# The Effect of Primary Air Preheat on the Primary Aeration of a Self-aspirating Burner

Apinunt Namkhat and Sumrerng Jugjai*

Combustion and Engine Research Laboratory (CERL), Department of Mechanical Engineering, Faculty of Engineering,
King Mongkut's University of Technology Thonburi (KMUTT),
Bangkok, Thailand 10140
*Corresponding Author: Tel: (662) 4709128, Fax: (662) 4709111,
E-mail: sumrueng.jug@kmutt.ac.th

***Abstract***

Air preheat is used in many applications for heat recovery. In recent years, the combustion with air at higher than atmospheric temperatures also occurs in the new type of a self-aspirating burner. In the present work is aimed at investigating the effects of changes in the combustion air temperature on the primary aeration and flame structure. These studies were performed for both with and without preheat case of combustion air. It is observed that the level of primary air entrainment is increased with increasing the heat input. At a high level of heat input, the primary air entrainment will be stable and not depending on the heat input, due to limitation of the size of mixing tube and the burner port. The preheated case gives a lower primary aeration than the without preheat case, because the preheating effect will make the fluid in the mixing tube has more viscosity. A yellow tip flame also occurs with increasing the preheated air temperature due to decreased primary aeration. As a result, it lead to the understanding of the influences of air preheat which affect primary air entrainment. This information may be helpful in designing a high-performance burner in the future.

***Keywords**:* Self-aspirating burner, preheating effect, primary aeration, flame structure

## 1. Introduction

Self-aspirating burners designed to be fueled by liquefied petroleum gas (LPG) are very popular for cooking in the household sector in Thailand. The total of LPG consumption is increasing every year [1]. The household sector accounts for about 54% of the country's total LPG consumption [1]. Therefore, the higher the performance of the self-aspirating burners being used in the country, the larger the amount of energy that can be saved by this major sector.

The overall efficiency of a self-aspirating burner is decided by the combustion and heat transfer performances, which depend on the design of the burner, stove and the pot [2]. In recent years, the self-aspirating burners has been carried out to improve thermal performance and to reduce pollutant emissions by developing the burner port geometry and the combustion system [3-5]. The results showed that the thermal efficiency of the proposed burner is higher than that of a conventional burner. However, through the preheating effect of the primary air [5], the amount of air entrainment is further reduced because of an increase in the flow resistance [6]. Therefore, incomplete combustion is taken place with a high level of CO emissions. The precise prediction of a value of the primary air entrainment is of importance for more complete combustion of the self-aspirating burners. Many studies have been conducted with the self-aspirating burners to predict the level of the primary air entrainment [7-10]. They found that primary air entrainment is a function of fuel gas flow rate, type of fuel gas, injector geometry, mixing tube geometry, and burner port geometry. However, most of the studies mentioned above are limited to the cold test case. The preheating effect caused by combustion was overlooked. A preliminary experimental study [11,12] on primary air entrainment of a self-aspirating burner with both hot test and cold test cases were conducted. The results showed that the hot test gives about a 22 percentage point (37% relative) lower primary aeration value than that of the cold test because of the preheating effect caused by combustion.

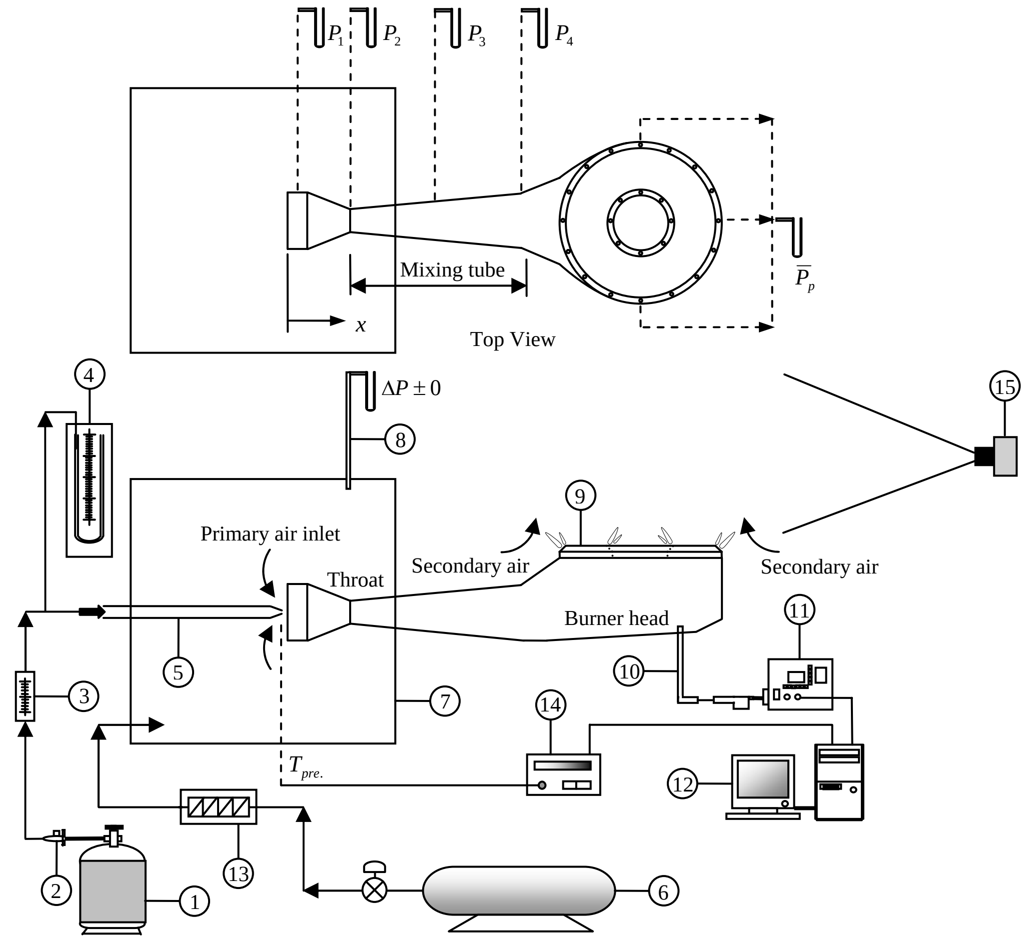
As a follow-up of Ref. [11,12], the purpose of the present study is to get a deeper understanding of the effects of changes in the combustion air temperature on the primary aeration and flame structure, considering air temperatures in the range 33$^{o}$C (without preheat case) to 300$^{o}$C. It lead to the understanding of the influences of air preheat which affect primary air entrainment. This information may be helpful in designing a high-performance burner in the future.

## 2. Methodology

Fig. 1 shows a schematic diagram of the primary aeration measurement using the oxygen sensor which is applied for both with and without preheat cases. It is composed of a self-aspirating burner with cross-sectional area of injector $A_i$ = 0.64 mm$^2$, cross-sectional area of throat $A_t$ = 254.47 mm$^2$, and overall cross-sectional area of the burner port $A_p$ = 245.44 mm$^2$. LPG is used as a fuel in the experiment, and the oxygen sensor is used to measure oxygen concentration with an accuracy of about 0.05%. An uncertainty analysis was carried out with the method proposed by Kline and McClintock [13]. Using a 95% confidence level, the maximum and minimum uncertainties in the presented primary aeration were found to be 3.3% relative and 1.6% relative, respectively.

In the without preheat case, the flow rates of LPG (1) are controlled by a pressure regulator (2). The flow meter (3) is installed downstream of a pressure regulator. The volume flow rates are measured in order to calculate the heat input ($q$) of the fuel gas. A mercury manometer (4) is used to measure the fuel pressure. Then, the fuel gas is injected by the injector orifice (5) into the mixing tube. Meanwhile, the primary air from the air compressor (6) is supplied to the air storage tank (7), which is provided to maintain the primary air temperature. The dimensions of the air storage tank are 40 x 40 x 40 cm. The air storage tank walls are covered with 4 cm thickness of ceramic fiber. The pressure within the air storage tank is maintained at an ambient condition, as measured by the water manometer 8. The primary air will be entrained into the mixing tube by a momentum-sharing process between the injected gas and the surrounding air. The mixture is distributed uniformly to the multiple port burner 9 with premixed flame. Meanwhile, the oxygen concentration in the mixture is measured by using a sampling gas line 10, which is located at the burner head, and then carried to the oxygen sensor 11. The primary aeration can be calculated following equation:

$$PA = \frac{\%O_2}{(A/F)_{stot.} \times (21 - \%O_2)} \times 100 \qquad (1)$$




| | | |
|---|---|---|
| 1. Fuel (LPG) | 6. Air compressor | 11. Oxygen sensor |
| 2. Pressure regulator | 7. Air Storage tank | 12. Computer |
| 3. Flow meter | 8. Water manometer | 13. Air heater |
| 4. Mercury manometer | 9. Multiple port burner | 14. Data logger |
| 5. Injector orifice | 10. Sampling tube | 15. Digital camera |

Fig. 1 Schematic diagram of primary aeration experiment

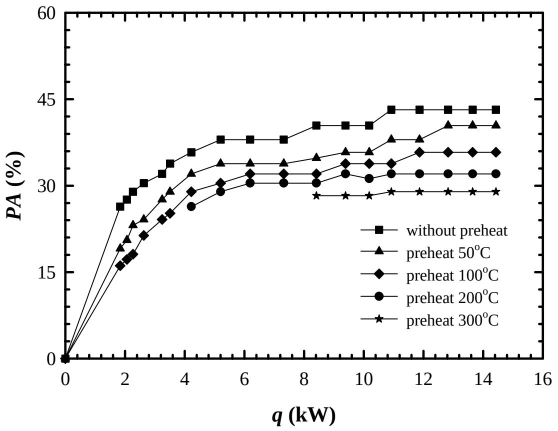



Fig. 2 Typical primary aeration of a self-aspirating burner

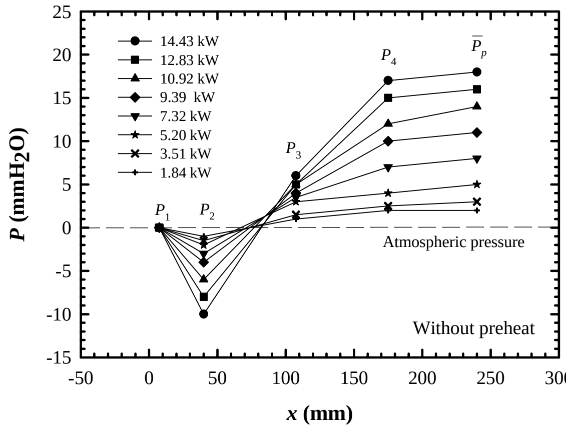



Fig. 3 Effecting of heat input on pressure drop along a self-aspirating burner

For the preheat case, a similar experiment is performed using the same procedure as described for the without preheat case, but with a primary air preheat. The air heater 13 is installed downstream of the air compressor and provided to control a primary air preheat. In this study, four preheated air temperatures ($T_{pre.}$) are selected for the experiments (50°C, 100°C, 200°C, and 300°C). These temperatures are performed with N-type thermocouple, which is located at the primary air inlet, and then carried to the data logger 14.

The static pressure ($P_1 - P_4$) at different locations within the mixing tube, as shown in Fig. 1 (top view), are also measured by the water manometer. Static pressure under the burner port is reported by using an average value of $\overline{P}_p$. Meanwhile, the flame images are also captured with a digital camera 15.

## 3. Results and discussion

### 3.1 Primary aeration ($PA$) and its variation with $q$

Fig. 2 shows typical primary aeration of a self-aspirating burner for both with and without preheated cases. It is clear that the primary aeration in both cases rapidly increases at the early stage with an increasing heat input ($q$). After that, the primary aeration is stable and no longer dependent on the heat input, due to limitations of mixing tube and burner port sizes. The primary aeration decreases with an increasing preheated air temperature ($T_{pre.}$). It is interesting to note that, the preheated air temperature of $T_{pre.}$ = 300°C gives about a 14 percentage point (33% relative) lower $PA$ value than that of the without preheat case, because the preheating effect causes expansion of the mixture and an increase in its viscosity.

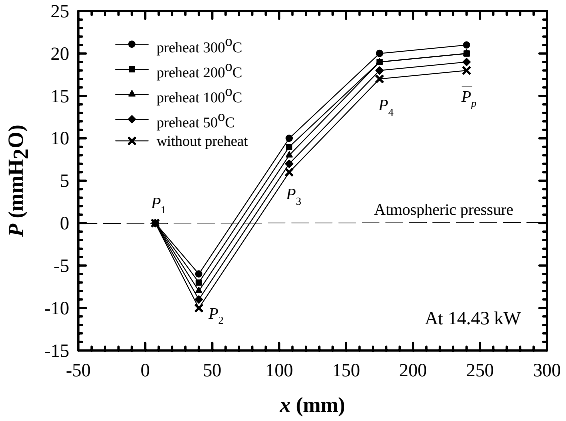



Fig. 4 Effecting of primary air preheat on pressure drop along a self-aspirating burner

### 3.2 Pressure drop ( $P$ ) and its variation with $x$

Fig. 3 shows typical variations of static pressure along the mixing tube for the without preheat case. All ranges of heat input show similar trends. At the mixing tube inlet, $P_1$ is zero because of its representation of an atmospheric pressure. Then, at the throat, the pressure decreases and becomes negative (or vacuum) pressure $P_2$ , which is helpful in primary aeration. Beyond the throat up to the burner port exit the pressure slightly increases, which contributes to the flow of fluid in the mixing tube. It is clearly seen that the vacuum magnitudes decrease with decreasing heat input. This results in low primary aeration.

Fig. 4 shows a comparison of static pressure along the mixing tube between with and without preheat cases. Both cases show similar trends as already described in the previous section. It was observed that the pressure distribution for the preheat case is greater than that of the without preheat case. Moreover, the pressure distribution also increases with the preheated air temperature.

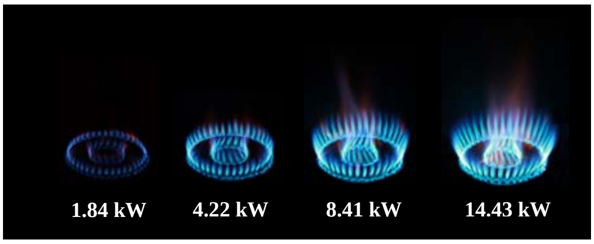



Fig. 5 Effecting of heat input on flame structure for without preheat case

This may be attributed to an expansion of the gas mixture flowing inside the mixing tube, which in turn results in the lowering of primary aeration.

### 3.3 Flame structure

The flame image of a self-aspirating burner in the open environment for the without preheat case, as shown in Fig. 5. The flame structure of a partially aerated burner has two distinct regions: the inner cone flames and the outer cone flames. The inner cone flames are the rich premixed flames burning with the entrained primary air, while the outer cone flames are the non-premixed flames due to the combustion of the unburnt fuel and intermediate species with the secondary air. It was observed that a yellow tip flame occurs in the inner cone flames as heat input decreases because of the lowering of primary aeration. On the other hand, when further increasing heat input, the inner cone flames are greenish-blue in colour showing the abundance of CH and $C_2$ chemiluminescence in the flames [2]. However, the yellow tip flame appears in the outer cone flames, because the mainly secondary air can not entrain from the surrounding above the burner plane. Flame appearance and flame stability are known to be affected by thermal

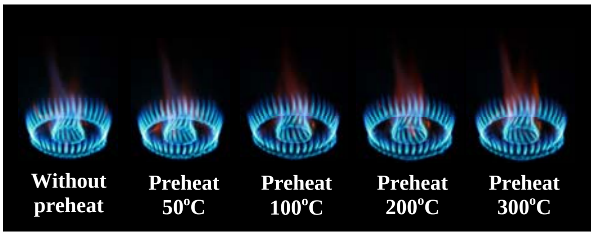



Fig. 6 Effecting of primary air preheat on flame structure at $q$ = 8.41 kW

input (flow rate of fuel) and primary aeration. It was found that the increase of thermal input leads to the increase of flame height, because of the high velocity of the gas mixture.

Fig. 6 illustrates the direct flame images obtained with the different preheated air temperatures to show the effect on the flame structures. It is clearly seen that a yellow tip flame occurs with increasing the preheated air temperature due to decreased primary aeration. Therefore, incomplete combustion is taken place with a high level of CO emissions. However, it is also observed that the flame height at all ranges of $T_{pre.}$ is quite stable. The high preheated air temperature causes low primary aeration and an increase in the burning velocity. Thus, the flame height is almost constant irrespective of the temperature of preheated primary air.

## 4. Conclusions

1. The $PA$ level in both with and without preheat cases rapidly increases at the early stage with increasing $q$. After that, it is stable and no longer dependent on $q$, due to limitations of mixing tube and burner port sizes.

2. The preheat case of $T_{pre.}$ = 300°C gives about a 14 percentage point (33% relative) lower $PA$ value than that of the without preheat case, because the preheating effect causes expansion of the mixture and an increase in its viscosity.

3. A yellow tip flame occurs with increasing the preheated air temperature due to decreased primary aeration. Therefore, incomplete combustion is taken place with a high level of CO emissions. However, the flame height is almost constant due to increased burning velocity.

4. In order to design a high-performance burner in the future, it is recommended that the preheating effect be taken into consideration in designing the mixing tube so as to obtain an accurate primary aeration.

## Nomenclature

| | |
|---|---|
| $A$ | cross-section area, mm$^2$ |
| $A/F$ | air-fuel ratio |
| $\%O_2$ | oxygen concentration, % |
| $P$ | pressure, N/m$^2$ |
| $\overline{P}$ | average pressure, N/m$^2$ |
| $PA$ | primary aeration, % |
| $q$ | heat input, W |
| $T$ | temperature, °C |
| $x$ | axial distance, mm |

## Subscripts

| | |
|---|---|
| $i$ | injector outlet |
| $p$ | burner port |
| $pre.$ | preheat |
| $stoi.$ | stoichiometric |
| $t$ | throat |

## 5. References

[1] Energy Policy and Planning Office, Ministry of Energy, Thailand (2007). *Energy database*, URL: http://www.eppo.go.th/info/index.html, access on 28/06/2007

[2] Basu, D., Saha, R., Ganguly, R. and Datta, A. (2008). Performance improvement of LPG cook stoves through burner and nozzle modifications, *Journal of the Energy Institute*, vol. 81(4), December 2008, pp. 218 – 225.

[3] Jugjai, S., Tia, S. and Trewetasksorn, W. (2001). Thermal efficiency improvement of an LPG gas cooker by a swirling central flame, *International Journal of Energy Research*, vol. 25(8), May 2001, pp. 657 – 674.

[4] Hou, S.S., Lee, C.Y. and Lin, T.H. (2007). Efficiency and emissions of a new domestic gas burner with a swirling flame, *Energy Conversion and Management*, vol. 48(5), January 2007, pp. 1401 – 1410.

[5] Jugjai, S. and Rungsimuntuchart, N. (2002). High efficiency heat-recirculating domestic gas burners, *Experimental Thermal and Fluid Science*, vol. 26(5), April 2002, pp. 581 – 592.

[6] Maughan, J.R., Cahoe, J.R. and Ghassemzadeh, R. (1992), *Autoregulation of primary aeration for atmospheric burners*, US Patent Number 5104311, USA, URL:http://www.patentstorm.us/patents/5104311.html, access on 02/11/2007

[7] Pritchard, R., Guy, J.J. and Connor, N.E. (1977). Handbook of industrial gas utilization: engineering principles and practice, Van Nostrand Reinhold Co., New York.

[8] Singh, G., Sundararajan, T. and Shet, U.S.P. (1999). Entrainment and mixing studies for a variable density confined jet, *Numerical Heat Transfer, Part A: Applications*, vol. 35(2), September 1998, pp. 205 – 223.

[9] Singh, G., Sundararajan, T. and Bhaskaran, K.A. (2003). Mixing and entrainment characteristics of circular and noncircular confined jets, *Journal of Fluids Engineering*, vol. 125(5), September 2003, pp. 835 – 842.

[10] Namkhat, A. and Jugjai, S. (2007). Primary air entrainment characteristics of a self-aspirating burner, paper presented in *the 21st Conference of Mechanical Engineering Network of Thailand*, Cholburi, Thailand.

[11] Namkhat, A. and Jugjai, S. (2009). Fundamental Study on Primary Air Entrainment of a Self-aspirating Burner: Comparison on Hot Test and Cold Test Case, paper presented in *the World Renewable Energy Congress 2009-Asia, The 3rd International Conference on "Sustainable Energy and Environment (SEE 2009)"*, Bangkok, Thailand.

[12] Namkhat, A. and Jugjai, S. (2010). Primary air entrainment characteristics for a self-aspirating burner: Model and experiments, *Energy*, vol. 35(4), April 2010, pp. 1701 – 1708.

[13] Kline, S.J. and McClintock, F.A. (1953). Describing uncertainties in single-sample experiments, *Mechanical Engineering*, vol. 75, January 1953, pp. 3 – 8.