The 5th TSME International Conference on Mechanical Engineering
17-19th December 2014, The Empress, Chiang Mai

AEC012

Self-aspirating, liquid fuel, annular porous burner (SLAPB)

Kumnuan Pontree and Sumrerng Jugjai *

Combustion and Engine Research Laboratory (CERL),
Department of Mechanical Engineering, Faculty of Engineering,
King Mongkut's University of Technology Thonburi (KMUTT), 126 Pracha Uthit Rd., Bangmod, Tungkru, Bangkok 10140
*Corresponding Author: E-mail: sumrueng.jug@kmutt.ac.th, Tel: 0-2470-9128, Fax: 0-2470-9111

Abstract

This study presents design and development of a novel, self-aspirating, liquid fuel, annular porous medium burner (SLAPB) with stabilized flame inside a packed bed of a porous medium burner using a liquid ethanol for understanding its combustion performance and emission characteristics. The SLAPB is built in an annular shape with opening area at the center for more secondary air (SA) entrainment. Moreover, a vaporizer for vaporizing the liquid ethanol is embedded inside the burner wall instead of placing above the porous medium burner at outside for direct heating. To start the SLAPB, a burner warm up is done by gaseous fuel combustion using liquefied petroleum gas (LPG) while liquid water is supplied into the vaporizer for cooling and drained at outside as the water turns into a hot steam. Upon steady state combustion is achieved at the SLAPB, the water is turned off and is switched to the liquid ethanol with premixed combustion occurred at an auxiliary conventional self-aspirating burner (CB) that temporarily connected to the terminal of the vaporizer. Then, the LPG at the SLAPB is turned off and is switched to the ethanol vapor from the auxiliary CB. Transient period of the SLAPB during the switching period from the LPG to the ethanol vapor is investigated for understanding the simultaneous combustion phenomena within the porous medium burner and the vaporization process within the vaporizer. Particular attention is paid to observing flame movement and how to obtain flame stabilization within the burner. Effects of the primary air (PA), firing rate (FR) and central secondary air (SA) on the flame stabilization, temperature profiles within the burner, flame length the post flame outside the burner and emission characteristics are investigated. The ethanol flame can be successfully stabilized within the burner with a temperature peak occurred at the middle region of the burner and with a relatively low emission of CO and NO_X of about 102-132 ppm, 28-41 ppm, respectively. The PA strongly affects the flame stabilization within the burner. Flame moves upstream as the PA increases and vice versa with the flame moves to the downstream as the PA decreases. The SLAPB can offer a relatively wide turndown ratio with the firing rate (FR) ranging from 16 kW-23 kW without the problem of flame stabilization and emission characteristics. The SLAPB yields a shorter post flame length with the central SA entrainment than that of without the central SA.

***Keywords**:* Liquid fuel, Self-aspirating, Annular bed, Porous medium

1. Introduction

Nowadays, Thailand has widely used a conventional self-aspirating burner (CB) (Fig.1) with focusing on food industry and household sector because the CB is easily affordable, installable and conveniently maintainable. The operating principle of the CB is a natural entrainment of a high velocity jet of fuel issued on the atmospheric ambient still air and this burner type consumes liquefied petroleum gas (LPG) as a fuel. The statistics of using LPG reported by ministry of energy shows an increasing trend every year, (household sector taken part in more over 50% of the total) [1], causing an increase in the LPG price. For energy security reason of the country, a concepts of using ethanol as a replacement of the LPG is proposed because the ethanol is made from the agricultures stuff which is domestically produced. However, thermal efficiency of the CB is relatively low (less than 30%) [2]. Thus, a porous medium burner is one of a good choice for helping to improvement in the thermal sufficiency [3].

Porous medium has been applied for improving burner efficiency because of its self-heat recirculating recovery from the exhaust gas to the fresh reactant, resulting in the combustion temperature of higher than the adiabatic one [4].

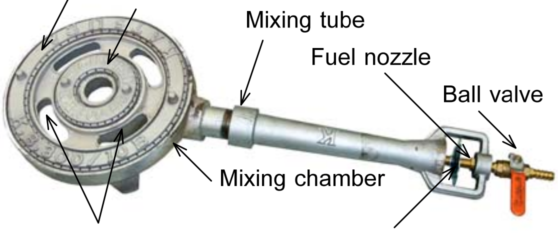


Fig. 1. Self-aspirating conventional burner (CB).

Both combustion and radiation intensities are significantly increased along with the flammability limit [5]. Previous investigations strongly emphasized on studying the combustion efficiency inside the porous medium based on mathematical modeling and experimental studies. Amanda J. Barra and Janet L. Ellzey [6] numerically studied heat recirculation within the porous medium wherein the premixed combustion of gaseous fuel is occurred. The combustion characteristics such as flame speed ratio, energy recirculation efficiency, preheat and reaction zones are defined. Results showed that combustion and radiative heat transfer processes were important and increasing equivalence ratio affected decreasing heat recirculation efficiency. W. Yoksenakul and S. Jugjai [7] designed and constructed a self-aspirating porous medium burner for gaseous fuel. A single cylindrical packed bed of Al_2O_3 spheres was used as a porous medium for submerged flame combustion. The experimental results indicated that the stability of combustion could be achieved and stabilized inside the porous medium with relatively low emission of CO and NO_X at the burner exit. Kaplan, M. and Hall, M.J. [8] examined the combustion of liquid fuel within the porous inert media (PIM). The fuel heptane was sprayed and impinged on the entrance of the porous medium section followed by combustion within it at a fixed fuel flow rate of approximately 0.025 lpm. Stable combustion within the porous medium was achieved at equivalence ratio of 0.57-0.67. Temperature at the equivalence ratio of 0.64 is as high as 1170-1370 ^{O}C was achieved inside the porous medium with CO and NO_X varied from 3-7 ppm and from 15-20 ppm, respectively. All literatures mentioned above stated that the combustion locations can be stabilized within porous medium with paying attention on premixed combustion of a gaseous fuel.

However, investigation of a self-aspirating burner using liquid fuel has not been studied before. Therefore, this research focuses on the flame stability within an annular porous medium of a self-aspirating burner using liquid ethanol. Temperature profiles within the porous medium, combustion performance and emissions characteristics of CO and NO_X at the burner exit are reported.

2. Design of SLAPB

Design of SLAPB relies on the same parameter as that of CB, i.e. pressure drop across the burner (ΔP) and mixing tube dimension. Porous medium is an annular packed bed of alumina spheres (Al_2O_3). Diameter of the Al_2O_3 spheres can calculate from Eq. (1) [9].

$$Pe = \frac{S_{\mathrm{L}} d_{\mathrm{p}} \rho}{k} \tag{1}$$

Peclet number (Pe) of greater than 65 can get flame submerged within the pack bed of the Al_2O_3 spheres and vice versa according to the quenching effect.

2.1 Packed bed length of the SLAPB

Length of the annular packed bed of the Al_2O_3 spheres is determined from a suggestion of J.R. Sodre & J.A.R. Parise [3], the equations of which had been adapted from Ergun's equation [10]. Attention has been paid to the correction factor (C) that corrects the interstitial velocity of the cylindrical to annular shapes as stated in Eqs. (2) and (3).

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

$$C = \frac{\bar{\upsilon}_{\mathrm{c}}}{\bar{\upsilon}} = \frac{\bar{\upsilon}_{\mathrm{wi}}}{\bar{\upsilon}}\frac{A_{\mathrm{wi}}}{A_{\mathrm{b}}} + \frac{\bar{\upsilon}_{\mathrm{t}}}{\bar{\upsilon}}\frac{A_{\mathrm{t}}}{A_{\mathrm{b}}} + \frac{\bar{\upsilon}_{\mathrm{we}}}{\bar{\upsilon}}\frac{A_{\mathrm{we}}}{A_{\mathrm{b}}} \tag{3}$$

For more accuracy calculation, the distribution of interstitial velocity profile had been divided into three regions keeping away from wall effects [13], i.e. an internal wall region ($\bar{\upsilon}_{\mathrm{wi}}$), a velocity transition region ($\bar{\upsilon}_{\mathrm{t}}$) at the middle, and external wall region ($\bar{\upsilon}_{\mathrm{we}}$).

2.2 Vaporizer length of the SLAPB

Vaporizer is designed and buried in the burner wall and turning around the burner for receiving heat to vaporize the liquid ethanol. Burner wall has been constructed using refractory mortar. An amount of energy (Q) that is utilized for vaporization process of the liquid ethanol is determined from a sensible heat, a latent heat and a superheated heat. Then length of the vaporizer can be calculated by using Eqs. (4) and (5) [11] based on the following assumptions; combustion system is steady state, heat transfer is one dimensional calculation, wall temperature is constant and, physical properties of ethanol are constant.

$$\dot{Q} = sk\left(T_{\mathrm{b}} - T_{\mathrm{s}}\right) \tag{4}$$

$$\dot{Q} = UA_{\mathrm{s}}\Delta T_{\mathrm{lm}} \tag{5}$$

3. Experimental apparatus

Fig. 2 shows photography of the constructed SLAPB. As is clearly seen the vaporizer is completely buried inside the wall of the packed bed of the porous medium for absorbing heat for vaporization. The porous medium is annular in shape to allow for the central secondary air (SA) from the bottom flowing upwards and burned with the post flame combustion at the burner exit for more complete combustion. Apart from the main burner of the packed bed porous medium, an auxiliary venturi-type burner is also connected with the outlet of the vaporizer on the right-hand side of the main burner to assure that the complete vaporization of the liquid ethanol is achieved before being switched to the main burner by controlling the nearby control valves.

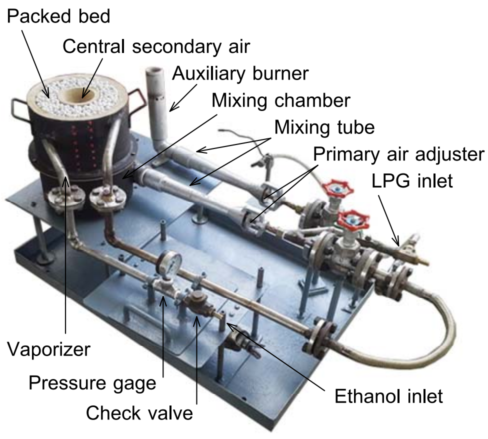
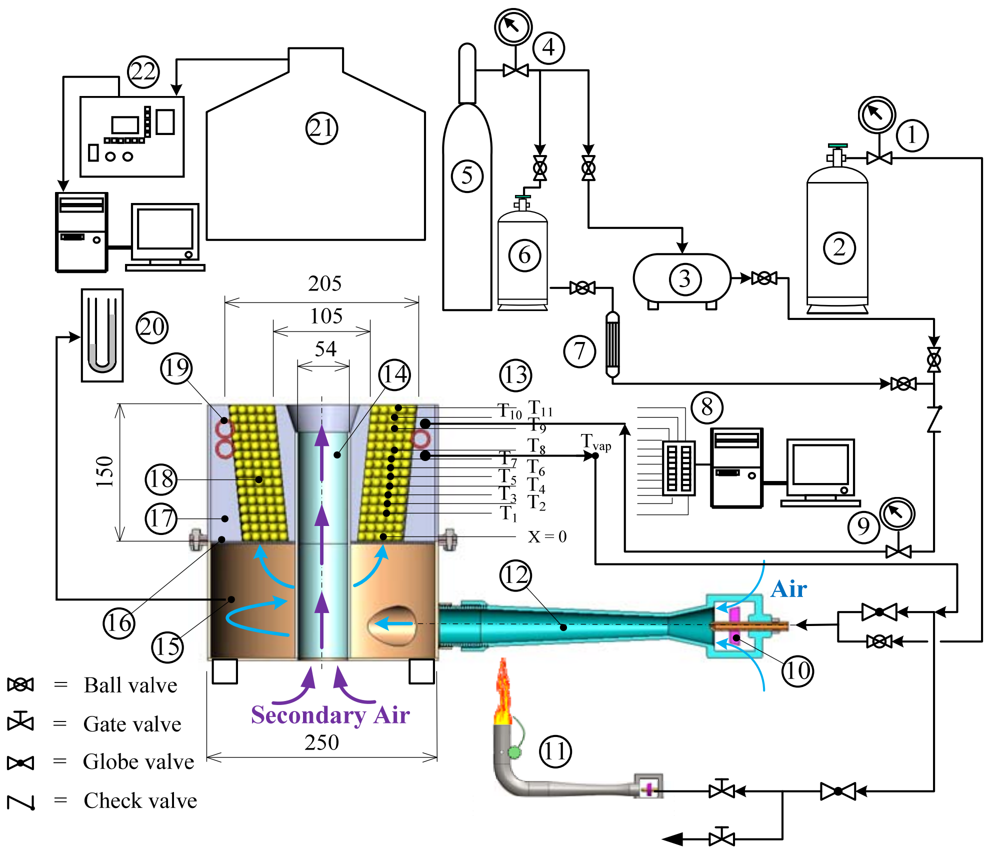


Fig. 2. Photography of the SLAPB.



1. Pressure regulator (LPG) 2. Fuel (LPG) 3. Water tank 4. Pressure regulator (N_2) 5. Liquid Nitrogen
6. Fuel Ethanol 7. Flow meter 8. Data logger 9. Pressure gage 10. Primary air adjuster 11. Auxiliary burner
12. Mixing tube 13. Thermocouples 14. Secondary pipe 15. Mixing chamber 16. Perforated stainless steel plate
17. Refractory mortar 18. Packed bed burner 19. Vaporizer 20. Manometer 21 Hood 22. Exhaust analyzer

Fig. 3. Experimental setup of the SLAPB.

Fig. 3 shows a schematic diagram of the experimental setup and details of the SLAPB. It consists of four main systems, i.e. a fuel supply system, burner system, temperature acquisition system and emissions measuring system. The temperature has been acquired by DATA LOGGER (EQ 600) using thermocouples of types B and N. An exhaust analyzer (MESSTECHNIK EHEIM series Visit-01L) is used for analyzing CO, CO_2, O_2, and NO_X emissions.

To start the SLAPB, a firing rate FR = 23 kW of energy input of the LPG is supplied into the main burner for warming up while liquid water is supplied into to the vaporizer for cooling and drained at outside as the water turns into a hot steam. As steady state combustion is achieved at the main burner, the water is turned off and is switched to liquid ethanol with premixed combustion occurred at the nearby auxiliary conventional self-aspirating burner (CB) that is temporarily connected to the terminal of the vaporizer. As steady state combustion of ethanol is established at the auxiliary burner without any re-condensation, turn off the LPG at the main burner and switch to the ethanol vapor from the auxiliary burner, using the nearby control valves.

4. Results and discussion

4.1 Flame stabilization within the SLAPB.

Fig. 4 shows transient behavior of temperatures within the packed bed of SLAPB during switching from LPG to ethanol vapor at firing rate of FR = 23 kW is presented. The initial LPG submerged flame for warming up the SLAPB is well stabilized with full opening of the primary air adjuster at the mixing tube inlet and with peak temperature occurred at T_9 is illustrated up to t =

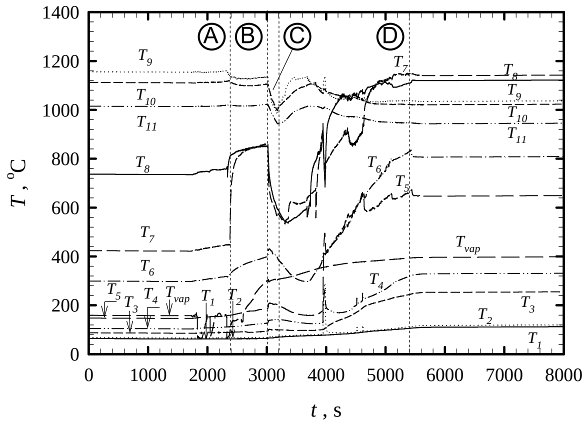


Fig. 4. Transient of temperature within the SLAPB.

2,200s before the primary air adjuster is completely closed followed by a small decrease in T_9 as depicted by point Ⓐ. At point Ⓑ, the LPG is completely turned off resulting in a further decrease in T_9 before increasing again when the ethanol vapor comes to replace the LPG at the point Ⓒ. During this time the primary air adjuster of the SLAPB mixing tube is carefully adjusted with strong temperatures fluctuation happening before flame stabilization with flat temperatures was achieved again at point Ⓓ where flame location occurred at T_7. Note that the stabilized location of submerged flame is changed from T_9 with LPG to T_7 with ethanol because the effect of equivalence ratio of ethanol is nearer stoichiometric condition than LPG because of a high oxygen composition of ethanol. A porous medium burner that is operated with liquid ethanol has been successfully accomplished.

4.2 Effect of primary aeration PA.

Fig. 5 shows an effect of the primary air adjuster angle θ (measured from a fully closed position) on flame stability within the porous medium. Temperature profile of LPG at fully open of θ is also included for comparison. θ is very sensitive to ethanol flame stabilization. Allowable range of θ was found from 0-160°. Beyond this range the flames become unstable by moving back to the upstream side and flash back due probably to the corresponding equivalence ratio reaches the stoichiometry. Burning velocity is higher than flow velocity of the mixture. Flame location is well confined to the bottom of the vaporizer irrespective of θ.

Fig. 6 shows the corresponding emissions of CO and NO_X with the variation in θ. At θ = 160°, the optimum point of burner is found with the lowest in CO emission of less than 150 ppm. NO_X is relatively low of less than 50 ppm due to the prominent characteristic of the porous medium burner.

4.3 Effect of firing rate FR

Fig. 7 shows effect of firing rate FR on flame stabilization within the porous medium. Flame location moves upstream when FR is increased from 16 kW to 23 kW due to a strong effect of energy recirculation. The temperature of combustion is also increased. Relatively high turndown ratio is achieved with stable combustion from 16-23 kW.

Fig. 8 shows the corresponding emissions of CO and NO_X with the variation in FR. Both CO and NO_X emissions increase when FR is increased. However, the central secondary air can help to enhanced combustion of post flame at outside the porous medium, resulting in a reduction in CO emission and the post flame length as shown in Fig. 9.

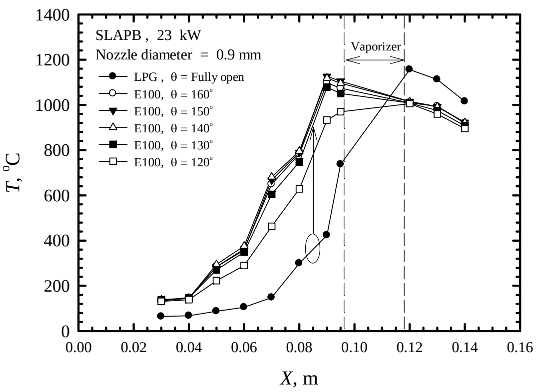


Fig. 5. Effect of primary aeration (PA).

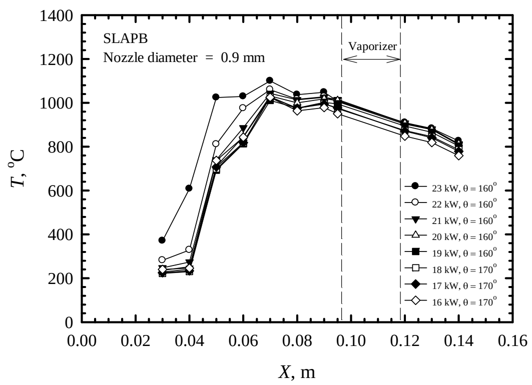


Fig. 7. Effect of firing rates (FR) on the temperature profile.

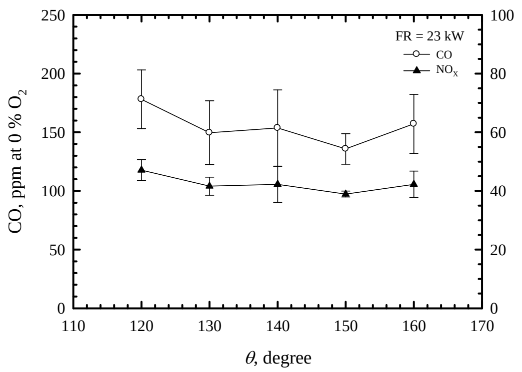


Fig. 6. Effect of primary aeration (PA) on emissions.

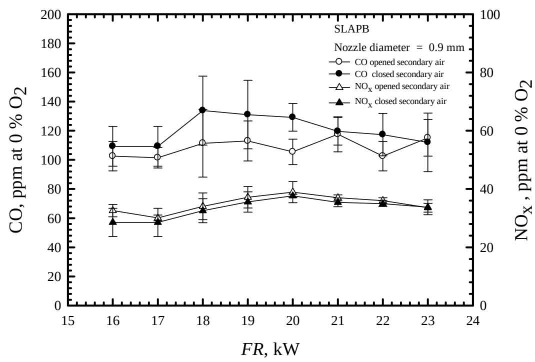


Fig. 8. Effect of firing rate (with and without central secondary air).

(a) (b)

Fig. 9. Photographes of the post flame with and without the central secondary air.

5. Conclusions

1. Flame stabilization in the SLAPB is accomplished by operating burner with ethanol.
2. Effect of the angle of the primary air adjuster was studied and it is very sensitive to the flame stabilization.
3. Effect of firing rate was studied and relatively high turn down ratio was found.
4. The central secondary air is very helpful in further enhancing combustion of the post flame at outside the SLAPB with a decrease in CO emission and flame length.

6. Acknowledgement

This research is sponsored by the Combustion and Engine search Laboratory (CERL), King Mongkut's University of Technology Thonburi (KMUTT).

7. References

[1] Energy Policy and Planning Office. *Energy database*. See also:, Thailand: Ministry of Energy http://www.eppo.go.th/info/index.html; 2013.

[2] Jugjai S, Rungsimuntuchart N. High efficiency heat-recirculation domestic gas burners. *Experimental Thermal and Fluid Science*, 2002;26(5):581-92.

[3] J.R. Sodre, J.A.R. Parise, Experimental *Thermal and Fluid Science,* 17 (1998) 265-275

[4] Weinberg, FJ. Combustion temperature: the future Nature 1971; 233:239-241.

[5] Lloyd, S. A. and Weinberg, F. J., 1974,"A burner for mixtures of very low heat content", Nature, Vol. 251, pp. 47–49.

[6] Barra, J.A. & Ellzey, L.J. (2004). Heat recirculation and heat transfer in porous burners, *Combustion and flame*, 137, 230-241.

[7] W. Yoksenakul, S. Jugjai. (2011). Design and development of a self-aspirating, porous medium burner with a submerged flam, *Energy*, vol.36, March 2011, pp. 3092-3100.

[8] Kaplan, M. and Hall, M.J., 1995, "The Combustion of Liquid Fuels Within a Porous Media Radiant Burner", *Experimental Thermal and Fluid Science,* Vol. 11, No. 1, pp. 13-20.

[9] Babkin VS, Korzhavin AA, Bunev VA. Propagation of premixed gaseous explosion flames in porous media. *Combustion and Flame,* 1991;87(2): 182-90.

[10] Ergun S. Fluid flow through packed columns. Chemical Engineering Progress 1952; 48:1179-1184.

[11] Yunus A. Cengel, (2006). Heat and mass transfer, 3rd edition, ISBN-13: 007-125739-8 or ISBN-10: 007-125739-X.