Thermal efficiency of self-aspirating porous medium burner for Small and Medium Scale Enterprises (SMEs)

Wasan Yoksenakul and Sumrerng Jugjai *

Department of Mechanical Engineering, King Mongkut's University of Technology Thonburi (KMUTT), Bangkok, Thailand 10140

* Corresponding Author: Tel: (662) 470 9128, Fax: (662) 4709111,
E-mail: sumrueng.jug@kmutt.ac.th

Abstract

A self-aspirating conventional burner, CB, is widely used for heating process of small and medium scale enterprises, SMEs, in Thailand but it has a relatively low thermal efficiency (<30%). This study is made to improve a thermal efficiency of self-aspirating burner by porous medium technology. A self-aspirating porous medium burner, SPMB, was already designed and constructed from my previous work. This experimental study is carried out to investigate the effect of firing rate, CL, and distance between the burner top and the bottom of the loading vessel, H, of the SPMB and CB on the thermal efficiency, η_{th}, and emission levels. Method of experiment and data result is based on European standard with the operating conditions of CL = 21-44 kW, H = 75-125 mm and LPG used as gas fuel. The thermal efficiency of the CB and SPMB were increased with the decreasing CL and H. An average of η_{th} of the SPMB is higher than the CB about of 4.58%, yielding a relatively high of energy saving of about 10.19% in average over the operating range. The SPMB emitted a relatively low average NO_x emission level of less than 59 ppm (corrected to 0% of O_2). But the CO emission levels of SPMB were relatively high as compared with the CB because of a lack of secondary air entrainment and incomplete combustion. Despite its relatively high CO emission of SPMB, the level was still lower than value of the industry standard in Thailand.

Key words: Self-aspirating burner; Porous medium burner; Thermal efficiency; Premixed flame; SMEs.

1. Introduction

Impinging flames are widely used in small and medium scale enterprises (SMEs) in Thailand because of the enhanced convective heat transfer rate in the impingement region around the stagnation point [1]. Self-aspirating conventional gas burners (CB) are normally used owing to their simplicity, low cost and easy handling but the CB has a relatively low thermal efficiency of about less than 30% [2], as shown in Fig. 1. With energy crisis in the world today when energy consumption is increasing whereas

Fig. 1 Self-aspirating conventional gas burner

the energy reserve is decreasing. So an improvement of thermal efficiency of the CB is a main objective of this work.

There are various techniques to enhance the thermal efficiency of the CB. One possibility is to make use porous medium burner technology because a combustion with matrix-stabilized has a self-preheating effect, resulting in a relative high burning velocity, a wide flammability and relatively low pollutants level [3-5]. Moreover the PMB has multimode of heat transfer, especially radiation mode that cause a higher thermal efficiency than the CB [6-7].

From a previous study, Ref. [8], the SPMB has been designed and completed preliminary testing in order to understand a mechanism of the SPMB such as temperature profile within packed bed, emissions level and primary aeration. But the all results from Ref. [8] based on a free flame, while flame type for a heating process in the SMEs is an impingement flame. In addition, the thermal efficiency, a key of burner performance, is not study in Ref. [8]. Therefore, the objective of this work is to experimentally study the effect of firing rate, CL, and distance between the burner top and the bottom of the loading vessel, H, on the thermal efficiency, η_{th}, and emission characteristics of the SPMB impinging flame. Finally, the thermal efficiency and emissions of the CB and the SPMB are compared.

2. Experiment setup

Details of the SPMB for thermal efficiency test in this study are well documented in Ref. [8] and thus only a brief description is given here. Fig. 2 shows a schematic diagram of the experimental setup for the SPMB, which consist mainly composed of four parts: a mixing tube 5, a mixing chamber 6, a perforated stainless steel plate 7 and a packed bed 8. The SPMB was placed on adjustable base 16. The flame from burners impinged on a cylindrical vessel containing water 15 with a flat bottom surface diameter of 920 mm and 800 mm height, which is made from a stainless steel. LPG 1 was selected as a fuel in the experiment because of its widespread use in Thailand's SMEs. The LPG contains 30% (by volume) of propane (C_3H_8) and 70% (by volume) of butane (C_4H_{10}) with a low heating value of about 106.5 MJ/m^3 [normal]. It is controlled by a pressure regulator with calibrated high pressure flow meter 2 and ball valve 3 that is connected with the fuel nozzle having diameter of 1.5 mm.

Water temperatures were monitored by a K-type sheath thermocouple 10 with a wire diameter of 0.5 mm and located at a quarter of vessel diameter, as shown in Fig. 2. The signal of thermocouple is digitized by a data logger 11 (Testo model 175-T3), and then transmitted to a personal computer. The oxygen sensor 12 is used to measure oxygen (O_2) concentration within the fresh mixture, which is sucked at the side wall of mixing chamber 6 , with an accuracy of about 0.05%. An uncertainty analysis of O_2

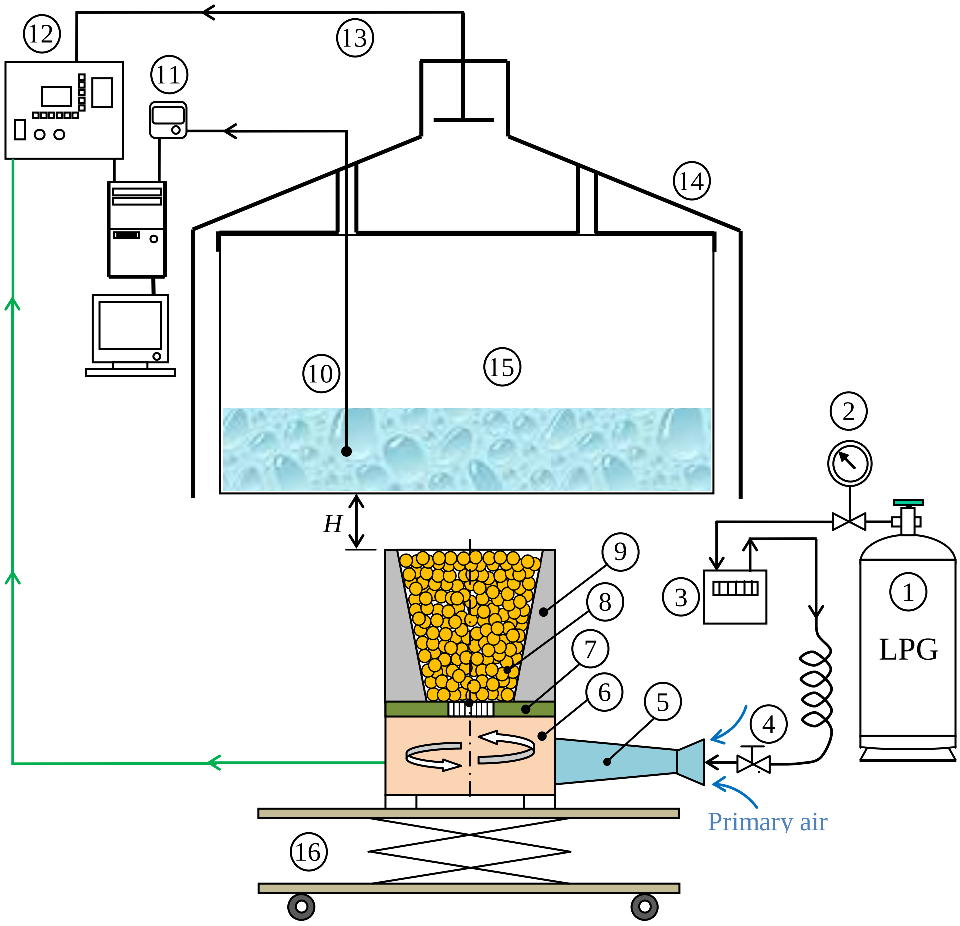

Fig. 2 Schematic diagram of SPMB's experiment setup 1. Fuel (LPG); 2. Pressure gauge; 3. high pressure gas flow meter; 4. Ball valve & gas fuel nozzle; 5. Mixing tube; 6. Mixing chamber; 7. Perforated stainless steel plate; 8. Packed bed burner; 9. High temperature cement; 10. Thermocouples; 11. Data logger; 12.Exhaust gas analyzer & oxygen sensor; 13. Sampling probe; 14. Hood; 15. Vessel containing water; 16. Adjustable base.

sensor was carried out with the method proposed by Kline and McClintock [9]. The oxygen concentration is used for estimating the primary aeration (PA) of the air entrainment into the mixing tube [10] to observe quality of the mixture.

A hood 14 for collecting a flue gas was designed and constructed from using European standards, EN 203-1:1992 [11] and EN 203-2:1995 [12], as a guideline. The vessel is covered by a hood for collecting the exhaust gases separately from the generated water steam, which is vented through the vertical channels integrated into the hood, see detail in Ref. [13]. The exhaust gases are then sampled by a probe 13 connected to an emission analyzer at the hood exit. Emission analysis is carried out by using a portable exhaust gas analyzer 12 (Messtechnik Eheim model Visit 01L). 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 $\pm$5 ppm (from the measure value) and a resolution of 1 ppm for both CO and NO_x. All emission measurements in this experiment are those corrected to 0% excess oxygen and dry-basis.

The thermal efficiency and emission tests in this work modified from the reference standard [11-12]. They were not operated simultaneously. For thermal efficiency test, the vessel is filled with 100 liters of water and the initial temperature of water was maintained about of 37-40°C in every experiment conditions and the burner with the fixed H was already in steady state (start from hot). Then the water temperature increased up to 90°C, the quantity of LPG and the usage time were recorded for the thermal efficiency calculation. After that the emissions data were measured while the burner was continually heated until the temperature of water was raised to 100°C.

Thermal efficiency, η_{th}, is calculated according to the European standards [12]. The η_{th} is defined as the ratio of the sensible heat absorbed by the specified water mass (m_w = 100 kg), to raised its temperature from an initial value $T_{w,i}$ to 90°C, to the combustion heat of the burned LPG, as expressed by Eq. (1)

$$\eta_{th} = \frac{m_w c_{p,w}(90 - T_{w,i})}{V_c \times LHV} \times 100\% \qquad (1)$$

where

$$V_c = V_{mes} \times \frac{p_a + p - p_w}{1013.25} \times \frac{288.15}{273.15 + T_g} \qquad (2)$$

and V_{mes} is measured by high pressure gas flow meter. p_w is approximated by the saturation pressure of the water vapor at the corresponding measured gas temperature, T_g. The reason for taking p_w into account as shown in Eq.(2) comes from the fact that the gas flow meter water used in the present study is a wet type. Therefore some of water vapor will contain within the gas because of vaporization of the water. As a consequence, the measured total gas pressure p has to be corrected by subtracting it with the partial pressure p_w of the water vapor containing within it. Neglecting p_w can cause a reduction in thermal efficiency by about 2% [13].

Table. 1 experimental conditions

Parameter	Value	Unit
CL	21, 34 and 44	kW
H	50, 75, 100 and 125	mm

The thermal efficiencies and emission characteristics of the CB and SPMB were compared experimentally at various firing rate, CL, and distance between the burner top and the bottom of the loading vessel, H, as shown in the Fig. 2. A detail of experimental conditions of the CB and the SPMB shows in table 1.

3. Results and discussion

3.1 Comparison of thermal efficiency

Fig. 3 shows the measured thermal efficiencies of the CB and the SPMB as a function of distance between the burner top and the bottom of the loading vessel, H, and firing rate, CL. As H increases, the thermal efficiency of both burners decreases monotonically. Except $CL \geq 34$ kW of the SPMB, the thermal efficiency increase to a maximum at H = 75 mm. This results show a good agreement with that of Ref. [14-15]. For $H < 75$ mm, complete combustion cannot be achieved before the flame is impinging on the vessel bottom, so resulting in a lower thermal efficiency. With an increasing of H, an intense combustion zone can be occurs and

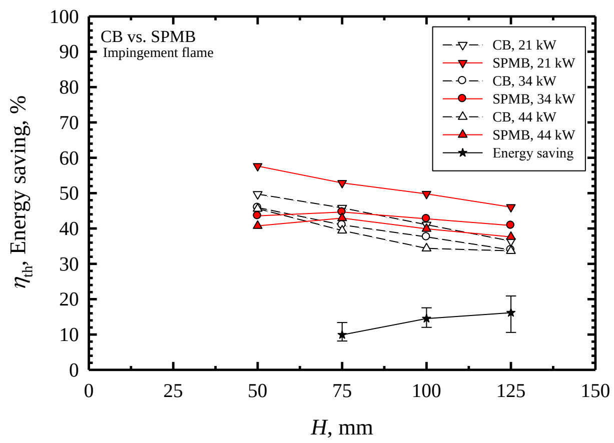

Fig. 3 Thermal efficiency and energy saving

the complete combustion allows the thermal efficiency to reach its maximum value. However, when the H exceeds a certain value, the hottest zone is at some distance away from the vessel bottom, and the thermal efficiency consequently decreases. The thermal efficiencies of the SPMB are almost higher than the CB because a flame of combustion with matrix-stabilized provides a multi-modes of heat transfer to bottom vessel, especially the radiative heat transfer, that causes a higher thermal efficiency [6-8], while a major heat transfer mode of the CB is mainly a convective heat transfer [2,16]. The maximum of thermal efficiencies of the SPMB and CB are shown in table 2.

3.2 Primary aeration

Fig. 4 shows the effect of H on primary aeration, PA, for the CB and SPMB. The measurement technique and estimation of the PA are used by Namkhat and Jugjai [10].

Table. 2 the maximum of thermal efficiency

CL, kW	CB		SPMB	
	η_{th}	H, mm	η_{th}	H, mm
21	49.70 %	50 mm	57.64 %	50 mm
34	45.89 %	50 mm	44.63 %	75 mm
44	45.58 %	50 mm	42.92 %	75 mm

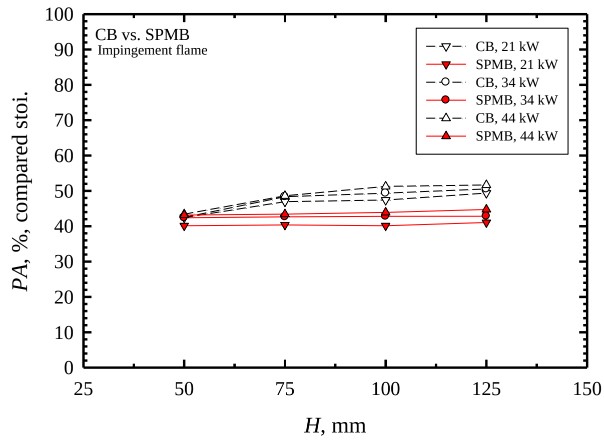

Fig. 4 Primary aeration of the CB and SPMB

For the CB, PA is almost increased with H and/or CL because of a fundamental phenomenon of the self-aspirating burner [17]. However the all of PA values of SPMB are lower than the CB for every test conditions because the viscosity of primary air of the SPMB is increased by a self-preheating effect [5], which is the outstanding characteristic of the porous medium burner. The measured PA of the SPMB is range from about 40-45% that implies a fuel-rich combustion regime. Thus the corresponding equivalence ratio is ranged from 2.22-2.50. This represents an advantage of combustion with porous medium technology that can be operated with fuel-rich condition.

3.3 Emission characteristics

With LPG combustion, the primary pollutants in the flue gas are CO and NO_x [18]. CO emission behavior of the CB and SPMB are illustrated in Fig. 5, in terms of the variation of CO emission against increasing of H. The CO emission level of theirs have a same trend, which the measured CO emissions decrease monotonically as H and/or CL increase because more secondary air is entrained towards the

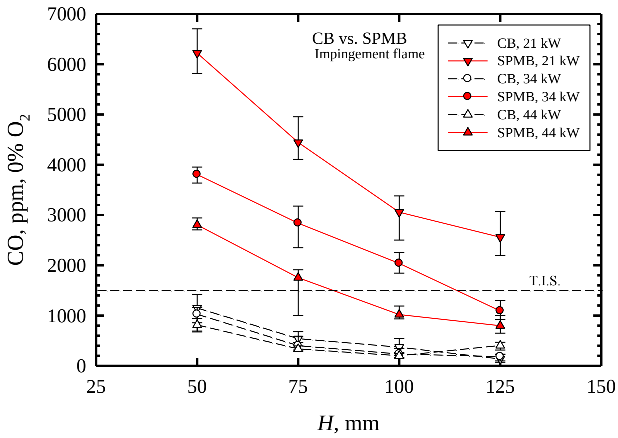

Fig. 5 CO emission between the CB and SPMB

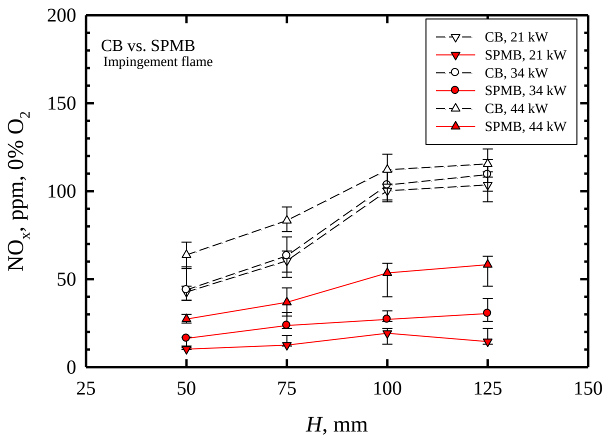

Fig. 6 NO_x emission between the CB and SPMB

reaction region to enhance the combustion [19]. But a multiple-jet flame from the CB is more entrained secondary air into the flame when compared with a single flame [1] from the SPMB that causes a short flame and low level of CO emission of the CB. However, at $H \geq 100$ mm and $CL > 34$ kW the CO emission level of the SPMB is lower than the Thai Industrial Standard (T.I.S.) [20], as shown in Fig. 5, due to a sufficient of primary air and secondary air, as shown in Fig. 4.

Fig. 6 shows dependence of NO_x emission on H for two different burners CB and SPMB. The trend of NO_x emission of both burners is similar that increases with increasing of H and/or CL because more complete combustion and high flame temperature [8] occurs as a result of increased amount of entrained primary air and secondary air, as shown in Fig. 4. The SPMB provides a lower NO_x emission than the CB. This verifies a unique characteristic of the porous medium burner that is capable of suppressing the NO_x formation [5-8]. At high H and/or CL of both burners, the increasing of NO_x may be caused by thermal NO_x [8].

3.4 Energy saving

$$EN = \frac{(\eta_{SPMB} - \eta_{CB})}{\eta_{SPMB}} \times 100\% \qquad (3)$$

Energy saving (EN) for the SPMB with respect to the CB is calculated by Eq. (3) [2]. Fig. 3 shows the calculated EN of the SPMB. As fixed H, EN in Fig. 3 is an average value of CL. At H = 50 mm, the EN can not calculated because the thermal efficiency of the CB is higher than the SPMB. As H increases from 75 mm, EN increases from 9.91% to the maximum value about of 16.15% at H = 125 mm, as a result of the high thermal efficiency of the SPMB is improved by radiative heat transfer [6-8].

From the result, the SPMB has a high thermal efficiency that causes a high energy saving [15]. AN average of η_{th} of the SPMB is higher than the CB about of 4.58%, yielding a relatively high of EN of about 10.19% in average over the operating range. Following the EN of the SPMB, we suggest to replace the CB in the SMEs of Thailand with the SPMB that will reduce cost of LPG consumption in Thailand about of 837 million baht/year (based on 2011) [21].

4. Conclusion

4.1 The thermal efficiency of the SPMB is higher than the CB because the heat transfer is enhanced by radiative heat transfer. The maximum thermal efficiency of the CB and the SPMB is 49.70% and 57.64%, respectively.

4.2 The turn-down ratio of SPMB is normally range for SMEs in Thailand, about 2.1.

4.3 The CO emission level of the SPMB is high when compared with the CB because of a lack of secondary air in the SPMB.

4.4 The level of NO_x emission of the SPMB is relatively low because of an advantage of combustion with the matrix stabilized flame.

4.5 A suggesting the possibility of the SPMB in replacing the CB because of high energy saving about of 10.19%.

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6. References

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