American Journal of Energy and Power Engineering
2014; 1(1): 1-8
Published online March 10, 2014 (http://www.aascit.org/journal/ajepe)

Keywords
Combustion Improvement,
Noise Reduction,
Quick Burner,
Dispersive Combustion,
Porous Flame Plate

Received: February 01, 2014
Revised: February 19, 2014
Accepted: February 20, 2014

Improvement and noise reduction for the active air inlet quick burner by using dispersive combustion method

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Citation
Chien-Chih Chen, Da-Yi Tsai, Chen-Ching Ting, Kuei-Yi Lin. Improvement and Noise reduction for the Active Air Inlet Quick Burner by Using Dispersive Combustion Method. *American Journal of Energy and Power Engineering.* Vol. 1, No. 1, 2014, pp. 1-8.

Abstract
An active air inlet quick burner is widely used in Asia for cooking due to it provides extremely large thermal power of ca. 5500 W, but its yellow flame shows incomplete combustion and a huge noise of ca. 100 dB is also generated. This article presents experimental data for combustion improvement and noise reduction using dispersive combustion method. For dispersing the single combustion, a porous flame plate was developed and covered on the burner, which forced mixture of the fuel gas and air to be dispersed through holes of the porous flame plate and yielded numer- ous fasciolar combustion. Adding the porous flame plate has built a mixing room, which provides the better mixing process. Moreover, the smaller combustion also yields the smaller combustion knock. Diameter and depth of the holes on the porous flame plate are used as the main influencing parameters, where the diameters are 2, 3, 3.4, 4 mm and the depths are 4.5, 10, 15, 20 mm. The results show that applying the porous flame plate has maximum doubly increased the thermal power and the noise is reduced to ca. 70 dB under the same thermal power condition.

1. Introduction

An active air inlet quick burner is especially applied in Asia. Applying the forced air inlet technique increases mass flow rate of the incoming fuel gas and air, so that the combustion power of the burner is enlarged. Figure 1 shows photo of such a commercial quick burner, which is mainly composed of the stove and the blower. The active air inlet quick burner is popularly applied due to it has extremely large combustion power of ca. 5500 W, but its too loud noise of ca. 100 dB hurts the long time cookers and its incomplete combustion also causes large energy loss. Therefore, studying noise reduction and combustion improvement for the commercial active air inlet quick burner is absolutely valuable.

Noise is a disgusting sound, which is produced by pressure oscillations being the succession of compression and rarefaction waves. A too loud noise often causes people to be impatient and disturbed [1, 2]. A hurted hearing nerve by noise could

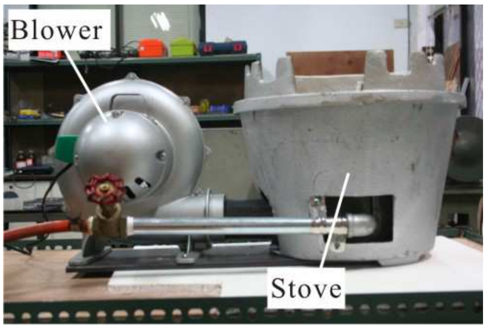


Figure 1. Photo of the active air inlet quick burner.

yield the results of provisional and even permanent deaf, so that noise reduction is always a very important topic [3, 4]. In general, the noise larger than 90 dB is very dangerous for the long time workers. Among the various noises, the noise produced by work is the most difficult to avoid, which also badly hurts people.

Noise of the active air inlet quick burner is mainly generated by pipe flow and combustion. The frequently used method for noise reduction of pipe flow is the filtering technique [3–7], which generally change the turbulent pipe flow to the laminar pipe flow. A turbulent pipe flow through a laminar pipe filter can decrease amplitude of the flow vibration and further reduce noise. In fact, the similar filtering technique can also be applied to reduce combustion noise through the dispersive combustion. The dispersive combustion can decrease the combustion knock related to the combustion noise. A study in advance on the noise contribution for the active air inlet quick burner indicated that the pipe flow provides noise of ca. 80 dB and the combustion noise is ca. 100 dB. It's well known that addition of noise uses the logarithmic calculation. In other words, the total noise in a close system is almost equal to the largest noise [8]. This result illustrates that reducing the combustion noise of the burner is the unique solution for noise reduction.

Moreover, the active air inlet quick burner shows yellow flame related to the incomplete combustion. For the purpose of noise reduction and combustion improvement, this work developed a porous flame plate to cover on the burner, which caused mixture of the fuel gas and air to be dispersed through holes of the porous flame plate and yielded numerous fasciolar combustion. A mixing room is therefore built between the flame plate and the burner, which provides the fuel gas and air the better mixing. In addition, the noise addition uses the logarithmic calculation, but the thermal energy addition is linear. That is, the dispersive combustion technique can reduce noise, but it does not decrease the combustion power. In fact, adding the porous flame plate on the burner has successfully reduced the noise and also improved the combustion. The successfully developed dispersive combustion technique can not only be applied in this special burner, but it can also be used in the conventional combustion.

2. Basic Theory

The widely applied active air inlet quick burner in Asia for cooking can provide maximum thermal power of ca. 5216.2 W. It also generates extremely large noise of ca. 100 dB, which badly hurts the long time cookers. This article uses the dispersive combustion method to reduce noise under the same thermal power condition and also increase the combustion efficiency of the active air inlet quick burner. Associated theories are detailed in the following subsections.

2.1. Thermal Power of Combustion

A home-made calorimeter is made in accordance with the first law of thermodynamics and ignores the additional kinetic energy in this work. Figure 2 shows schematics of the home-made calorimeter.

The total increased heat ($\sum Q_{out}$) within the thermal insulating system heated by the burner is equal to the input heat (Q_{in}) [10].

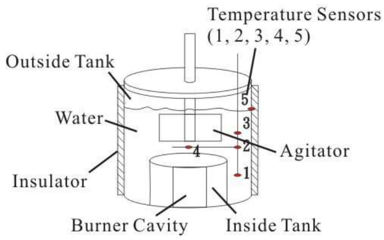


Figure 2. Schematics of the home-made calorimeter.

$$Q_{in} = \sum Q_{out} \tag{1}$$

The total increased heat ($\sum Q_{out}$) can be further expressed as

$$\sum Q_{out} = \sum m_i s_i \Delta T_i, \tag{2}$$

where m_i is the constituent masses, s_i and ΔT_i are the corresponding thermal capacities and temperature differences of the constituents within the thermal insulating system respectively. The considered constituents of the home-made calorimeter for heat absorption are the water and the agitator which are the heated bodies. Equation(2) can be further written as follows:

$$\sum Q_{out} = mwater \cdot swater \cdot \Delta Twater + magitator \cdot sagitator \cdot \Delta Tagitator, \tag{3}$$

where m, s, ΔT with subscripts are mass, thermal capacities, and temperature differences respectively [9–11]. The thermal power (P_t) is determined by the rate of energy transfer to the heated bodies.

$$P_t = \frac{\sum Q_{out}}{t}, \tag{4}$$

where t is the heated time interval. Thermal power of the quick burner is taken for stable and quasi constant. The thermal efficiency (η) is defined as

$$\eta = \frac{\sum Q_{out}}{Q_{in}} \times 100\%. \tag{5}$$

2.2. Addition of Noise

A sound wave is the spatial and the temporal vibration of the density, the pressure, and the temperature in the medium. Intensity of the sound wave is defined as

$$Intensity = \frac{Energy}{Time \cdot Area} = \frac{Power}{Area}$$

Typical unit for expressing the intensity of a sound wave is $[W \cdot m^{-2}]$ [8].

Intensity of the human's threshold of hearing (TOH) is ca. 10^{-12} $W \cdot m^{-2}$, which is corresponding to the pressure of ca. 0.3 billionths of an atmosphere. The human ear can detect extremely large range of intensities, so that a scale based on multiples of 10 is frequently used by physicists to measure intensity. The noise (N) for measuring intensity is the decibel scale (dB) [8], which is defined as

$$N = 10 log \frac{I}{ITOH} \tag{6}$$

where I is any intensity and I_{TOH} is intensity of the human's threshold of hearing. Another expression with pressure for the noise (N) is

$$N = 20 \log \frac{P}{P_0} \tag{7}$$

$$P = P_0 10^{\frac{N}{20}} \tag{8}$$

where P and P_0 are two different pressures. Addition of the sound waves with pressure of P_1, P_2, ..., P_n can be written as follows:

$$\begin{aligned} P &= \sum_{i=1}^{n} P_n \\ &= P_1 + P_2 + ... + P_1 \\ &= P_0[10^{\frac{N_1}{20}} + 10^{\frac{N_2}{20}} + ... + 10^{\frac{Nn}{20}}] \\ &= P_0 \sum_{i=1}^{n} 10^{\frac{Nn}{20}} \end{aligned} \tag{9}$$

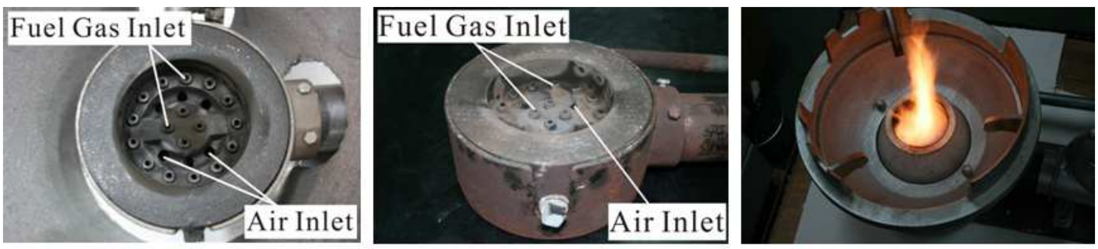
where $N_1, N_2, \ldots, N_n$ are the corresponding values of noise to $P_1, P_2, \ldots, P_n$. Addition of the noises is the logarithmic calculation.

$$N = 20 \log \frac{\sum_{i=1}^{n} P_n}{P_0} = 20 \log \sum_{i=1}^{n} 10^{\frac{Nn}{20}} \tag{10}$$

Equation(10) indicates the fact that addition of noise is the logarithmic calculation and the total noise is almost the same as the largest noise among the noises.

3. Experimental Details

The studied active air inlet quick burner has an U-form concave room for mixing the fuel gas and air. Bottom of the U-form concave room has some fuel gas inlet holes arranged in two circles and some air inlet holes arranged in one circle in between. Figure 3 shows photos of the active air inlet quick burner, where figs. 3(a)-3(c) are top view, side view, and flame respectively. In order to promote mixture of the fuel gas and air, the side wall of the U-form concave room is built in some air inlet holes arranged in two circles. Figure 3(c) clearly shows the concentrated and yellow flame, which illustrates the incomplete combustion. This work developed the porous flame plate for dispersing combustion. Experiments measured noise and combustion power using the home-made calorimeter as shown in fig. 2.



(a) Top view. (b) Side view. (c) Flame.

Figure 3. *Photos of the active air inlet quick burner.*

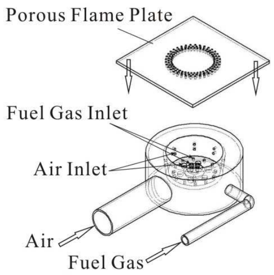


Figure 4. *Schematic description of the installation.*

3.1. Porous Flame Plate

The developed dispersive combustion method used the porous flame plate to cover on the U-form concave room of the active air inlet quick burner and therefore built a mixing room of the fuel gas and air. A conical flow diversion is connected under the porous flame plate. Figure 4 shows schematic description of the installation. Diameter and depth of the holes on the porous flame plate are the main influencing parameters in experiments. Table 1 shows run conditions with the fuel gas flow rate of 9 [$L \cdot min^{-1}$].

Table 1. *Run conditions.*

	Porous Flame Plate			
Diameter (mm)	2,	3,	3.4,	4
Depth (mm)	4.5,	10,	15,	20

Building the porous flame plate used the same total area of all holes, where the total area of the fuel gas and air inlet holes is 1088.37 mm^2, the area of the fuel gas inlet holes is 270.37 mm^2, and the area of the air inlet holes is 818 mm^2. Three porous flame plates with hole diameters of 2, 3, and 4 mm were first built in plate thickness of 4.5 mm. Figure 5 shows photos of the porous flame plate with plate thickness of 4.5 mm and hole diameters of 2, 3, 4 mm. The different hole depths are then made by inserting different lengths of copper pipe into holes of the three porous flame plates.

(a) φ=2 mm. (b) φ=3 mm. (c) φ=4 mm.

Figure 5. *Photos of the porous flame plate with hole diameters of 2, 3, and 4 mm.*

Figure 6 shows photos of a porous flame plate with hole depths of 4.5, 10, 15, and 20 mm.

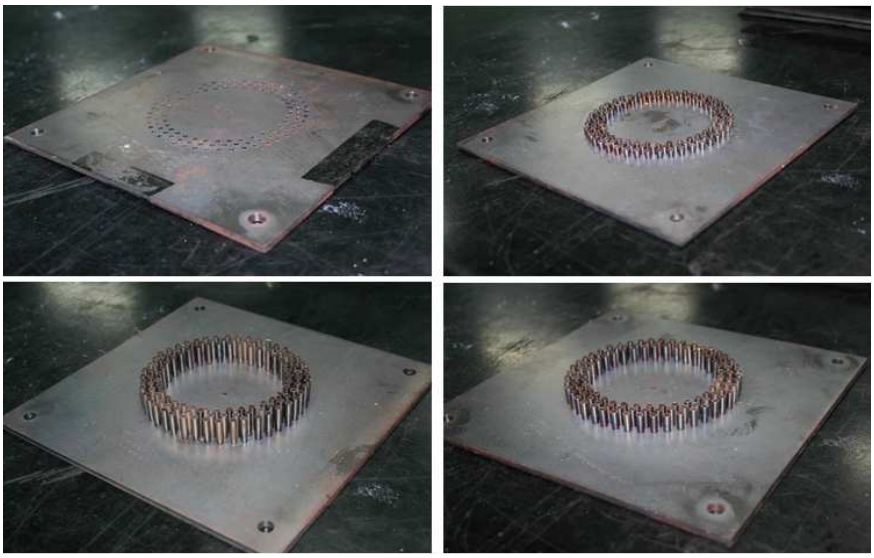


Figure 6. *Photos of the porous flame plate with hole depths of 4.5, 10, 15, and 20 mm.*

Figure 7 shows photo of the optimal porous flame plate with holes diameter of 2 mm and holes depth of 15 mm.

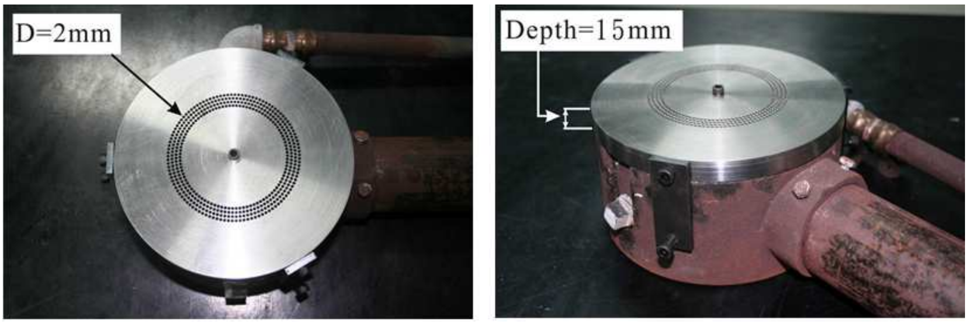


Figure 7. *Photos of the optimal porous flame plate with holes diameter of 2 mm and holes depth of 15 mm.*

3.2. Combustion Power Measurements

A home-made calorimeter with standard error of ca. 4% for determining combustion power of the burner is mainly made of the cylindrical ferreous tank, the water, and the agitator. In process, 20 kg agitated water is in the cylindrical ferreous tank to absorb the combustion heat and keep the uniform temperature. There are five temperature sensors set at five different positions in the water to determine the average temperature. Figure 2 shows schematics of the home-made calorimeter and fig. 8 is its photo.

Figure 8. *Photo of the home-made calorimeter.*

3.3. Noise Measurements

Noise measurements used sound meter with distances of 30, 60, and 90 cm from the burner.

Figure 9 shows schematic setup of noise measurements.

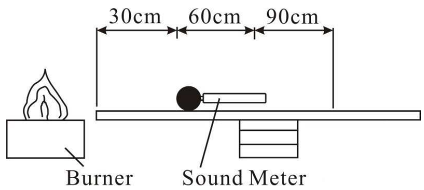


Figure 9. *Schematic setup of noise measurements.*

4. Results and Discussion

Experimental study in this work is focused on combustion improvement and noise reduction for the active air inlet quick burner using dispersive combustion method, where a porous flame plate is developed for generation of the dispersive combustion. Diameter and depth of the holes on the porous flame plate are the main influencing parameters, where the applied hole diameters are 2, 3, 3.4, 4 mm and the depths are 4.5, 10, 15, 20 mm. Figure 10 shows comparison of combustion power between the original and the improved burners, where thickness of the added porous flame plates is 4.5 mm and their hole diameters are 2, 3, and 4 mm respectively.

Figure 10 clearly indicates that adding the porous flame plates has increased the combustion power due to the better mixing of the fuel gas and air in the mixing room. Moreover, the larger the holes diameter, the larger the combustion power. The better gas mixture causes the combustion to be more complete and the combustion power to be increased. In addition, the added porous flame plates with holes diameter of 4 mm has the largest combustion power with ca. double improvement. The reason is that the friction loss (h_L) of flow in a straight pipe is proportional to ratio of the pipe length (L) and diameter (D) as follows [12]:

$$h_L = f\frac{L}{D}\frac{\rho V^2}{2g}, \tag{11}$$

where f is friction factor of pipe, ρ is flow density, V is flow velocity, and g is acceleration of gravity. That is, the larger holes diameter or the smaller the holes depth, the smaller the friction loss of flow in a straight pipe.

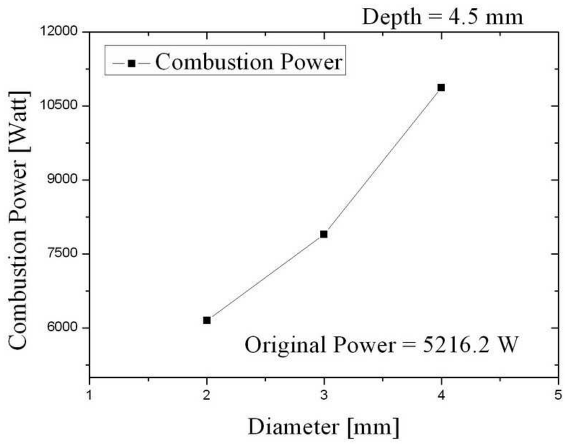


Figure 10. Comparison of combustion power among the various hole diameters.

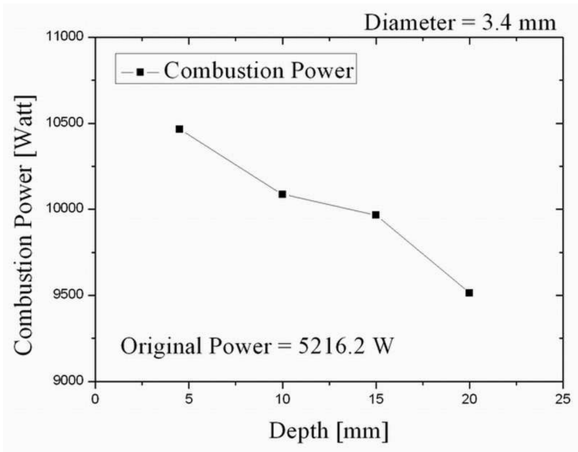


Figure 11. Comparison of combustion power among the various hole depths.

Figure 11 shows comparison of combustion power among the various hole depths of 4.5, 10, 15, and 20 mm with the hole diameter of 3.4 mm. The results show that the added porous flame plate with holes depth of 4.5 mm has the largest combustion power. Moreover, the smaller the holes depth, the larger the combustion power. This result agrees to theoretical prediction in terms of eq.(11).

Figure 12 shows comparison of noise among the various hole diameters of 2, 3, and 4 mm with holes depth of 4.5 mm. Figure 12 indicates that adding the porous flame plate has clearly reduced the noise and the porous flame plate with holes diameter of 2 mm receives the largest noise reduction of ca. 25 dB averagely. The larger the holes diameter, the louder the noise. The reason is that the smaller holes diameter has larger friction loss in terms of eq.(11), which further causes the smaller flow rate of the smaller holes diameter.

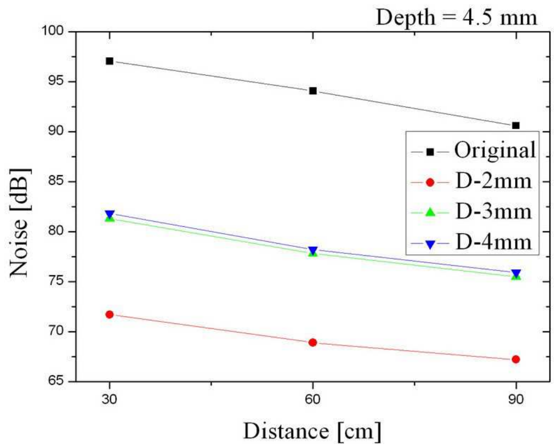


Figure 12. Comparison of noise among the various hole diameters.

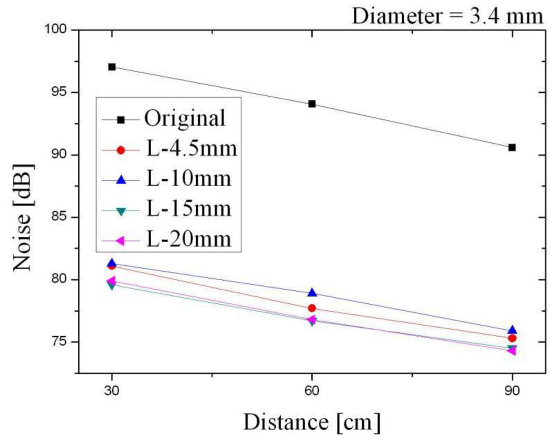


Figure 13. Comparison of noise among the various hole depths.

Figure 13 shows comparison of noise among the various hole depths of 4.5, 10, 15, and 20 mm with holes diameter of 3.4 mm. Figure 13 indicates that adding the porous flame plate has clearly reduced the noise and the porous flame plates with hole depths of 15 and 20 mm receive the largest noise reduction of ca. 18 dB.

In this work, the applied fuel gas is liquefied petroleum gas which has theoretical combustion power of 12021.72 W. Figs. 14 and 15 show comparisons of thermal efficiency among the various hole diameters of 2, 3, 4 mm with holes depth of 4.5 mm and the various hole depths of 4.5, 10, 15, 20 mm with holes diameter of 3.4 mm. Figure 14 shows that the added porous flame plate with holes diameter of 4 mm has the largest thermal efficiency of ca. 90% which is ca. double value of the original 43.34%. Similarly, the added porous flame plate with holes depth of 4.5 mm as shown in fig. 15 has the largest thermal efficiency of ca. 87%.

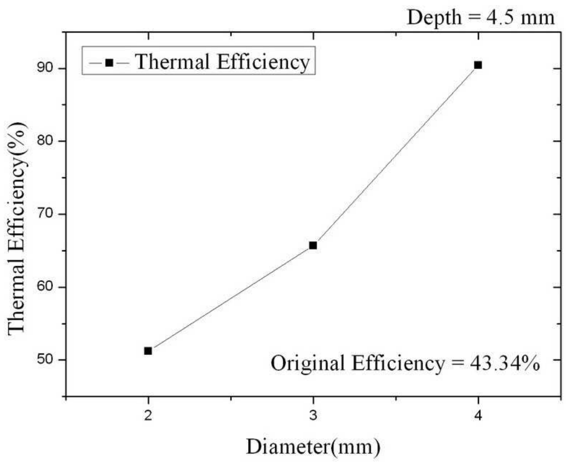


Figure 14. *Comparison of thermal efficiency among the various hole diameters.*

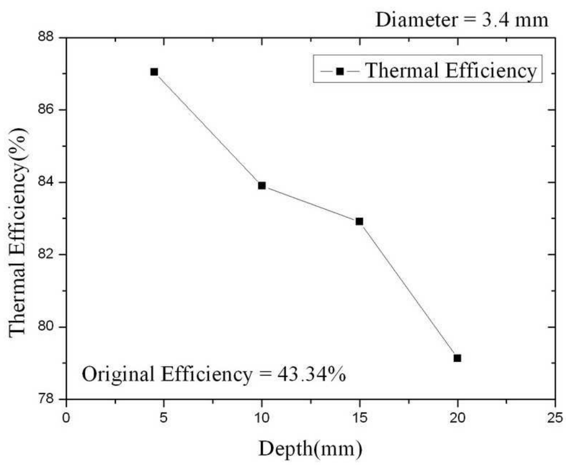


Figure 15. *Comparison of thermal efficiency among the various hole depths.*

Figure 16. *A practical picture of the improved burner flame.*

Figure 16 exhibits a practical picture of the improved burner flame. The applied porous flame plate is with holes diameter of 2 mm, holes depth of 15 mm, and holes area of 1088.37 mm^2. The reached combustion power is ca. 5500 W and noise is ca. 70 dB at measured distance of 30 cm. In other words, the improved burner has reached noise of ca. 70 dB under the same thermal power of ca. 5500 W.

5. Conclusions

Experimental study on combustion improvement and noise reduction of the commercial active air inlet quick burner by building various porous flame plates with hole diameters of 2, 3, 3.4, 4 mm and hole depths of 4.5, 10, 15, 20 mm are successfully carried out. Moreover, a home-made calorimeter with standard error of ca. 4% for measurements of the burner combustion power is also built. The results show that the combustion power of 10872.73 W with holes depth of 4.5 mm and holes diameter of 4 mm has ca. doubly improved. The largest noise reduction is with holes depth of 4.5 mm and holes diameter of 2 mm, which reaches ca. 71 dB. The largest noise reduction appears at holes depth of 15 mm with holes diameter of 3.4 mm. Adding the porous flame plate with holes depth of 4.5 mm and holes diameter of 4 mm has the maximum thermal efficiency of 90.44% which is ca. double value of the original 43.34%.

Acknowledgements

The authors would like to acknowledge the financial support from the National Foundation of Taiwan and under Grant No. NSC97-2221-E-027-031 as well as the Institute of Occupational Safety & Health of Taiwan.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this article.

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