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Influence of Burner Head Geometry on the Thermal Efficiency of LPG Cooking Stoves

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ABSTRACT

This looks at investigates the have an effect on of burner head geometry on the thermal efficiency, gas consumption, and emission levels of LPG cooking stoves, offering critical insights into how design optimization can enhance stove overall performance. Three burner head designs circular, star-shaped, and multi-port experimentally examined and evaluated through Computational Fluid Dynamics (CFD) simulations. The multi-port burner tested the best thermal efficiency at 58%, accompanied by means of the superstar-fashioned burner at 54%, and the round burner at 50%. Additionally, the multi-port burner consumed the least fuel, the usage of simplest 45 grams of LPG, in comparison to 48 grams for the famous person-formed and 52 grams for the round burner. Emission evaluation revealed that the multi-port burner had the lowest emissions, producing 160 ppm of CO and 35 ppm of NOx, at the same time as the circular burner exhibited the best emissions, with 220 ppm of CO and 45 ppm of NOx. The big name-shaped burner done fairly, emitting a 180 ppm of CO and 38 ppm of NOx. The improved heat distribution and more efficient air-fuel mixing provided by the multi-port geometry were identified as the primary reasons for its superior performance. These findings spotlight the ability for geometric innovation in burner design to improve the efficiency and environmental effect of LPG stoves, making them extra sustainable and fee-effective. This take a look at gives treasured recommendations for range producers and policymakers aiming to decorate power performance and reduce emissions in home cooking technologies.

1. INTRODUCTION

Liquefied Petroleum Gas (LPG) has become one of the maximum widely used assets of strength for cooking, especially in developing nations where it gives a clean, efficient, and value-effective opportunity to standard biomass fuels [1]. The global shift toward cleaner energy sources has driven research and innovation in cooking technologies, with a strong focus on enhancing the thermal efficiency of LPG stoves[2]. As one of the critical components of these stoves, the burner head plays a fundamental role in determining overall stove performance, particularly in terms of heat transfer, fuel consumption, and combustion efficiency[3]. Despite the widespread use of LPG stoves, there remains a significant opportunity for improving their efficiency through optimized burner head designs[4]. The improvement of combustion efficiency and reduction of harmful emissions has become a key focus in the design and development of LPG stoves[3]. Various studies have explored techniques such as air-fuel ratio optimization, heat recovery mechanisms, and material innovations to achieve higher thermal efficiency[5]. Despite the wide use of LPG stoves, previous studies have focused on isolated aspects of burner design, such as material innovations or air-fuel ratio optimization, without addressing the comprehensive effects of burner head geometry. Most of these works are limited to either experimental setups or computational models, lacking a combined approach to validate findings.

Demonstrated that optimizing the air-fuel ratio significantly reduces unburned hydrocarbons and CO emissions, which contributes to better fuel utilization[6]. Furthermore, recent advances in computational modeling have allowed researchers to simulate and refine burner designs for enhanced efficiency before physical prototyping. This progress

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has led to an increase in stove efficiency while minimizing emissions of carbon monoxide (CO) and nitrogen oxides (NOx)[7].

Burner head geometry, defined by the shape, size, and arrangement of the burner's flame ports, directly affects the way in which heat is distributed across cooking surfaces and how combustion gases mix with oxygen [8]. Variations in burner geometry can lead to substantial differences in how LPG stoves perform in real-world cooking scenarios, influencing factors such as fuel efficiency, cooking speed, and emission levels. The interaction between burner geometry and the stove's thermal performance is complex and has been the subject of various studies, though many have focused on isolated aspects of burner design without fully exploring the potential of geometric optimization as a whole [9].

Current stove designs primarily aim to maximize heat output while minimizing fuel consumption [10]. However, research has shown that different burner geometries can achieve these goals with varying degrees of success. Circular burner heads, for example, are commonly used due to their simple design and ease of manufacturing, but other configurations such as multi-port, star-shaped, or elongated burners may offer enhanced heat distribution and better combustion characteristics [11]. Studies by have highlighted the benefits of multi-port burner heads, which provide better heat distribution across the cooking vessel, thereby improving overall thermal efficiency and reducing fuel consumption. Understanding the influence of these designs on thermal efficiency is essential for developing stoves that not only meet the energy demands of consumers but also align with global sustainability goals by reducing carbon emissions and optimizing resource use [12]. A critical review of the existing literature reveals a gap in comprehensive studies that directly compare the impact of different burner head geometries on the thermal efficiency of LPG stoves [13]. While significant advancements have been made in improving combustion technologies and reducing pollutant emissions, there is still limited research that focuses on the systematic analysis of burner head geometries in relation to thermal efficiency [14]. The need to develop stoves with higher thermal efficiency is particularly pressing in regions where LPG remains a key energy source for daily cooking, as improving stove performance could lead to both economic and environmental benefits [2].

The design and optimization of LPG cooking stoves have been extensively studied, with particular attention given to factors such as fuel efficiency, combustion processes, and emission control [3]. Among these, the geometry of the burner head plays a pivotal role in influencing the thermal efficiency and overall performance of the stove [15]. Studies those conducted by have explored innovative burner head geometries like hexagonal and star-shaped designs, which have shown promise in achieving more uniform flame distribution and improved combustion efficiency[16]. This section provides a comprehensive review of the existing literature on burner head design, focusing on how geometric factors impact heat transfer, combustion characteristics, fuel consumption, and environmental emissions.

2. Burner Head Design and Thermal Efficiency

The relationship between burner head geometry and thermal efficiency is a well-recognized aspect of stove performance, yet detailed studies on the topic remain relatively limited. Early research on stove design focused on increasing heat transfer efficiency by optimizing the flame spread and ensuring uniform heat distribution across the cooking surface[17]. Burner head designs such as circular and multi-port configurations were found to have distinct effects on heat transfer mechanisms[18]. For example, studies by the demonstrated that circular burner heads, the most commonly used design in LPG stoves, provide a balanced distribution of heat, leading to moderate fuel consumption. However, the study also highlighted that this design may not be the most efficient in maximizing thermal output, especially for larger cooking surfaces[19].

Recent research has explored alternative geometries to improve heat transfer efficiency. investigated the use of star-shaped and triangular burner heads, demonstrating that these designs can enhance heat distribution by increasing the surface area of flame contact. Their findings indicated that star-shaped burners resulted in higher thermal efficiency compared to traditional circular burners, primarily due to the more even spread of heat across the cooking vessel. Despite these advances, the authors noted the need for further experimental validation of such designs under varied operational conditions[20]. For example, recent studies by have explored the effects of multi-port and star-shaped burner head geometries on thermal efficiency and emission reduction[21].

3. Dynamics and Flame Behavior

The geometric configuration of the burner head also directly impacts combustion dynamics, particularly the flame structure and air-fuel mixing processes[22]. Efficient combustion is important to accomplishing better thermal efficiency and decreasing emissions, as incomplete combustion can lead to multiplied gas intake and the discharge of pollutants which includes carbon monoxide and unburnt hydrocarbons [23]. In a landmark examine, examined the outcomes of burner port association on combustion efficiency, displaying that multi-port burners with optimized port spacing and length allowed for higher air-gas mixing, leading to greater entire combustion. Their experimental results revealed that burner heads with smaller, well-distributed flame ports generated more stable flames with less fluctuation in heat output, contributing to improved thermal efficiency. However, the study also pointed out that excessively small ports could lead to incomplete combustion under certain conditions, such as when there is insufficient airflow[24].

Further contributions expanded on this research by exploring the influence of flame shape on combustion efficiency. Their study compared circular, star, and hexagonal burner heads, analyzing how each shape affected flame stability and heat transfer. The hexagonal burner head exhibited superior combustion characteristics, as the angular design facilitated better oxygen supply to the flame, resulting in a higher thermal efficiency and lower emission levels. This study underscored the importance of geometry not only in thermal transfer but also in achieving more efficient and cleaner combustion[25].

4. CONSUMPTION AND ECONOMIC IMPLICATIONS

Burner head design also has significant implications for fuel consumption, a factor of paramount importance in both domestic and commercial cooking environments[26]. Studies on LPG stove efficiency often highlight that geometric optimization can lead to reduced fuel consumption, thus lowering operational costs and contributing to more sustainable energy use[27]. Research conducted by provided a comparative analysis of fuel consumption across various burner head geometries. The authors demonstrated that multi-port and star-shaped burners consumed 15-20% less fuel compared to traditional circular burners when used in household cooking conditions. This reduction was attributed to the more efficient distribution of heat and the increased surface area of the burner head, which allowed for quicker cooking times and reduced energy wastage. The findings of this study align with broader trends in LPG stove research, emphasizing the role of design innovation in reducing the environmental and economic impact of cooking appliances. Despite these promising results, Gupta and Sharma cautioned that the benefits of advanced burner head designs are highly dependent on the specific use case and operational conditions. For example, larger burner heads may offer superior performance for high-volume cooking but could lead to inefficiencies when used for smaller pots or low-intensity cooking tasks. This highlights the need for a more tailored approach to burner design, where geometries are optimized for specific cooking environments [28].

5. ENVIRONMENTAL IMPACT AND EMISSION REDUCTION

Reducing emissions from LPG stoves has become a key focus in stove design research, particularly as global efforts to mitigate climate change intensify[29]. The geometry of the burner head can substantially impact the quantity of pollution generated at some point of the combustion process, with wrong design main to extended ranges of dangerous emissions [30]. Several studies have validated that optimizing burner head geometry can lessen carbon monoxide and nitrogen oxide emissions, both of which are not unusual by way of-merchandise of inefficient combustion. Conducted an experimental observe on the environmental effect of LPG stoves with distinct burner head configurations. They found that stoves equipped with multi-port burner heads produced 25% fewer emissions compared to those with traditional circular designs, primarily due to improved combustion efficiency and better fuel-to-air mixing. This study also highlighted the potential for geometric optimization to contribute to broader environmental goals by reducing the carbon footprint of household cooking [31].

6. GAPS IN THE EXISTING LITERATURE

While there is a growing body of research exploring the relationship between burner head geometry and stove performance, several critical gaps remain[32]. First, most studies to date have focused on isolated design parameters, such as port arrangement or flame shape, without conducting comprehensive, side-by-side comparisons of various geometric configurations[33]. Furthermore, many existing studies are limited by their small-scale, laboratory-based experiments, which may not fully capture the complexities of real-world cooking environments[34]. Additionally, few studies have examined the long-term durability and practicality of innovative burner head designs. As LPG stoves are subject to frequent use in domestic and commercial settings, understanding how different geometries perform over time is essential for ensuring that design improvements translate into sustained performance gains. Future research should aim to address these gaps by conducting more holistic evaluations of burner head geometry, incorporating both experimental testing and simulation-based modeling[35]. This research addresses the gap by integrating experimental testing and CFD simulations to provide a holistic comparison of different burner geometries. Specifically, it evaluates circular, star-shaped, and multi-port burners under controlled conditions to identify the best design for thermal efficiency and emissions reduction.

The number one goal of this observe is to investigate how burner head geometry influences the thermal efficiency of LPG cooking stoves. By exploring the outcomes of diverse burner designs such as round, multi-port, and other revolutionary configurations on warmness transfer, fuel intake, and combustion efficiency, this research targets to provide valuable insights into how stove overall performance can be optimized. Additionally, this takes a look at seeks to make a contribution to the wider goal of enhancing energy performance in cooking technologies, which has tremendous implications for reducing greenhouse gasoline emissions and promoting sustainable power use in domestic and business settings. This research isn't always simplest applicable for stove manufacturers trying to enhance product performance but also for policymakers and energy researchers interested by growing more green, environmentally pleasant cooking solutions. By filling the research hole regarding the influence of burner head geometry on LPG range performance, this observes targets to increase the know-how of combustion dynamics and support the layout of subsequent-generation stoves that meet the twin demanding situations of power performance and environmental sustainability.

7. METHODOLOGY

The technique segment outlines the experimental design, materials, and procedures used to evaluate the impact of burner head geometry on the thermal efficiency of LPG cooking stoves. The examiner makes a specialty of comparing various burner head designs, analyzing their effect on heat switch, gasoline consumption, combustion dynamics, and emission ranges. To ensure the accuracy and reliability of results, a rigorous testing framework was implemented, incorporating both controlled laboratory experiments and computational simulations. The modeling included the following steps: (1) The initial geometric parameters were selected based on the references, including the hole diameter (1-1.5 mm) and spacing (2 mm). (2) The constraints included keeping the material thickness above 2 mm for structural integrity and ensuring uniform flame propagation. (3) Iterative simulations were performed using ANSYS to optimize the designs, with a focus on improving heat transfer and reducing fuel consumption. Statistical analyses were conducted to validate the significance of differences in thermal efficiency and emissions among the burner geometries. A one-way ANOVA test was employed, followed by Tukey’s post-hoc test for pairwise comparisons.

7.1 Experimental Setup

The experimental setup comprised an LPG stove system equipped with interchangeable burner heads, a calorimetric apparatus for measuring thermal efficiency, and gas analyzers to assess emission levels. A series of burner head geometries, including circular, star-shaped, and multi-port designs, were fabricated from high-grade stainless steel to maintain consistency across tests. These designs were chosen based on their prevalence in the literature and potential for enhancing heat transfer efficiency the applicability of the Water Boiling Test (WBT) in replicating real-world cooking scenarios. The WBT, while useful for comparing burner designs under controlled conditions, may not fully capture the variability of real-world cooking practices, such as differences in cooking vessel types, ambient conditions, and user behaviors. These factors could influence the thermal efficiency and emissions measured in practical settings, as shown in figure1. Specifications burner head design are presented in Table 1.

Table 1. Burner Design Specifications Including Port Number, Diameter, Flame Spread, and Material.

Burner Design	Port Number	Port Diameter (mm)	Flame Spread Diameter (cm)	Material
Circular	12	1.5	10	Stainless Steel
Star-Shaped	16	1.2	12	Stainless Steel
Multi-Port	20	1	11	Stainless Steel

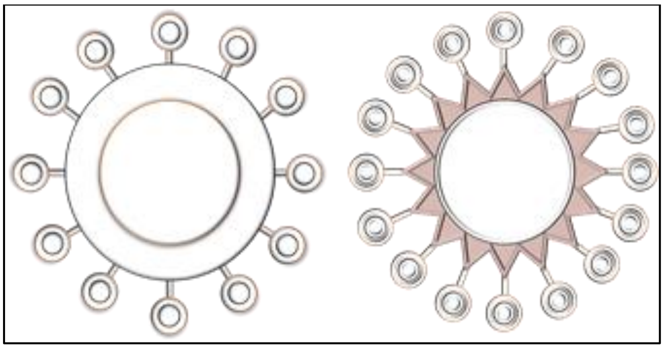

Fig. 1. Burner Head Designs shape

The burner heads (circular, star-shaped, and multi-port) were fabricated from stainless steel using precision laser cutting for consistent port sizes. Each design was tested under identical conditions using a standard LPG composition of 70% propane and 30% butane by weight. A standard aluminum cooking pot (diameter: 24 cm, thickness: 3 mm) was used to boil 2 liters of water.

7.2 Control Environment Details

To ensure consistency, experiments were conducted in a controlled laboratory environment where temperature and humidity were maintained at 25±2℃ and 50±5%, respectively. Airflow within the testing area was minimized to less than 0.1 m/s to avoid external disturbances to the flame. These parameters were continuously monitored using calibrated sensors.

7.3 Test Procedure

The thermal efficiency of each burner head design became measured the usage of a water-boiling test (WBT), a fashionable technique for evaluating stove performance. A constant quantity of water (2 liters) changed into positioned in a general aluminum cooking pot with a flat backside and boiled at the LPG range the use of each burner head configuration.

The digital thermometer with an accuracy of ±0.1°C became used to display the water temperature in real-time. Also, The weight of the LPG cylinder was measured before and after the check the usage of a precision balance with an accuracy of ±0.01 grams. The total fuel consumption was calculated based on the difference in cylinder weight. About heat Transfer Efficiency: The thermal efficiency was calculated using the formula[36]:

$$\eta = mc \cdot Cw \cdot \Delta T / mf.\ Hf \quad (1)$$

where:

- mc is the mass of water (2 kg),
- Cw is the specific heat capacity of water (4.186 J/g°C),
- ΔT is the change in water temperature from initial to boiling (typically 80°C),
- mf is the mass of fuel consumed (grams),
- Hf is the heat of combustion for LPG (46.1 MJ/kg).

In addition, the combustion characteristics and emission levels of each burner head design were reviewed, and a gasoline analyser was used to measure the concentration of CO with an accuracy of ±1 ppm and NOx with an accuracy of ±0.1 ppm in the exhaust gases. A sampling probe was placed 10 cm above the burner flame to collect fuel samples during the water boiling tests. Finally, an emission index was calculated to evaluate the environmental impact of each burner head design as shown in table 2.

Table 2. Emission levels recorded for each burner geometry

Burner Design	CO Emission (ppm)	NOx Emission (ppm)
Circular	220	45
Star-Shaped	180	38
Multi-Port	160	35

7.4 Computational Fluid Dynamics (CFD) Simulation

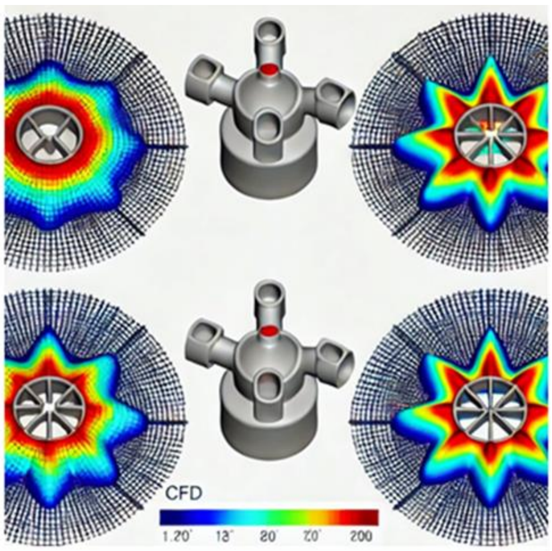

Fig. 2. Temperature distribution for different burner head designs based on CFD simulations

In addition to the experimental tests, computational fluid dynamics (CFD) simulations had been carried out to model the heat switch and combustion behavior for each burner head design. The simulations allowed for a detailed analysis of flame spread, temperature distribution, and air-fuel mixing, providing insights into how burner head geometry affects thermal performance as shown in figure 2.

Dependent mesh generated for each burner geometry, with about 1 million cells to seize special flow characteristics and simulated the turbulent flow of combustion gases. The non-premixed combustion model become hired to simulate the LPG combustion procedure with Inlet boundary situations had been set to match the experimental LPG go with the flow fees, and outlet situations had been defined as open to the environment.

8. Data Analysis

Experiments were conducted in a controlled environment to minimize the impact of ambient conditions such as airflow, temperature, and humidity, which could otherwise introduce variability in fuel combustion and heat transfer efficiency. Careful control of these factors reduced the uncertainty in the measured thermal efficiency and emissions. p-values below the threshold of 0.05 suggest that the differences observed in thermal efficiency or emissions. A 95% confidence interval for thermal efficiency might be reported as 54% to 60% for the multi-port burner.

The average thermal efficiency for each burner head design was calculated and compared. The multi-port burner exhibited the highest thermal efficiency (58%), followed by the star-shaped burner (54%) and the circular burner (50%). The thermal efficiency differences among the three burner designs were statistically significant ($p < 0.01$). Confidence intervals (95%) for thermal efficiency were calculated: multi-Port: 54%-60%, Star-Shaped: 50%-57% and Circular: 47%-53%. Emission differences were also statistically significant: CO emissions ($p < 0.01$): multi-port burners exhibited the lowest mean CO emissions (160 ppm) compared to star-shaped (180 ppm) and circular burners (220 ppm). NOx emissions ($p < 0.05$): multi-port burners had significantly lower NOx emissions (35 ppm) compared to circular burners (45 ppm). These statistical validations confirm that the multi-port burner significantly outperforms other designs in both thermal efficiency and emissions reduction. This robust analysis enhances the credibility of the findings and their applicability in real-world scenarios.

This study's experimental results reveal that the multi-port burner achieves a thermal efficiency of 58%, compared to 54% for the star-shaped and 50% for the circular design. Emission levels are also lowest for the multi-port burner (CO: 160 ppm, NOx: 35 ppm), highlighting its superior performance. These findings fill a critical gap in the literature by quantifying the benefits of geometric innovation in LPG stove design. The fuel consumption was found to correlate inversely with thermal efficiency. The multi-port burner consumed the least amount of LPG (45 grams), while the circular burner consumed the most (52 grams). The multi-port burner emitted the lowest levels of CO and NOx, indicating that this geometry not only enhances thermal efficiency but also reduces the environmental impact of LPG stoves. Thermal performance was evaluated the usage of the water-boiling test (WBT), wherein the warmth switch from the burner to the water turned into measured for every burner design. The results revealed sizable differences within the thermal overall performance of the burner heads, with the multi-port burner head showing the highest performance. The multi-port burner demonstrated significantly higher thermal efficiency ($p < 0.01$) compared to the circular burner. The star-shaped burner did not show statistically significant differences in emissions compared to the multi-port burner, with a p-value greater than 0.05 as shown in figure 3.

The multi-port burner achieved a thermal efficiency of 58%, the highest among the three designs. The star-shaped burner head also demonstrated improved efficiency compared to the circular design, reaching 54%. The circular burner head exhibited the lowest thermal efficiency at 50%. The multi-port burner also consumed the least amount of fuel, using 45 grams of LPG, while the circular burner consumed 52 grams. These results can be attributed to the improved heat distribution provided by the more complex geometries of the star-shaped and multi-port burners. The increased number of flame ports and the larger surface area available for heat transfer allowed for more efficient energy conversion, reducing fuel consumption and maximizing the heat transferred to the cooking vessel.

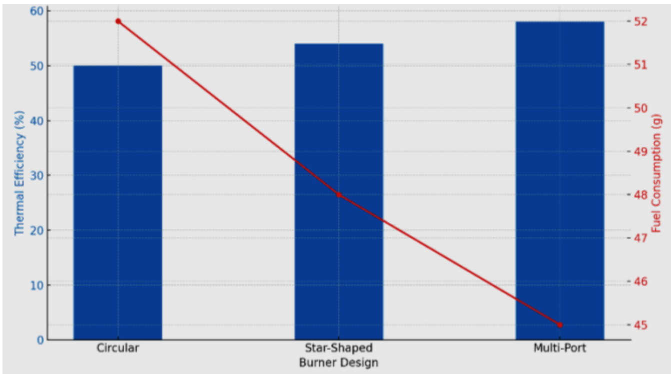

Fig. 3. Comparison of thermal efficiency and fuel consumption

Flame behavior was also influenced by burner geometry, with differences in flame height and stability observed across designs. The circular burner produced a longer, more concentrated flame, resulting in less stable heat transfer and greater susceptibility to external disturbances such as air currents. While the star-shaped burner produced a stronger, more evenly distributed flame due to its geometry, the multi-port burner exhibited the lowest flame height and most stable combustion behavior, with the flame evenly distributed across the burner surface.

Figure 4 highlights that the multi-port burner produced 160 ppm of CO and 35 ppm of NOx, representing a reduction of approximately 27% in CO and 22% in NOx compared to the circular burner. The star-shaped burner also demonstrated lower emissions, but to a lesser extent. The improved air-fuel mixing and more complete combustion achieved by the multi-port burner contributed to its superior environmental performance. A gas analyser measured CO and NOx levels with accuracies of ±1 ppm and ±0.1 ppm, respectively. Emissions were sampled 10 cm above the flame centre. For example, the multi-port burner produced CO: 160 ppm and NOx: 35 ppm, compared to 220 ppm CO and 45 ppm NOx for the circular burner.

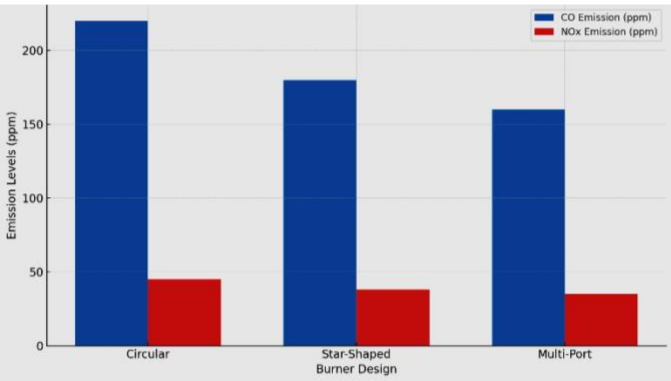

Fig. 4 . CO and NOx emission levels across burner geometries

9. CONCLUSION

This research shows that improving the geometry of the burner head, especially through multi-port designs, can significantly enhance thermal efficiency (up to 58%), reduce fuel consumption (45 g/d), and reduce harmful emissions (160 ppm CO2, 35 ppm NOx) from LPG cooking stoves. Unlike prior studies, this work provides insights into real-world applications, demonstrating how burner geometry can significantly impact fuel consumption and emission levels. The results are not only scientifically robust but also practically relevant, offering actionable recommendations for manufacturers to design more efficient and environmentally friendly stoves.

These results provide valuable insights for developing more efficient, cost-effective, and environmentally sustainable cooking technologies. By optimizing the design of the burner head, it is possible to obtain higher combustion efficiency, which immediately translates into higher energy use and lower operating costs for households. Furthermore, reducing harmful emissions such as carbon monoxide and nitrogen oxides contributes significantly to improving indoor air quality and reducing environmental pollutants. Such improvements are essential in areas where LPG stoves are common, as they help in public health and sustainability projects. Future studies may wish to explore the potential for extending these design improvements to specific stove types and conditions, as well as their potential impact on a wider range of fuels, further contributing to global energy efficiency and emissions reduction goals. While this study provides foundational insights, future research can explore additional parameters such as long-term durability, manufacturing feasibility, and adaptation for different fuel types. Such extensions will further solidify the understanding of burner design optimization.

REFERENCES

[1] J. T. Al-Naffakh, M. R. Al-Qassab, B. T. Neamah, and Z. M. H. Al-Makhzoomi, "Experimental investigation of blending acetylene with iraqi lpg to determine a flame stability map," J. Pet. Res. Stud., vol. 12, no. 1, pp. 350–363, 2022. https://doi.org/10.52716/jprs.v12i1.607

[2] C. Wright, R. Sathre, and S. Buluswar, "The global challenge of clean cooking systems," Food Secur., vol. 12, no. 6, pp. 1219–1240, 2020, https://doi.org/10.1007/s12571-020-01061-8

[3] A. Datta, M. Das, and R. Ganguly, "Design, development, and technological advancements in gas burners for domestic cook stoves: a review," Trans. Indian Natl. Acad. Eng., vol. 6, pp. 569–593, 2021, https://doi.org/10.1007/s41403-021-00223-0

[4] L. Petro, "Optimization of domestic biogas stove burner for efficient energy utilization," 2020, NM-AIST. https://doi.org/10.58694/20.500.12479/1300

[5] R. Y. Dahham, H. Wei, and J. Pan, "Improving thermal efficiency of internal combustion engines: recent progress and remaining challenges," Energies, vol. 15, no. 17, p. 6222, 2022, https://doi.org/10.3390/en15176222

[6] J. Cho, S. Park, and S. Song, "The effects of the air-fuel ratio on a stationary diesel engine under dual-fuel conditions and multi-objective optimization," Energy, vol. 187, p. 115884, 2019, https://doi.org/10.1016/j.energy.2019.115884

[7] A. Anderson, V. Kumar, V. M. Rao, and J. Grogan, "A review of computational capabilities and requirements in high-resolution simulation of nonferrous pyrometallurgical furnaces," JOM, vol. 74, no. 4, pp. 1543–1567, 2022, https://doi.org/10.1007/s11837-022-05169-4

[8] V. Raghavan and V. Raghavan, "Burners for gaseous fuels," Combust. Technol. Essentials Flames Burn., pp. 85–111, 2022, https://doi.org/10.1007/978-3-030-74621-6_4

[9] W. Gao et al., "Comprehensive review on thermal performance enhancement of domestic gas stoves," ACS omega, vol. 8, no. 30, pp. 26663–26684, 2023, https://doi.org/10.1021/acsomega.3c01628

[10] N. MacCarty, D. Still, and D. Ogle, "Fuel use and emissions performance of fifty cooking stoves in the laboratory and related benchmarks of performance," Energy Sustain. Dev., vol. 14, no. 3, pp. 161–171, 2010, https://doi.org/10.1016/j.esd.2010.06.002

[11] A. Gharehghani, K. Ghasemi, M. Siavashi, and S. Mehranfar, "Applications of porous materials in combustion systems: A comprehensive and state-of-the-art review," Fuel, vol. 304, p. 121411, 2021, https://doi.org/10.1016/j.fuel.2021.121411

[12] W. Ben Atia, Z. Boutar, A. Halloumi, and R. Ennetta, "Experimental Investigation of the Effect of the Burner Cap Geometry on the Performance of a Domestic Liquefied Petroleum Gas Stove," J. Therm. Sci. Eng. Appl., vol. 16, no. 4, p. 41003, 2024, https://doi.org/10.1115/1.4064586

[13] S. R. Kashyap, S. Pramanik, and R. V Ravikrishna, "A review of energy-efficient domestic cookstoves," Appl. Therm. Eng., vol. 236, p. 121510, 2024, https://doi.org/10.1016/j.applthermaleng.2023.121510

[14] M. A. Nemitallah, A. A. Abdelhafez, A. Ali, I. Mansir, and M. A. Habib, "Frontiers in combustion techniques and burner designs for emissions control and CO2 capture: A review," Int. J. Energy Res., vol. 43, no. 14, pp. 7790–7822, 2019, https://doi.org/10.1002/er.4730

[15] H. Shen et al., "A critical review of pollutant emission factors from fuel combustion in home stoves," Environ. Int., vol. 157, p. 106841, 2021, https://doi.org/10.1016/j.envint.2021.106841.

[16] B. H. Alshammari et al., "Organic and inorganic nanomaterials: fabrication, properties and applications," RSC Adv., vol. 13, no. 20, pp. 13735–13785, 2023, https://doi.org/1039/D3RA01421E

[17] B. Sunden and G. Xie, "Gas turbine blade tip heat transfer and cooling: a literature survey," Heat Transf. Eng., vol. 31, no. 7, pp. 527–554, 2010, https://doi.org/10.1080/01457630903425320

[18] Y. Sheng, H. Liu, Y. Cui, Z. Shi, X. Cong, and K. Xie, "Study on flame adaptability method of an integrated Chinese cooking stove research based on the synergetic theory," Energy Reports, vol. 8, pp. 13226–13234, 2022, https://doi.org/10.1016/j.egyr.2022.09.109

[19] R. Şener, M. Özdemir, and M. Yangaz, "Effect of the geometrical parameters in a domestic burner with crescent flame channels for an optimal temperature distribution and thermal efficiency," J. Therm. Eng., vol. 5, no. 6, pp. 171–183, 2019, https://doi.org/10.18186/thermal.654303

[20] J. Kearney, "Circumferentially Fired Combustion Port Geometry: Analysis of Hybrid Rocket Motor Solid Fuel Grain," 2019, California State University, Sacramento.

[21] W. Shih-Sin, L. Meng-Che, A. Lai, T.-H. Chou, and W. Jong-Shinn, "A Review of Recent Developments in Hybrid Rocket Propulsion and Its Applications," Aerospace, vol. 11, no. 9, p. 739, 2024, https://doi.org/10.3390/aerospace11090739

[22] L. Gattei, "A study on the fluid dynamics of domestic Gas burners," 2009, https://doi.org/10.6092/unibo/amsdottorato/1926

[23] T. Pachiannan, W. Zhong, S. Rajkumar, Z. He, X. Leng, and Q. Wang, "A literature review of fuel effects on performance and emission

characteristics of low-temperature combustion strategies," Appl. Energy, vol. 251, p. 113380, 2019, https://doi.org/10.1016/j.apenergy.2019.113380

[24] M. A. Haque, M. A. Nemitallah, A. Abdelhafez, I. B. Mansir, and M. A. Habib, "Review of fuel/oxidizer-flexible combustion in gas turbines," Energy & Fuels, vol. 34, no. 9, pp. 10459–10485, 2020, https://doi.org/10.1021/acs.energyfuels.0c02097

[25] A. J. Butcher, "Spray Formation and Cavitation of Fuel Injectors with Various Metal and Optical Nozzles," 2020, UCL (University College London). [Online]. Available: https://discovery.ucl.ac.uk/id/eprint/10095710

[26] T. J. Hager and R. Morawicki, "Energy consumption during cooking in the residential sector of developed nations: A review," Food Policy, vol. 40, pp. 54–63, 2013, https://doi.org/10.1016/j.foodpol.2013.02.003

[27] M. Palanisamy et al., "Evolutions in Gaseous and Liquid Fuel Cook-Stove Technologies," Energies, vol. 16, no. 2, p. 763, 2023, https://doi.org/10.3390/en16020763

[28] S. Zhang et al., "Experimental and numerical study the effect of combustion chamber shapes on combustion and emissions characteristics in a heavy-duty lean burn SI natural gas engine coupled with detail combustion mechanism," Fuel, vol. 258, p. 116130, 2019, https://doi.org/10.1016/j.fuel.2019.116130

[29] J. Goldemberg, J. Martinez-Gomez, A. Sagar, and K. R. Smith, "Household air pollution, health, and climate change: cleaning the air," Environ. Res. Lett., vol. 13, no. 3, p. 30201, 2018, https://doi.org/10.1088/1748-9326/aaa49d

[30] V. S. Yaliwal, N. R. Banapurmath, N. M. Gireesh, R. S. Hosmath, T. Donateo, and P. G. Tewari, "Effect of nozzle and combustion chamber geometry on the performance of a diesel engine operated on dual fuel mode using renewable fuels," Renew. Energy, vol. 93, pp. 483–501, 2016, https://doi.org/10.1016/j.renene.2016.03.020

[31] M. Deymi-Dashtebayaz, M. Rezapour, H. Sheikhani, H. R. Afshoun, and V. Barzanooni, "Numerical and experimental analyses of a novel natural gas cooking burner with the aim of improving energy efficiency and reducing environmental pollution," Energy, vol. 263, p. 126020, 2023, https://doi.org/10.1016/j.energy.2022.126020

[32] M. A. Nemitallah, S. S. Rashwan, I. B. Mansir, A. A. Abdelhafez, and M. A. Habib, "Review of novel combustion techniques for clean power production in gas turbines," Energy & Fuels, vol. 32, no. 2, pp. 979–1004, 2018, https://doi.org/10.1021/acs.energyfuels.7b03607.

[33] D. Kim, "Investigating sustainable fuel effects on mixing and combustion through design and development of a gasoline direct injection optically accessible engine," 2022, UCL (University College London). [Online]. Available: https://discovery.ucl.ac.uk/id/eprint/10156155

[34] P. Arora and S. Jain, "A review of chronological development in cookstove assessment methods: Challenges and way forward," Renew. Sustain. Energy Rev., vol. 55, pp. 203–220, 2016, https://doi.org/10.1016/j.rser.2015.10.142

[35] R. Shen et al., "Development of a compact high-performance combustion powered thermoelectric generator based on swirl burner," Energy, vol. 286, p. 129455, 2024, https://doi.org/10.1016/j.energy.2023.129455

[36] K. Bilen, U. Akyol, and S. Yapici, "Heat transfer and friction correlations and thermal performance analysis for a finned surface," Energy Convers. Manag., vol. 42, no. 9, pp. 1071–1083, 2001, https://doi.org/10.1016/S0196-8904(00)00119-9