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Analysis Study of Thermal and Exergy Efficiency in Double-Layers Porous Media Combustion Using Different Sizes of Burner: A Comparison

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ABSTRACT

Experimental investigations are currently exploring the impact of adding porous layers within burner housing on thermal and exergy efficiency. Specifically, the focus is on understanding the significance of double layers on porous media combustion and how it can improve fuel mixing and flame stability. Premixed butane-air combustion in rich conditions was examined using three different sizes of burners (i.e., 23 mm, 31 mm, and 44 mm) porous media with equivalence ratios ranging from ϕ = 1.3 to 2.0. The experimental findings revealed a substantial improvement in performance efficiency (thermal and exergy) as the equivalence ratio increased. This study reveals that smaller burner diameters (ID, inner diameter = 23 mm) provide greater efficiency than larger ones (ID = 31 mm and 44 mm). The maximum flame temperature and porous wall temperature are found to decrease as the equivalence ratio increases. The highest temperature measured was 924.82°C for 23 mm, 910.23°C for 31 mm, and 850.76°C for 44 mm at ϕ = 1.3. Lastly, the thermal and exergy efficiency in a 23 mm porous media burner (PMB) is higher at ϕ = 2.0 at 84.30% and 83.47%, respectively. It can be concluded that the diameter size of the burner and equivalence ratio for double-layer porous material influence the performance (efficiency) of PMB.

Keywords: Burner, exergy efficiency, porous media, rich combustion, surface flame, thermal efficiency

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INTRODUCTION

In recent years, the use of fossil fuels has intensified global warming and pollution. These fossil fuels threaten the nation and will impact the economy in the future due to depletion. This issue has impacted the demand for crude oil and has been increasing the price until today, which cannot be overlooked. A free flame from a combustion burner commonly generates higher pollution emissions and less efficiency, leading to high fuel consumption and environmental problems due to improper air-fuel mixing inside the burner.

Home burners like portable butane stoves are now widely recognized and used for domestic and commercial applications. In a normal household burner, combustion is a free flame, with heat transmission primarily by conduction. Porous media combustion (PMC) has grown more popular in residential burners in recent years due to its superior features over free flame combustion (Mujeebu et al., 2009; Javier et al., 2003). Indeed, double-layer porous media are becoming increasingly attractive to researchers because of their flame stability, high thermal efficiency, and decreased pollutant emissions (Zeng et al., 2017; Hashemi & Hashemi, 2017; Chen et al., 2019).

Many scholars have attempted to study double-layer PMC with various types of characteristics such as porous media materials (Liu et al., 2016), porosity (Yu et al., 2013), diameter size and thickness (Janvekar et al., 2017), and layers of pores (Dai et al., 2018) to enhance porous medium combustion's efficiency and performance. Furthermore, premixed fuel-air combustion is more likely to be acceptable for domestic burner stoves because it may improve performance while operating with flame control, provide minimal emission, and shorten the residence time of the gas mixture. Mishra and Muthukumar (2018) conducted an experimental study on fabricating and developing a self-aspirating liquefied petroleum gas (LPG) cooking stove with a two-layer porous radiant burner and three different types of orifice diameters. The results reveal that the maximum thermal efficiency of the porous radiant burner is 75.1% in the power range of 1–3 kW, whereas the traditional burner is only 65%. At the same time, Fan et al. (2019) numerically studied the combustion efficiency of microburners with single-layered and double-layered walls. The SiC inner wall significantly improves the heat recirculation effect of a double-layered micro burner compared to a quartz burner. Furthermore, compared to the SiC burner, the heat loss rate can be reduced by utilizing quartz exterior walls. Ghorashi et al. (2018) studied experimentally pollution emission of the burners with the effect of diameter hole on silicon carbide (SiC) and alumina oxide (Al_2O_3) with three different pore densities (i.e., 10, 20, and 30 pores per inch). Their results indicated that CO concentration decreases in the Al_2O_3 porous medium compared to that of the SiC porous medium.

Various studies of the characteristics of the PMB have been conducted due to the variation of equivalence ratio in the combustion. To maintain steady flame operation, the influence of the equivalence ratio on PMB stability becomes crucial in terms of sustainability and performance. The implementation of porous media inside burners also plays an important role in temperature distribution (Wang et al., 2014; Li et al., 2019) and thermal efficiency (Sharma et al., 2009). In fuel-rich combustion, Dhamrat and Ellzey (2006) investigated a porous media reactor with rich equivalence ratios ranging from 1.5 to 5.0 and discovered that the initial fuel-air mixture intake velocity increases with conversion efficiency. In addition, a study made by Ismail et al. (2013) found that the thermal efficiency of the porous media burner improved with the rise in fuel-air mixture ratio as fuel mass fraction increased to create higher heating value in alumina foam (Al_2O_3) in fuel-rich equivalence ratio at $\phi = 1.3$ to $\phi = 1.6$. Qu et al. (2015) studied the combustion of premixed methane air in a two-zone alumina pellets burner, and the findings revealed that raising the equivalence ratio and pellet diameter enhanced the flame stability limits.

In the last few years, most researchers have focused on studying an alternative method to improve thermal and exergy efficiency inside a burner's combustion. Mohseni et al. (2021) examined the effect of inserted porous media, perforated fins, and 8-tube and 24-tube outlets on the geometry model at the outlet micro-combustor to improve the thermal efficiency and performance of exergy. Meanwhile, Cai et al. (2021) examined the effect of inserting a bluff body in a hydrogen-fueled meso-combustor by optimizing thermal performance and exergy efficiency. They observed that the exergy efficiency of the bluff-body combustor is higher than that of the conventional combustor. Different studies by Johar et al. (2017) focus on analyzing thermal storage's energy and exergy efficiency integrated with a micro-cogeneration system. Also, Nadimi and Jafarmadar (2019) used a micro-combustor for thermophotovoltaic systems to investigate energy conversion and exergy efficiency to improve thermal performance.

In similar work, Sharma et al. (2016) conducted an experimental study on the thermodynamics performance of a double-layered porous burner made of alumina and silicon carbide. According to the findings, the highest efficiency of the porous media stove is determined to be ~10 % greater than that of a standard conventional stove. Since it affects the distribution of heat and reactants inside the porous medium, burner diameter is essential in PMC. This study could use porous media materials to monitor flame characteristics and combustion efficiency, and the findings could be examined to determine the optimal burner diameter, which might provide valuable insight into the design and optimization of PMC systems for enhanced combustion performance.

As a result, investigations on the thermal management (performances) of double-layer PMB in premixed butane-air combustion with varied burner sizes remain insufficient. This study aims to investigate the influence of burner diameter size on thermodynamic efficiencies, such as thermal and exergy of PMB performance and flame characteristics for double-layer porous media configurations using premixed butane-air combustion under rich conditions.

EXPERIMENTAL SETUP

Figure 1 (a) depicts a schematic design of the experimental setup used to examine the combustion of double-layer porous media with varied equivalence ratios. The burner housing comprises mild steel with a constant length of 100 mm and an inner diameter (ID) of 23 mm, 31 mm, and 44 mm. On the top of the burner are two porous media stacks with large pore sizes (alumina foam) for the reaction zone and small pore sizes (porcelain foam) for the pre-heat zone (Figure 2).

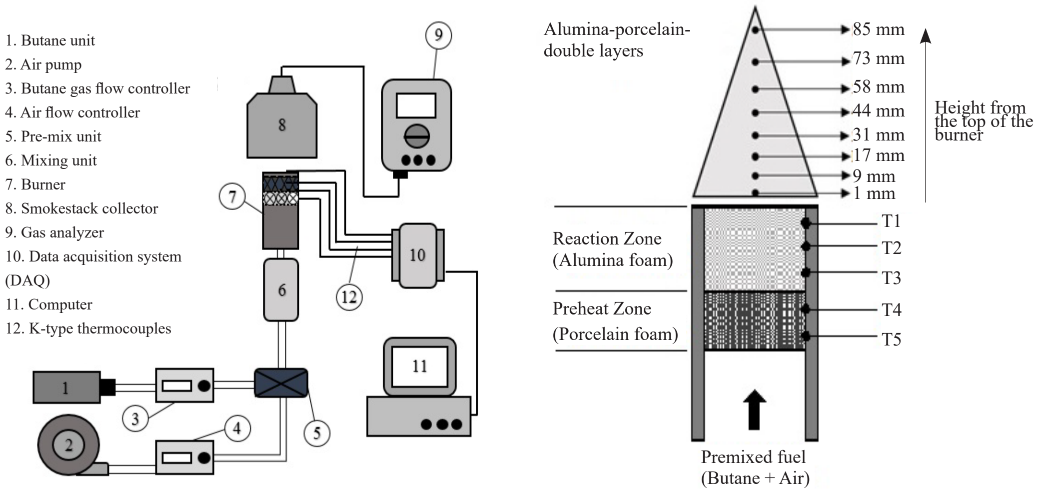


Figure 1. Schematic diagram of the experimental setup and layout, (a) the porous media combustion (PMC) system, and (b) the double layers porous configuration with thermocouples placement.

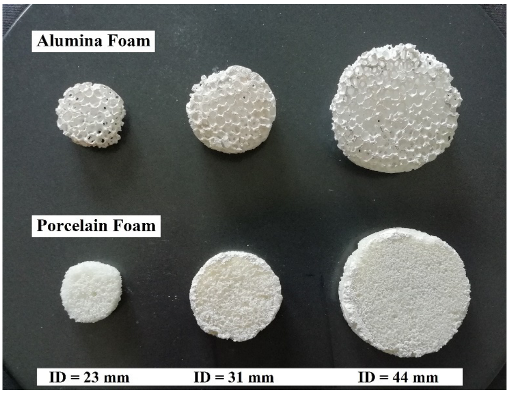


Figure 2. Photographic image of the alumina and porcelain foam in different sizes of burner (i.e., 23 mm, 31 mm, and 44 mm)

The alumina and porcelain foam utilized in this study were fabricated and modified in diameters (ID) of 23 mm, 31 mm, and 44 mm, respectively. The properties of the porous media materials employed in this experiment are shown in Table 1. Two digital flow meters with a control valve (Vögtlin instrument) measure the butane fuel (C_4H_{10}) and airflow rates. Both digital flow meters display the value in liters per minute (L/min) for measuring flow rate.

The temperature readings were monitored using a K-type thermocouple and recorded using Advantech DAQ (Data acquisition) devices (Model: USB-4718) with 8 thermocouple input channels at a sampling rate of one data (temperature) per second.

Temperature measurements were collected, analyzed, and saved on a personal computer. All eight thermocouples were mounted on the top of the PMB at varying heights [Figure 1 (b)] to evaluate the flame temperature distributions. Meanwhile, the thermocouple indicates T1, T2, and T3, which were used to determine the average porous wall temperature of alumina foam and T4 and T5 of porcelain foam. For the initial conditions, the experiments were carried out at room temperature.

Table 1
Porous media materials specifications for porcelain and alumina foam

Specifications	Porcelain	Alumina
Pore size	26 ppcm	8 ppcm
Porosity	86%	84%
Made by	School of Materials and Mineral Resources Engineering, Universiti Sains Malaysia	Goodfellow Cambridge Limited (LS 3699006/1), England
Type	Foam	Foam

Note. ppcm - pore per centimeter

The difference between air-fuel ratios is used to supply air and butane fuel, which is then routed to the burner through a rubber tube. The experiments were carried out using a fuel source with a butane cartridge manufactured by Milux Sdn. Bhd. (Malaysia). A commercial aquarium air pump manufactured by Atman Co. Ltd. (China) provided natural air. Before entering the burner, air and butane fuel were mixed in the box. The images representing the outside wall burner housing temperature were captured using the FLUKE Thermal Imager (Ti27 Industrial Commercial model). Carbon monoxide (CO) and nitric oxide (NO) pollution emissions in part per million (ppm) are measured using a handheld flue gas analyzer type (Kane 251 Combustion Analyzer). The equivalent ratio, ɸ, was determined for each experiment based on the air and fuel flow rates. Table 2 shows the detailed mass flow rate of butane fuel and air used, including the relevant equivalence ratios.

Table 2
The specification of mass flow rate for butane fuel and air at various equivalence ratios

Equivalence Ratio, ɸ	1.3	1.5	1.8	2.0
Air (liters/min)	3.10			
Butane fuel (liters/min)	0.13	0.15	0.18	0.20

Porous media porosity and configurations are important factors that affect the flame stability and temperature distributions inside the burner. For complete combustion, the chemical formula for butane gas and natural air is as Equation 1.

$$C_4H_{10} + 6.5\ (O_2 + 3.76\ N_2) \rightarrow 4\ CO_2 + 5\ H_2O + 24.44\ N_2 \quad (1)$$

where,
O_2 - Oxygen
N_2 - Nitrogen
CO_2 - carbon dioxide

The assessment of thermal efficiency, $\eta_{Thermal}$ of the burner performance for heating purposes based on the water boiling test, the energy provided, Q_{actu} [Energy generated from combustion (J/s)], is equal to the energy generated, Q_{total} [total energy (J/s)] by combustion as in Equation 2.

$$Q_{total} = \dot{m} \times C_v \tag{2}$$

where $\dot{m}$ is the mass flow rate of the butane fuel and C_v [Calorific value of butane fuel (J/kg)] is the calorific value of the butane fuel. Furthermore, the energy generated by the combustion burner is denoted by Q_{actu} (Equation 3):

$$Q_{actu} = [(M_w C_w + M_c C_p) \times (50°\text{C} - T_o)] / \text{time} \tag{3}$$

where,
M_w - Mass of water (kg)
C_w - Specific heat of water (kJ/kg.K)
M_c - Mass of container (kg)
C_p - Specific heat of container (kJ/kg.K)

M_w and M_c are the masses of water and container, respectively. The water's and the container's standard specific heat values are 4.1826 kJ/kg.K for the water and 0.5024 kJ/kg.K for the container. Another thing is the ambient temperature of the room, 302 K (Equation 4).

Hence, the total exergy in the combustion burner is:

$$Q_{exergy} \text{ [Total exergy (J/s)]} = (Q_{actu} / \dot{m}) - T_o (S_{max} - S_{amb}) \tag{4}$$

where S_{amb} [Specific entropy at ambient temperature (J/kg.K)]is the total entropy at room temperature, whereas S_{max} [Specific entropy at maximum temperature (J/kg.K)] represents the total entropy at the highest flame temperature.

While exergy efficiency, η_{Exergy} based on basic thermodynamics fundamentals from the second law allows for the direct derivation of exergy analysis. The procedure for calculating these parameters was the same as in prior research (Equations 5 & 6) (Ismail et al., 2020).

$$\eta_{Thermal} = (Q_{actu} / Q_{total}) \times 100\% \tag{5}$$

$$\eta_{Exergy} = (Q_{exergy} / Q_{total}) \times 100\% \tag{6}$$

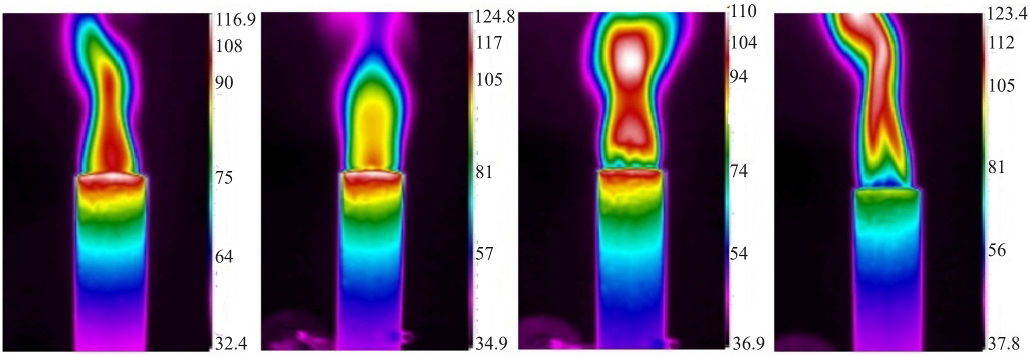
where Q_{actu} is the energy produced by the combustion, Q_{exergy} is the overall exergy in the combustion, and Q_{total} is the energy provided by the combustion.

RESULTS AND DISCUSSION

Experiments were conducted to investigate the thermal and exergy efficiency of porous medium combustion double layers. In these experiments, the equivalence ratio is measured from 1.3 to 2.0. The effect of the equivalence ratio on flame stability and emissions is a factor that influences the performance of PMB. Figure 3 illustrates a photographic picture of the surface flame characteristics for burner diameter, ID = 23 mm double-layer configurations ranging from $\phi = 1.3$ to 2.0 taken with a Nikon J1 digital camera. Based on the findings, the surface flame is stable at $\phi = 1.3$ and 1.5 with a predominance of blue flame but unstable at $\phi = 1.8$ and 2.0 with an orange flame. Furthermore, the surface flame images reveal that the flame length increases when the equivalence ratio rises from 1.3 to 2.0 as the butane fuel mass flow rate rises.

ϕ : 1.3 ϕ : 1.5 ϕ : 1.8 ϕ : 2.0

Figure 3. Photographic images of the surface flame stability with the double-layer configuration using a digital camera



ϕ : 1.3 ϕ : 1.5 ϕ : 1.8 ϕ : 2.0

Figure 4. Thermal images of the porous media burner (PMB) with varied equivalence ratio

Figure 4 depicts the thermal pictures as the equivalence ratio fluctuates based on the temperature wall of the PMB. The thermal pictures are characterized by porous wall temperature, indicating the location of the thermocouples and porous medium. The porous wall temperature of double layers PMB decreases substantially as the equivalence ratio increases (from ɸ = 1.3 to 2.0), as seen in the picture, where the red contour color gradually disappears. Heat radiation from the porous burner housing is stronger at ɸ = 1.3 and diminishes at ɸ = 2.0 (see the contour color of purple around the burner housing). It is due to the propagation of the flame speed combustion when the butane fuel mass flow increases.

The CO emission in double layers PMB measured with a portable flue gas analyzer was within the 12–67 ppm range for all equivalence ratios. While NO emission measurements were taken, they were within the 5–14 ppm range. It has been shown that emissions concentrations are still at a low pollution level and below an acceptable limit for human health (Ghorashi et al., 2018).

For the temperature distribution, Figures 5 (a), (b), and (c) show the maximum flame temperature of the PMB as well as the average porous wall temperature of the pre-heat and reaction zones with variations in equivalence ratio. The highest temperature measured by eight thermocouples positioned on top of the burner at different equivalence ratios is the maximum flame temperature (Gao et al., 2012). It is also noted that the maximum flame temperature reduces when the equivalence ratio increases from ɸ = 1.3 to 2.0. At PMB ID = 23 mm, maximum flame temperature is recorded at 924.37°C at ɸ = 1.3, followed by 887.43°C at ɸ = 1.5, 840.35°C at ɸ = 1.8, and 825.17°C at ɸ = 2.0. The same trend happens to PMB ID = 31 mm, where the maximum flame temperature is recorded at 910.23°C at ɸ = 1.3, followed by 850.34°C at ɸ = 1.5, 830.73°C at ɸ = 1.8, and 820.11°C at ɸ = 2.0. Also, at PMB ID = 44 mm, the maximum flame temperature is recorded at 850.76°C at ɸ = 1.3, followed by 824.68°C at ɸ = 1.5, 817.68°C at ɸ = 1.8, and 810.66°C at ɸ = 2.0.

The findings reveal that porous materials aided the burner in improving heat recirculation and retention within the burner. This phenomenon arises owing to flame stability in double layers PMB at ɸ = 1.3 and 1.5 but becomes unstable as the mass flow fuel mixture increases (ɸ = 1.8 and 2.0). The maximum flame temperature decreased significantly with increased equivalence ratios owing to the lower power output generated from the combustion for three different PMB IDs. Thus, as shown in Figure 4, double-layer porous media increased internal heat recirculation in the pre-heat zone, and the heat was transferred from the reaction zone to the pre-heat zone via radiation heat.

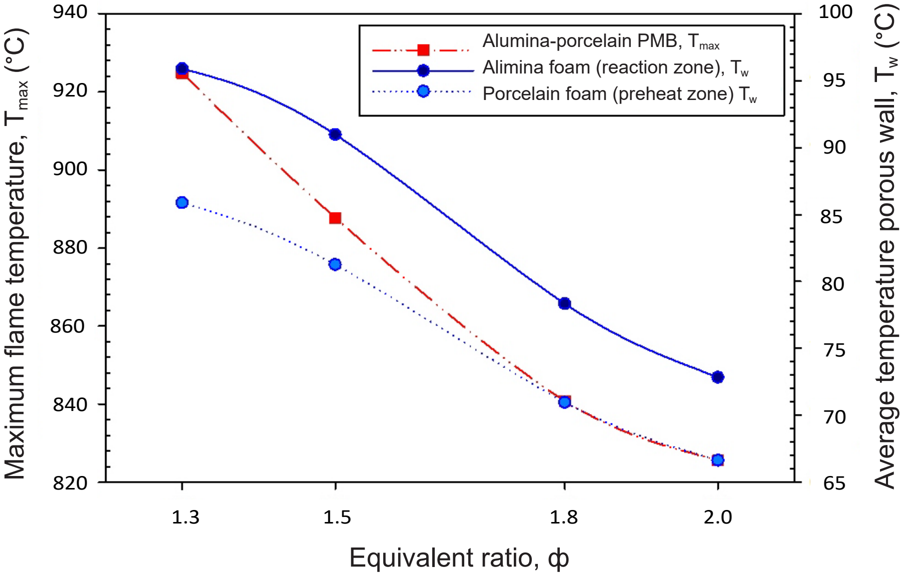
The average temperature of the burner wall is another critical element in assessing the efficiency of porous medium combustion. It illustrates a declining trend in average wall burner temperature as equivalence ratios rise from ɸ = 1.3 to 2.0 for pre-heat and reaction zones for all three different PMB ID. From Figure 5 (a), (b), and (c), the highest average wall temperature achieved at ɸ = 1.3 is 95.43°C (reaction zone) and 85.52°C (pre-heat zone) for PMB ID = 23 mm. Then, it starts to reduce the highest average temperature porous wall as the PMB ID = 31 mm at 93.42°C (reaction zone) and 84.75°C (pre-heat zone), and then PMB ID = 44 mm at 90.68°C (reaction zone) and 35.86°C (pre-heat zone), respectively. According to the results, the temperature decreases significantly at small burner diameters (PMB ID = 23 mm) but only slightly at large burner diameters (PMB ID = 44 mm), implying that the different burner sizes in PMC have a significant impact on controlling the temperature of double-layer porous walls. Surprisingly, the average porcelain foam porous wall temperature (pre-heat zone) appears to be almost consistent with an increase in the equivalence ratios (from ɸ = 1.3 to ɸ = 2.0) in larger diameter burners (PMB ID = 44 mm) compared to the others (PMB ID = 23 mm and 31 mm) due to the quenching effect that occurs inside porcelain foam, which prevents the flame from propagating far enough to reach the burner wall in bigger PMBs.

From Equations 2 and 3, the thermal efficiency, η_{Thermal}, and exergy efficiency, η_{Exergy} achieved for double-layer porous medium design with various equivalence ratios for three different PMB IDs are shown in Figure 6 (a), (b), and (c). PMB ID's thermal and exergy efficiency = 23 mm, 31 mm, and 44 mm double layers PMB improved as the premixed butane-air equivalence ratios increased from 1.3 to 2.0. Besides, at PMB ID = 23 mm, the results also show the percentage performance efficiency is higher at ɸ = 2.0 with η_{Thermal} = 84.30% and η_{Exergy} = 83.47%, respectively. While the lowest percentage efficiency performance at ɸ = 1.3 with η_{Thermal} = 71.80% and η_{exergy} = 70.95%. Then, the thermal and exergy efficiency starts to reduce as the burner diameter size (PMB ID) increases from 23mm to 31 mm and 44 mm. At PMB ID = 31 mm, the highest thermal and exergy efficiency happen at ɸ = 2.0 with η_{Thermal} = 78.90% and η_{Exergy} = 78.07%, while the lowest thermal and exergy efficiency happen at ɸ = 1.3 with η_{Thermal} = 68.80% and η_{Exergy} = 65.91%. Moreover, at PMB ID = 44 mm, the highest thermal and exergy efficiency happen at ɸ = 2.0 with η_{Thermal} = 75.00% and η_{Exergy} = 74.18%, while the lowest thermal and exergy efficiency happen at ɸ = 1.3 with η_{Thermal} = 63.40% and η_{Exergy} = 62.55%, respectively.

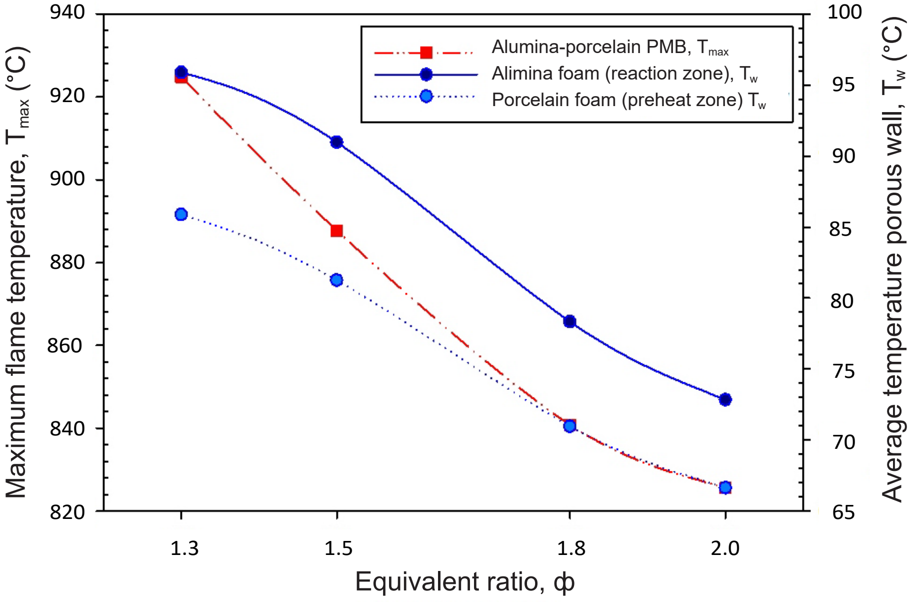
The thermal and exergy efficiency rises as the fuel mass flow rates (butane fuel) improve with increases in equivalence ratios, indicating that it substantially impacts both thermal and exergy performances. The increase in thermal efficiency with a higher fuel flow rate is related to lower convective and radiative heat losses, whereas increased exergy efficiency implies better heat energy utilization inside PMBs.

Moreover, the amount of exergy the system destroys is determined by the difference in efficiency between thermal and exergy. Exergy destroyed is the amount of energy that could have been used for useful work but was wasted due to irreversibilities (Dincer & Bicer, 2020). The exergy destroyed is determined to be 0.83% for PMB ID = 23 mm at ɸ = 1.5 and 2.0, followed by ɸ = 1.3 at 0.85% and ɸ = 1.8 at 0.88%. On the other hand, for PMB ID = 31 mm, the amount of exergy destroyed is 2.89% at ɸ = 1.3, 0.85% at ɸ = 1.5, 0.84% at ɸ = 1.8, and 0.83% at ɸ = 2.0. Additionally, the exergy destroyed for PMB ID = 44 mm at ɸ = 1.3 is 0.85%, followed by ɸ = 1.5 and 1.8 at 0.83% and ɸ = 2.0 is

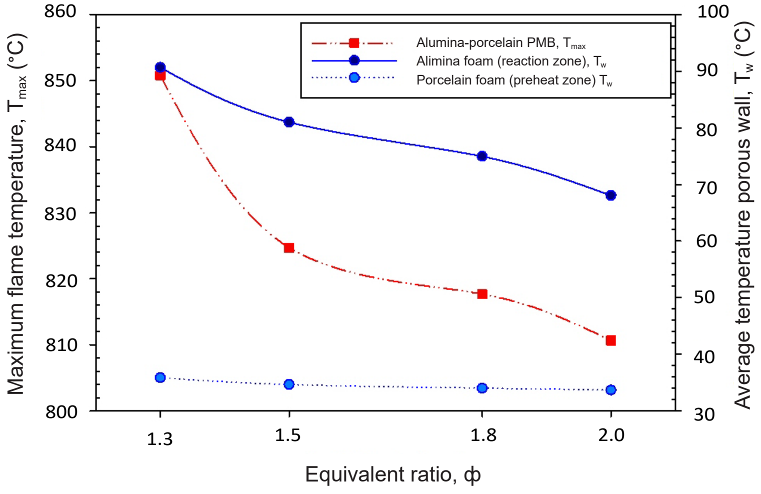
0.82%, respectively. According to the findings, the highest amount of exergy destroyed occurred inside PMB ID = 31 mm at ф = 1.3 and was wasted on the environment, which cannot be recovered.



(a)

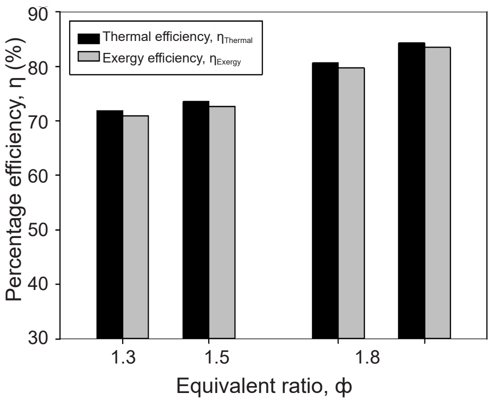


(b)

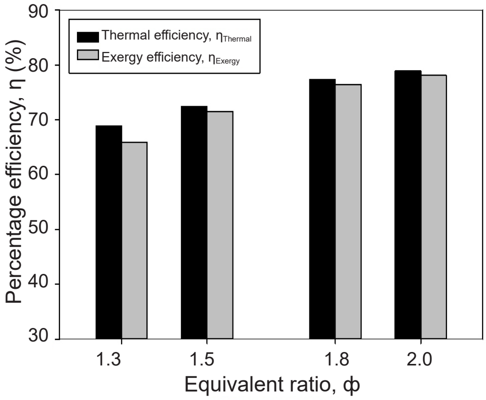


(c)

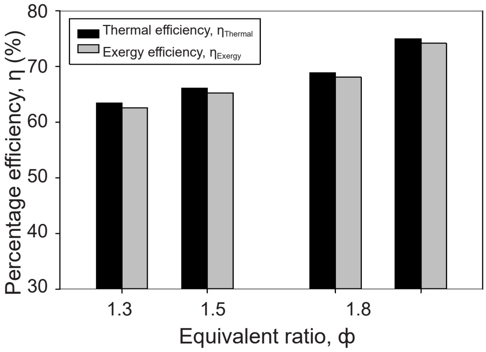
Figure 5. Maximum flame temperature and average temperature porous wall varies with equivalence ratio: (a) 23 mm, (b) 31 mm, and (c) 44 mm



(a)



(b)



(c)

Figure 6. Thermal efficiency, $\eta_{Thermal}$, and exergy efficiency, η_{Exergy} with varies equivalence ratios: (a) 23 mm, (b) 31 mm, and (c) 44 mm

The impact of improving PMB performance efficiency is attributed to reduced radiation heat transfer from the porous media burner wall as fuel mass flow rates in premixed combustions increase. It can be concluded that the mass flow input of the mixture significantly affects the thermal performance of the PMB's (Ismail et al., 2013). Overall, it can be said that the double-layer designs and equivalence ratio affect the thermal and energy efficiency characteristics.

CONCLUSION

In this research, a double-layer porous media combustion with varied burner diameters was constructed and experimentally tested for thermal and exergy efficiency. Studies were carried out with three different sizes of burner, PMB ID = 23 mm, 31 mm, and 44 mm, at equivalence ratios, $\phi = 1.3, 1.5, 1.8$, and 2.0. The following are the study's primary findings:

1. The highest flame temperature was found in PMB ID = 23 mm, T_{max} [maximum temperature (°C)] = 924.37°C at $\phi = 1.3$ for various equivalence ratios, while the lowest flame temperature was obtained in PMB ID = 44 mm, T_{max} = 810.66°C at $\phi = 2.0$.
2. In addition, for both pre-heat and reaction zones for three different PMB IDs, the wall porous temperature decreases as the equivalence ratio increases.
3. The highest thermal and exergy efficiency were observed in PMB ID = 23 mm at $\phi = 2.0$ with 84.30% and 83.47%, respectively.
4. The exergy destroyed, e_{des} [Exergy destroyed (W)] in all the experiments in the range of 0.82% to 0.88% except for the PMB ID = 31 mm at $\phi = 1.3$ is 2.89%, which is higher.

The results demonstrate that the temperature distribution, thermal efficiency, and exergy efficiency analyses show that the equivalence ratio significantly defines the PMB characteristics. This study reveals that the advantages of utilizing porous media materials and smaller diameter burners produced better performances are related to the thermal and exergy efficiency using double-layer configurations. Therefore, this study indicates to other researchers the advantages of varying burner sizes for improving PMB performance in the future.

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REFERENCES

Cai, T., Zhao, D., & Karimi, N. (2021). Optimizing thermal performance and exergy efficiency in hydrogen-fueled meso-combustors by applying a bluff-body. *Journal of Cleaner Production*, *311*, Article 127573. https://doi.org/10.1016/j.jclepro.2021.127573

Chen, X., Li, J., Feng, M., Zhao, D., Shi, B., & Wang, N. (2019). Flame stability and combustion characteristics of liquid fuel in a meso-scale burner with porous media. *Fuel*, *251*, 249-259. https://doi.org/10.1016/j.fuel.2019.04.011

Dai, H., Zhao, Q., Lin, B., He, S., Chen, X., Zhang, Y., Niu, Y., & Yin, S. (2018). Premixed combustion of low-concentration coal mine methane with water vapor addition in a two-section porous media burner. *Fuel*, *213*, 72-82. https://doi.org/10.1016/j.fuel.2017.09.123

Dhamrat, R. S., & Ellzey, J. L. (2006). Numerical and experimental study of the conversion of methane to hydrogen in a porous media reactor. *Combustion and Flame*, *144*(4), 698-709. https://doi.org/10.1016/j.combustflame.2005.08.038

Dincer, I., & Bicer, Y. (2020). Chapter 2: Fundamentals of energy systems. In I. Dincer & Y. Bicer (Eds.), *Integrated Energy Systems for Multigeneration* (pp. 33-83). Elsevier.

Fan, A., Li, L., Yang, W., & Yuan, Z. (2019). Comparison of combustion efficiency between micro combustors with single- and double-layered walls: A numerical study. *Chemical Engineering and Processing – Process Intensification*, *137*, 39-47. https://doi.org/10.1016/j.cep.2019.02.004

Gao, H. B., Qu, Z. G., He, Y. L., & Tao, W. Q. (2012). Experimental study of combustion in a double-layer burner packed with alumina pellets of different diameters. *Applied Energy*, *100*, 295-302. https://doi.org/10.1016/j.apenergy.2012.05.019

Ghorashi, S. A., Hashemi, S. A., Hashemi, S. M., & Mollamahdi, M. (2018). Experimental study on pollutant emissions in the novel combined porous-free flame burner. *Energy*, *162*, 517-525. https://doi.org/10.1016/j.energy.2018.08.005

Hashemi, S. M., & Hashemi, S. A. (2017). Flame stability analysis of the premixed methane-air combustion in a two-layer porous media burner by numerical simulation. *Fuel*, *202*, 56-65. https://doi.org/10.1016/j.fuel.2017.04.008

Ismail, A. K., Abdullah, M. Z., Zubair, M., Ahmad, Z. A., Jamaludin, A. R., Mustafa, K. F., & Abdullah, M. N. (2013). Application of porous medium burner with micro cogereration system. *Energy*, *50*, 131-142. https://doi.org/10.1016/j.energy.2012.12.007

Ismail, N. C., Abdullah, M. Z., Mazlan, N. M., & Mustafa, K. F. (2020). Entropy generation and exergy analysis of premixed fuel-air combustion in microporous media burner. *Entropy*, *22*(10), Article 1104. https://doi.org/10.3390/e22101104

Janvekar, A. A., Miskam, M. A., Abas, A., Zainal, Z. A., Juntakan, T., & Abdullah, M. Z. (2017). Effects of the preheat layer thickness on surface/submerged flame during porous media combustion of the micro burner. *Energy*, *122*, 103-110. https://doi.org/10.1016/j.energy.2017.01.056

Javier, E. S., Mehta, S. A., & Moore, R. G. (2003). An experimental study of controlled gas-phase combustion in porous media for enhanced recovery of oil and gas. *Journal of Energy Resources Technology*, *125*, 64-71. https://doi.org/10.1115/1.1510522

Johar, D. K., Sharma, D., Soni, S. L., Gupta, P. K., & Goyal, R. (2017). Experimental investigation and exergy analysis on thermal storage integrated micro-cogeneration system. *Energy Conversion and Management*, *131*, 127-134. https://doi.org/10.1016/j.enconman.2016.10.075

Li, Q. Q., Li, J., Shi, J. R., & Guo, Z. L. (2019). Effect of heat transfer on flame stability limits in a planar micro-combustor partially filled with porous medium. *Proceedings of the Combustion Institute*, *37*(4), 5645-5654. https://doi.org/10.1016/j.proci.2018.06.023

Liu, Y., Fan, A., Yao, H., & Liu, W. (2016). A numerical investigation on the effect of wall thermal conductivity on flame stability and combustion efficiency in a mesoscale channel filled with fibrous porous medium. *Applied Thermal Engineering*, *101*, 239-246. https://doi.org/10.1016/j.applthermaleng.2016.02.099

Mishra, N. K., & Muthukumar, P. (2018). Development and testing of energy efficient and environment-friendly porous radiant burner operating on liquefied petroleum gas. *Applied Thermal Engineering*, *129*, 482-489. https://doi.org/10.1016/j.applthermaleng.2017.10.068

Mohseni, S., Nadimi, E., Jafarmadar, S., & Rezaei, R. A. (2021). Enhance the energy and exergy performance of hydrogen combustion by improving the micro-combustor outlet in thermofluidic systems. *International Journal of Hydrogen Energy*, *46*(9), 6915-6927. https://doi.org/10.1016/j.ijhydene.2020.11.114

Mujeebu, M. A., Abdullah, M. Z., Bakar, M. Z. A., Mohamad, A. A., & Abdullah, M. K. (2009). Application of porous media combustion technology – A review. *Applied Energy*, *86*(9), 1365-1375. https://doi.org/10.1016/j.apenergy.2009.01.017

Nadimi, E., & Jafarmadar, S. (2019). The numerical study of the energy and exergy efficiencies of the micro-combustor by the internal micro-fin for thermophotovoltaic systems. *Journal of Cleaner Production*, *235*, 394-403. https://doi.org/10.1016/j.jclepro.2019.06.303

Qu, Z. G., & Feng, X. B. (2015). Catalytic combustion of premixed methane/air in a two-zone perovskite-based alumina pileup-pellets burner with different pellet diameters. *Fuel*, *159*, 128-140. https://doi.org/10.1016/j.fuel.2015.06.066

Sharma, M., Mahanta, P., & Mishra, S. C. (2016). Usability of porous burner in kerosene pressure stove: An experimental investigation aided by energy and exergy analyses. *Energy*, *103*, 251-260. https://doi.org/10.1016/j.energy.2016.02.100

Sharma, M., Mishra, S. C., & Acharjee, P. (2009). Thermal efficiency study of conventional pressure stoves equipped with porous radiant inserts. *International Energy Journal*, *10*(4), 247-254.

Wang, H., Wei, C., Zhao, P., & Ye, T. (2014). Experimental study on temperature variation in a porous inert media burner for premixed methane-air combustion. *Energy*, *72*, 195-200. https://doi.org/10.1016/j.energy.2014.05.024

Yu, B., Kum, S. M., Lee, C. E., & Lee, S. (2013). Combustion characteristics and thermal efficiency for premixed porous-media types of burners. *Energy*, *53*, 343-350. https://doi.org/10.1016/j.energy.2013.02.035

Zeng, H., Wang, Y., Shi, Y., Ni, M., & Cai, N. (2017). Syngas production from CO_2/CH_4 rich combustion in a porous media burner: Experimental characterization and elementary reaction model. *Fuel*, *199*, 413-419. https://doi.org/10.1016/j.fuel.2017.03.003