}}\frac{A_{we}}{A_b} \quad (2)$$

Peclect number (*Pe*) [8] is used to estimate porous diameter as shown by Eq (3), If *Pe* > 65 flame can propagate within packed bed. On the other hand, if *Pe* < 65 flame cannot propagate within the packed bed because of a strong quenching effect. Thus to design the practical burner, the packed bed of APMB should be designed based on *Pe* > 65.

$$Pe = \frac{S_L d c_p \rho}{k} \quad (3)$$

Fig. 2 shows a relationship between the firing rate (FR) and packed bed or burner length Which was estimated by Eq (1) and (2).

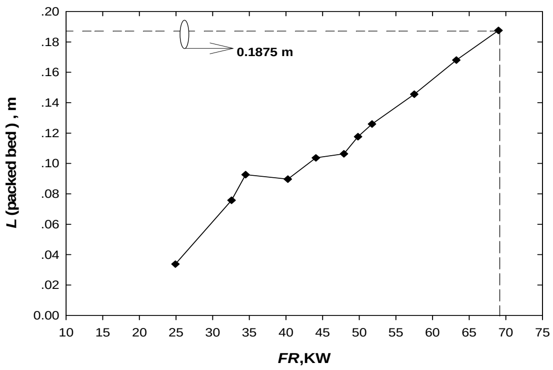


Fig 2. A relationship between firing rate (*FR*) and burner length (*L*)

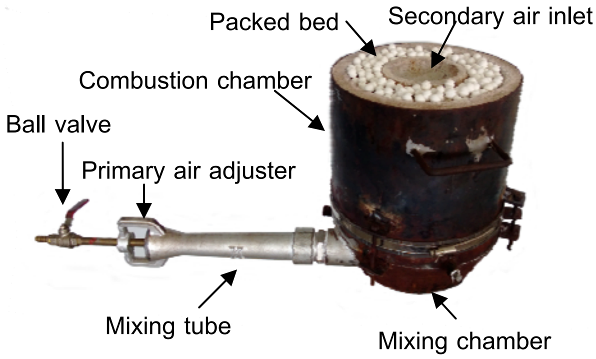
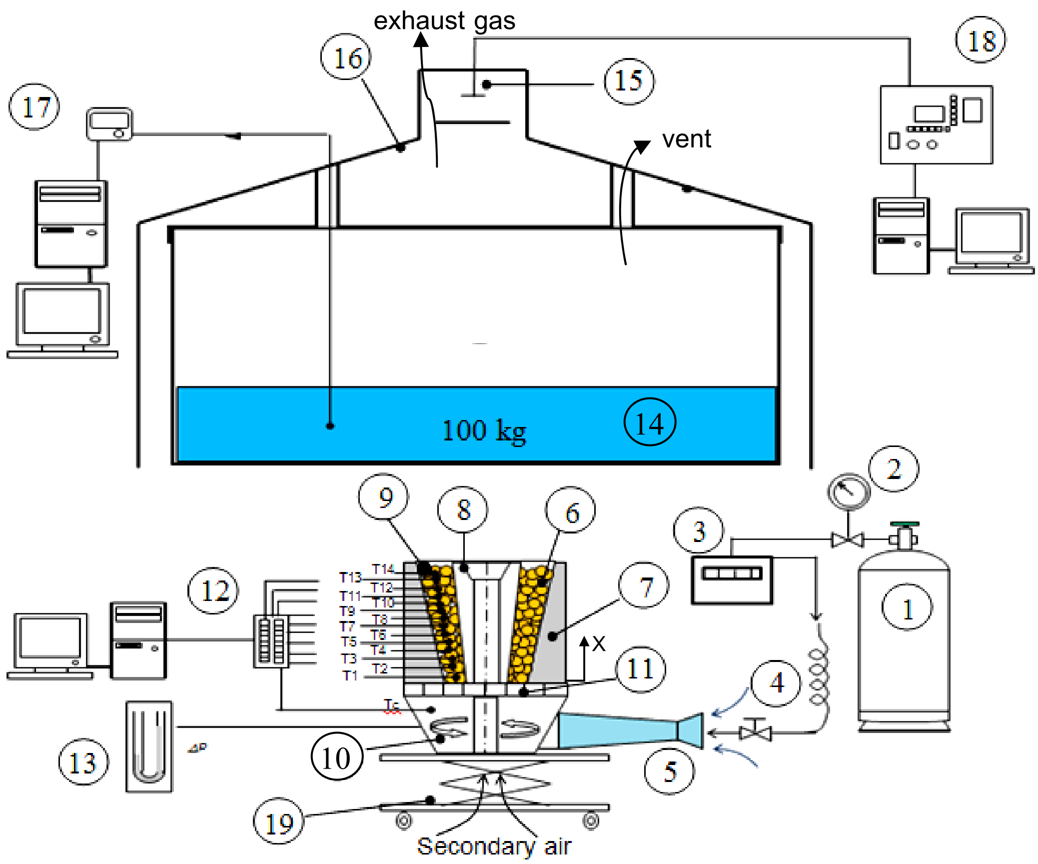


Fig 3. Photograph of the self-aspirating annular porous medium burner (APMB)

Generally, the operating range of CB (KB-10) is about *FR* = 20 - 70 kW and it depends on nozzle diameter and heating value. Thus, to ensure that the operating range of APMB will cover the operating range of CB (KB-10), *FR* = 70 kW was selected as the design value of packed bed length of the APMB. Thus, as shown in Fig 2. at *FR* = 70 kW, the packed bed length is 0.1875 m.

2.2. Experimental setup

Fig 3. shows a photograph of the APMB and Fig 4. shows a schematic diagram of the experimental setup for an impinging flame of the APMB for thermal efficiency testing. This consists of components / systems such as: the burner and fuel supply system, thermal efficiency testing system and gas sampling system. A mixing tube(5) was made by cast iron and connected with mixing chamber(10), which was made by cylindrical steel of 3 mm in thickness wall. Combustion chamber(7) was made by cylindrical steel of 3 mm in thickness wall and surrounded by high temperature cement, secondary air inlet(8) was made by cast iron tube with 50 mm diameter and surrounded by high temperature cement. Porous medium which was made from alumina oxide (Al_2O_3) with 15 mm diameter was randomly arranged to construct the packed bed(6) that is 0.1875 m in height. To improve flame stabilization and to prevent flame flashback, the annular with conical packed bed shape was arranged to achieve the purpose. The packed bed was supported by perforated stainless steel plate(11) with a net flow area of about 706.5 mm^2 at the plate to allow for the incoming flow of the air/fuel mixture from the mixing chamber. The APMB was placed on adjustable base(19). Flame impinged on a cylindrical vessel containing water(14) with flat bottom surface diameter of 920 mm and 800 mm height which is made from a stainless steel. LPG (1) was used as fuel in the experiment. It contains 40% (by volume) of propane (C_3H_8) and 60% (by volume) of butane (C_4H_{10}) with a low heating value of about 108 MJ/m3. The LPG flow rates were controlled by a pressure regulator with calibrated pressure gauge(2), and volume flow rates were measured by flow meter(3) the packed bed burner temperatures were measured by setting 14 locations of different thermocouples depending on location



1. Fuel (LPG) 2. Pressure regulator 3. High pressure gas flow meter 4. Ball valve & fuel nozzle 5. Mixing tube 6. Packed bed 7. High temperature cement 8. Secondary air inlet 9. Thermocouples 10. Mixing chamber 11. Perforated stainless steel plate 12. Data logger & computer display 13. Water manometer 14. Vessel containing 15. Probe samping 16. Hood 17. K-type thermocouple 18. Exhaust gas analyzer & oxygen sensor & computer display 19. Adjuster base

Fig 4. Schematic diagram of the experimental setup of the self-aspirating annular porous medium burner (APMB)

as denoted by T_1 - T_{14} as shown in Fig. 4, where the combustion zone takes place. The tip of these thermocouples (T_1 - T_{14}), are located in the middle of the packed bed between inner combustion chamber wall and secondary air inlet wall The temperature at T_1-T_6 are N-type with 1.5 mm sheath diameter and the temperature at T_7-T_{14} are B-type bare thermocouples (Pt/Pt-Rh 13%) with 0.1 mm wire diameter and 4 mm sheath diameter which is made from ceramic. The signals of thermocouple are digitized by a general-purpose data logger (12) (Delta model DT-600), and then transmitted to a personal computer. The pressure drop across the packed bed (ΔP) is measured by water manometer (13) at the side wall of mixing chamber. Water temperature was monitored by a K-type thermocouple(17) with a wire diameter of 0.5 mm. A hood(16) for collecting a flue gas was designed and constructed based on European standards, *EN* 203-1:1992 and *EN* 203-2:1995 [6], as a guideline. The vessel(14) is covered by a hood(16) for collecting the exhaust gases separately from the generated water steam. Emission analysis of the dry air combustion products at the exit of the hood (15) is carried out by using a portable exhaust analyzer (Messtechnik Eheim model Visit01L) (18). A gas processing system of CO and NO_x is especially tuned for electrochemical sensors, ensuring long-time stability and accuracy of measurement. The measuring range of the analyzer is 0-10,000 ppm for CO and 0-4,000 ppm for NO_x with a measuring accuracy of about ±5 ppm (from the measure value) and a resolution of 1 ppm for both CO and NO_x. All measurement of emissions in the experiment are corrected to 0% excess oxygen and dry basis.

Diffusion flame mode was burned to start up the APMB for preventing flame flashback before switching to a submerged partially premixed flame. The diffusion flame is made by fully closing a primary air adjuster at the mixing tube inlet and using a relatively low firing rate (*FR*). Then the primary air adjuster is gradually opened to allow for a more primary air being entrained into the mixing tube. This makes the flame being transformed into a more partially premixed one. At a certain value of opening of the primary air adjuster the flame over the packed bed automatically propagates into the packed bed. Then after flame propagated into packed bed about 15-20 minute, the stabilized combustion process was obtained.

3. Results and discussion

3.1 Effect of burner to pot distance (*H*) on emission characteristics

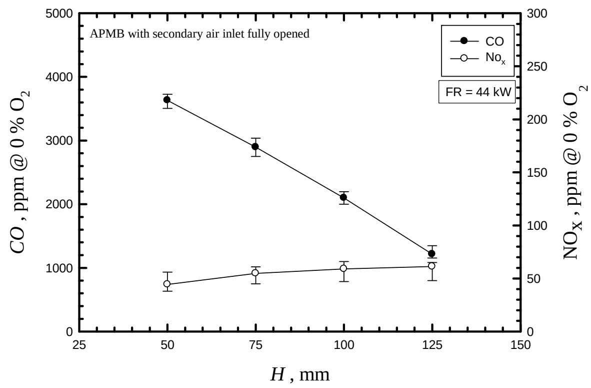


Fig. 5 Effect of burner to pot distance (*H*) on emission characteristics

Fig. 5 show effect of *H* on CO and NO_x emissions at constant firing rate of 44 kW. Amount of CO emission decrease as H increase because more secondary air entrained toward to the flame and more residence time which lead to more complete combustion. The level of NO_x emission is slightly increase as *H* increase because of more complete combustion and high flame temperature. Thus *H* = 125 mm was selected to estimated thermal efficiency of APMB because it gives an acceptable emission level.

3.2. Effect of firing rate (*FR*) on pressure drop

Fig. 6 shows variation of pressure drop (ΔP) across packed bed of APMB and pressure drop of CB with variation of *FR* at *H* = 125 mm. All measured values are tested based on impinging flame. ΔP of both burners are almost linearly increased with *FR* because of a basic nature of the self-aspirating burner [9]. However, both burners have the same trend of pressure drop because calculation of APMB is based on the basic characteristics of CB. Thus, it is agree that the calculation of APMB is rather precise.

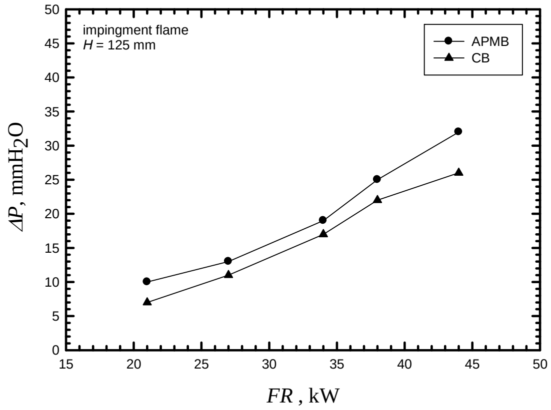


Fig. 6 Effect of firing rate (*FR*) on pressure drop

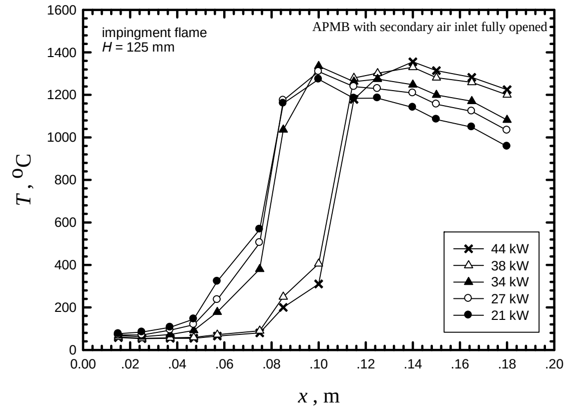


Fig. 7 Effect of firing rate (*FR*) on temperature Distribution along packed bed

3.3 Temperature distribution

Fig. 7 shows effect of firing rate *FR* on temperature distribution along axis *X* of packed bed at varying firing rate *FR* from 21 to 44 kW Variation of the firing rate *FR* is obtained by varying the inlet pressure of the gaseous fuel at the fuel nozzle. The peak temperature that is shown in Fig. 7 imply a reaction zone or flame location within the packed bed. At a low firing rate, *FR* = 21 kW the location of flame is at *x* = 0.09 m with maximum temperature of about 1273 ^{o}C. As the firing rate increase to *FR* = 44 kW, flame location is moved to x = 0.14 m with maximum temperature of about 1355 ^{o}C, the flame shows a trend of moving to the downstream region, because of increasing of flow velocity of mixture with increase gas pressure input. All temperature distribution in Fig. 7 shows that at the downstream region the temperature has a trend decrease because of heat loss to surrounding and water load. Generally, the APMB can operate higher than 44 kW, but this is beyond the limitation of the apparatus. Thus, *FR* = 44 kW is maximum value in this research.

3.4 Emission characteristics

Fig. 8 shows variation of CO emission with *FR* and effect of secondary air. CO emission of APMB is decrease as *FR* increase because of more primary air entrainment due to basic nature of self-aspirating burner. when comparing between the APMB with secondary air and without secondary air ones found that CO emission of the APMB without secondary air is higher than the APMB with secondary air because of lack of secondary air. This indicated that the existence of secondary air inlet can significantly reduce CO emission. When comparing the APMB with secondary air with CB, ones found that emission of CB is lower than the APMB because the flame of CB is multiple-jet flame that has more entrained secondary air into the flame as compared with a single flame from APMB. However, at high *FR*, APMB has CO emission lower than Thailand industrial standard (*T.I.S*) which is indicated that the APMB is a practical burner.

Fig. 9 shows that the emission level of NO_x is increased with *FR* and existence of secondary air because of more complete combustion and high flame temperature. The APMB provides a lower NO_x emission than the CB because the advantage of the porous medium technology that is capable of suppressing the NO_x formation [10].

3.5 Thermal Efficiency

Fig. 10 shows the measured thermal efficiencies of the CB and the APMB as function of *FR* and secondary air. Thermal efficiency, η_{th}, is calculated according to European standard [6]. As firing rate, *FR* increases, the thermal efficiency of both burners are slightly decrease because a high heat loss to surrounding. The maximum value of APMB is 51.53 % and CB is 36.4% were obtained at low *FR* of both burners. As compared between APMB with secondary air and without air ones found that thermal efficiency of the APMB with secondary air is higher than the APMB without secondary air because of a more complete combustion due to sufficient combustion air. it is clear that the advantage of porous medium [2,5] and the existence of secondary air can improve the thermal efficiency of the APMB.

3.6 Energy saving

Energy saving (*EN*) as shown in Fig 11. for the APMB with respect to the CB is calculated by Eq.(4). Basic idea of *EN* is based on the same thermal output of each burner at different input. *EN* of both conditions decreases as *FR* increased because of a high heat loss.

$$EN = \frac{\eta_{APMB} - \eta_{CB}}{\eta_{APMB}} x100\% \qquad (4)$$

The maximum *EN* is 30.34% at *FR* = 27 kW and occur with APMB with secondary air inlet. Thus, we suggest to replace the CB in the SMEs of Thailand with the APMB because the APMB will reduce cost of LPG consumption.

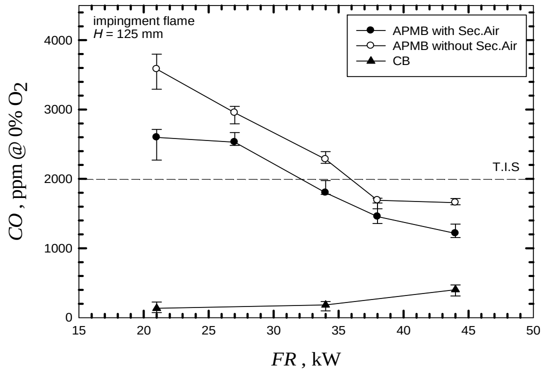


Fig. 8 Effect of firing rate (*FR*) on CO emission

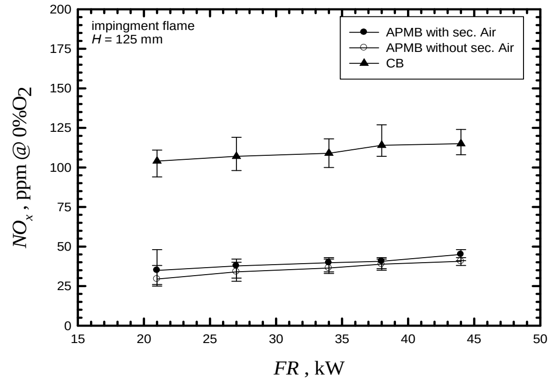


Fig. 9 Effect of firing rate (*FR*) on NO_x emission

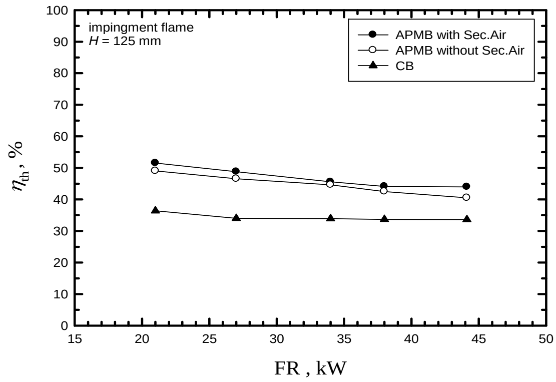


Fig. 10 Comparison of thermal efficiency

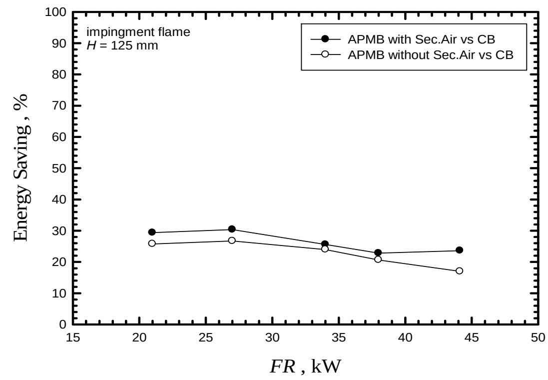


Fig. 11 Comparison of energy saving

4. Conclusions

4.1 Design and development of APMB are successfully. Flame can be stabilized within the -packed bed with operating rang, *FR* = 21-44 kW.

4.2 The existence of secondary air can significantly reduce CO emission and improve thermal efficiency of APMB.

4.3 Comparison of NO_x emission between the APMB and the CB, NO_x emission of APMB is lower than the CB because the advantage of the porous medium technology that is capable of suppressing the NO_x formation

4.4 More enchantment of thermal efficiency of the APMB is obtained by using porous medium technology. For all condition, the thermal efficiency of the APMB is more than the CB of about 12.52%

5. Acknowledgement

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