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Enhancement of Thermal Efficiency in Gas-Fired Heaters Through a Novel Double-Walled Chimney Design: Experimental and CFD Analysis

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Abstract: In the Middle East, gas-fired heaters are conventionally favored due to their reliability, cost-effectiveness, and minimal environmental impact. However, the challenges associated with traditional designs, such as low thermal efficiency, high fuel consumption, emissions of environmental pollutants, indoor gas leakage, moisture absorption, uneven heat distribution, and non-compliance with design standards, necessitate innovative solutions. A novel gas-fired heater design is thus presented in this investigation, incorporating a double-walled chimney equipped with an intermediate ejector, blades, and a mesh plate. These components were integrated to enhance the overall performance by optimizing airflow dynamics, thereby improving efficiency and ensuring uniform flame formation. An experimental heater model was constructed, and a series of controlled experiments, along with Computational fluid dynamics (CFD) modeling, were performed. The thermal efficiency was found to improve by an average of 10% compared to conventional models, elevating the efficiency from 75% to 85%. This increase was attributed to the preheating of the inlet air in the double chimney, proper air distribution within the combustion chamber through mesh plate application, and the reduction of excess air volume by controlling the air inlet. Enhanced safety was also observed in the proposed design, with no exchange of air with the room, thereby alleviating concerns related to indoor gas leakage and moisture absorption. A minor trade-off was noted with a 3 ppm increase in nitrogen oxides ((NO_x) emissions, an effect of reduced excess airflow to the combustion chamber; however, this was deemed acceptable in light of the substantial efficiency increase. Furthermore, the decreased natural gas consumption rendered the model economically attractive. Overall, the proposed gas-fired heater design offers significant potential for improving residential heating systems, addressing environmental issues, and maximizing energy savings, and is aligned with the global pursuit of energy-efficient and sustainable solutions.

Keywords: Gas-fired heater; Double-walled chimney with intermediate ejector; Pollutant emissions; Efficiency; Combustion optimization; Computational fluid dynamics

1 Introduction

The Middle East, renowned for its abundant natural gas reserves, particularly in nations such as Saudi Arabia, Qatar, and the United Arab Emirates, has led to the prevalent use of gas-fired heaters. These heaters are fundamental in offering warmth to residential, commercial, and industrial spaces, owing to their cost-effectiveness, efficiency, and reliability.

1.1 First to Third Generation Gas-Fired Heaters

Historically, first-generation gas-fired heaters in the Middle East have been associated with certain limitations. Reliance on indoor air for combustion was found to cause uneven temperature distribution and even pose suffocation risks. In response, second-generation heaters were developed with fans to aid air exchange and ameliorate temperature distribution. Third-generation heaters introduced further advancements, including a double-wall chimney and external air sourcing for combustion, negating the need for indoor air. However, these designs necessitated specific building structures and chimney arrangements [1]. Ventless gas-fired heaters emerged as an efficient alternative, operating without chimneys and even during power outages, although safety concerns have been observed in specific environments [2].

1.2 Existing Research and Limitations

Extensive studies on gas-fired heaters have explored combustion processes and efficiency. Faulkner's investigation calculated the stoichiometric air ratio for various heaters, revealing that the air influx during combustion in conventional gas-fired boilers was about four times the stoichiometric requirement, significantly affecting efficiency [3]. Traynor et al. [4] evaluated oxygen consumption and emissions from ventless heaters, identifying potential air quality issues due to occasional exceedance of pollutant concentrations over guidelines. Woodring et al. [5] subsequently addressed these concerns by establishing dilution ventilation requirements, and Setini [6] demonstrated that natural ventilation could maintain optimal temperature and carbon dioxide concentration.

Efforts to optimize efficiency-related parameters in gas-fired heaters have been undertaken. Bekele et al. [7] analyzed the influence of obstacles on thermal performance, noting an enhancement in the Nusselt number, albeit at the cost of increased pressure drop.

1.3 Novel Heater Design

This investigation introduces a groundbreaking heater design that addresses the constraints of existing models. By employing a double-wall chimney coupled with an ejector system to supply combustion air from external and ambient sources without the need for electrical suction, the entry of toxic gases into the room is effectively prevented. Furthermore, the inclusion of a specialized air distributor was found to augment combustion and minimize environmental pollutants. The strategic incorporation of blades within the combustion chamber enhances heat transfer, thereby boosting the heater's overall efficiency.

2 Literature Review

The literature on gas-fired heaters predominantly focuses on their combustion mechanisms, efficiency optimization, and air quality management. In line with this, the design proposals and practical measures previously introduced have shed light on various aspects of gas-fired heaters.

2.1 Combustion Processes and Efficiency

Research by Faulkner [3] underlined the inefficiencies in conventional gas-fired boilers due to excess air during combustion. Efforts to rectify these issues have been seen in the investigation by Bekele et al. [7], where the effect of obstacles on thermal performance was scrutinized, resulting in enhanced Nusselt numbers.

2.2 Air Quality and Safety Concerns

Studies on ventless heaters by Traynor et al. [4] identified concerns regarding air quality due to concentrations of CO_2, CO, and NO_2. Subsequent research by Woodring et al. [5] and Setiani [6] provided solutions through dilution ventilation and natural ventilation, respectively.

2.3 Innovations and Future Directions

The novel design proposed in this study builds upon previous research, incorporating innovations to overcome the limitations of existing models. By enhancing safety, combustion efficiency, and environmental considerations, this design represents a significant step toward revolutionizing the heater market and setting new standards for performance and sustainability.

3 The Proposed Design

An innovative design is proposed to overcome the limitations commonly associated with conventional gas-fired heaters, with an emphasis on optimizing performance and efficiency. This novel approach redefines airflow dynamics and offers comprehensive enhancements to overall heater performance.

3.1 Integration of Double-Walled Chimney and Ejector System

At the core of the proposed design lies the combination of a double-walled chimney and an intermediate ejector, facilitating the intake and preheating of external air. This mechanism eradicates the need for indoor air combustion, thereby addressing the primary limitation of first-generation heaters. Notably, the absence of any electrical devices or fans for air suction into the combustion chamber differentiates this design from its predecessors [1]. Safety is prioritized through the prevention of air or combustion products entering the room, and gas pilot wires sealed with non-combustible material at the heater's base are introduced to eliminate air leakage.

3.2 Suction Force Mitigation

To tackle the challenge of suction forces in the vicinity of the ejector, a fine hole with a diameter of 1 cm is strategically incorporated at the midpoint of the ejector throat. This alleviates turbulence and pressure fluctuations, thus enhancing the stability of airflow dynamics. The hole serves as a pressure relief mechanism, mitigating the negative effects of suction forces while preserving the efficiency of the ejector.

3.3 Heat Transfer Optimization

Blades are integrated within the design to reduce outlet velocity and absorb flow energy, thereby optimizing heat transfer. Such enhancement in thermal performance has been previously identified as beneficial [8]. Further, the employment of a mesh plate beneath the burner ensures uniform flame formation and offsets potential imbalances caused by the uneven distribution of incoming air. Figure 1 presents the applied mesh plate in the heater. The diffusion property of the mesh plate encourages a well-mixed air-fuel ratio across the burner surface, leading to a more consistent combustion process.

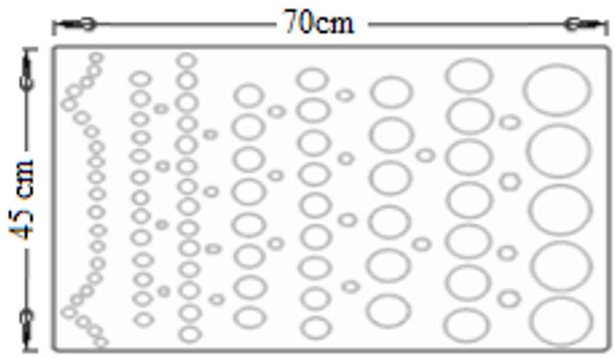

Figure 1. Mesh plate for uniform air distribution in burner

3.4 Emission Control and Air Distribution Regulation

Strategically positioned holes near the air inlet in the plate regulate incoming air velocity, thus avoiding uneven distribution as it enters the combustion chamber. The incorporation of chamfered nozzles with varying diameters facilitates suction-driven creation of these holes. These innovative features contribute to optimal combustion conditions, which, in turn, minimize the production of harmful byproducts such as carbon monoxide and nitrogen oxides. This promotes a safer and more environmentally sustainable operation.

3.5 Detailed Design Structure

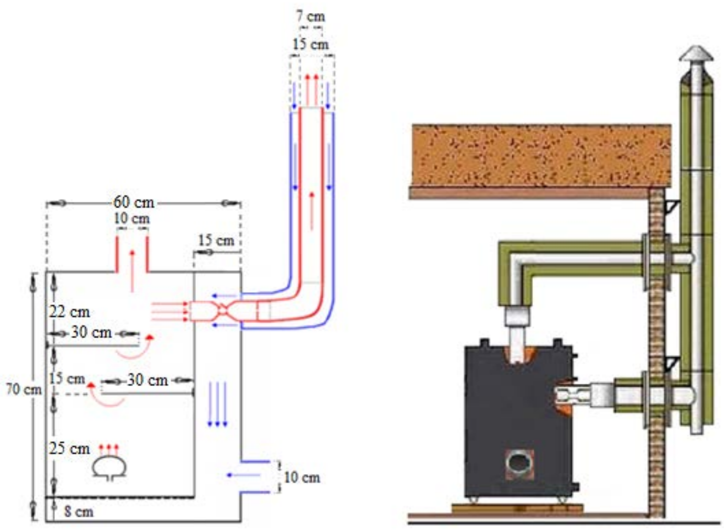

Figure 2. Schematic diagram of the designed heater

The schematic representation of the proposed design includes precise positioning of blades, mesh plate, and air inlets and outlets, as illustrated in Figure 2. This configuration allows for the examination of combustion product discharge effects on performance and efficiency. An additional air inlet provided at the bottom facilitates pilot ignition and controls excess air entry into the combustion chamber.

3.6 Implications for Residential Applications

The proposed design is particularly relevant to residential applications, where safety considerations are paramount. By addressing the aforementioned challenges and integrating innovative features, this design presents a promising advancement in the field of gas-fired heaters, setting new standards for performance, safety, and environmental sustainability.

4 Combustion Processes

The significant role of gas-fired heaters in Middle Eastern countries is manifested in their contribution to a variety of applications, delivering heat and energy solutions. Natural gas, procured from independent gas fields and oil wells in these regions, serves as the primary fuel [1]. The diverse composition of this raw natural gas encompasses a spectrum of hydrocarbons, along with certain impurities. These hydrocarbons, which include methane (CH_4) as the most abundant, ethane (C_2H_6), propane (C_3H_8), butane (C_4H_{10}), and natural gasoline, contribute substantially to the energy content of the gas, and find utility in various industrial and fuel applications [2].

Raw natural gas also comprises impurities such as water, carbon dioxide (CO_2), carbon monoxide (CO), nitrogen (N_2), hydrogen sulfide (H_2S), and helium (He). Many of these impurities, due to their undesirable nature, necessitate removal to ensure the safe and efficient use of natural gas [3]. Despite the presence of various hydrocarbons in the raw natural gas, methane prominently dominates the composition. Known for its clean-burning characteristics, methane, upon combustion, primarily yields water (H_2O), emitting lesser quantities of carbon dioxide (CO_2) compared to other fossil fuels [4]. This characteristic positions natural gas as an environmentally friendlier option for energy production, mitigating the impact of carbon dioxide emissions on the environment [5].

4.1 Combustion Process in Gas-fired Heaters

Gas-fired heaters predominantly rely on the combustion of methane and air. The balanced stoichiometric combustion equation for methane (CH_4), involving oxygen (O_2) and nitrogen (N_2), is presented as follows:

$$CH_4 + 2O_2 + 7.52N_2 \rightarrow CO_2 + 2H_2O + 7.52N_2 \tag{1}$$

This equation introducesCH_4 as methane, the central component of natural gas, O_2 as oxygen, required for the combustion process, and N_2 as nitrogen, serving as a diluent in air [6]. The actual reaction occurs in diluted mixtures and the presence of excess air. The corresponding combustion equation under adiabatic conditions is formulated as follows [9]:

$$CH_4 + \frac{2}{\emptyset}\left(O_2 + \frac{100-\gamma}{\gamma}N_2\right) \rightarrow CO_2 + 2H_2O + 2\left(1 - \frac{1-\emptyset}{\emptyset}O_2\right) + \frac{2}{\emptyset}\left(\frac{100-\gamma}{\gamma}\right)N_2 \tag{2}$$

In this equation, φ represents the ratio of the stoichiometric air amount to the actual air amount, and γ denotes the percentage of oxygen present in the air, typically approximating to 22% under standard conditions [7]. This equation, subject to the constraint $0 \leq \phi \leq 1$, governs the process of complete combustion with excess air.

4.2 Impact of the Air Ratio φ on Combustion

As the air ratio φ increases, the combustion process witnesses a higher supply of excess air, ensuring the availability of more oxygen for the reaction. This enhanced availability facilitates more complete combustion, resulting in an increased production of carbon dioxide (CO_2) and water vapor (H_2O). However, the excess air can also promote the formation of nitrogen oxides (NO_x), especially at elevated temperatures, due to the reaction of nitrogen in the air with oxygen.

Conversely, a decrease in the air ratio φ implies less excess air during combustion. This can cause incomplete combustion, leading to the production of carbon monoxide (CO) instead of CO_2, along with soot or unburned hydrocarbons. Such incomplete combustion is less efficient and can result in higher pollutant levels in the exhaust gases.

The most efficient combustion is achieved when the air ratio φ aligns with the stoichiometric value, implying that exactly the right amount of air is supplied to fully react with all the fuel. This condition guarantees complete combustion, thereby maximizing the energy released during the reaction. However, real-world applications often use some excess air to ensure safety, compensate for variations in fuel composition, and allow for a margin of error.

4.3 Role of Oxygen Concentration in Combustion Efficiency

The oxygen percentage in the air, typically around 22% under standard conditions, also plays a critical role in determining combustion efficiency. Higher oxygen concentrations can foster more complete combustion, leading to increased energy release and reduced formation of harmful byproducts. Conversely, lower oxygen levels can induce incomplete combustion, resulting in reduced efficiency and increased emissions. Therefore, achieving the right balance between excess air and oxygen concentration becomes essential for optimal combustion performance and minimal environmental impacts.

5 Results and Discussion

5.1 Heat Transfer

The installation of blades inside the heater, which served to obstruct the flow of hot product gas, led to the prevention of rapid gas outflow from the chimney, thereby enhancing the residence time of flue gases. Consequently, energy transfer to the room was facilitated rather than dissipated, culminating in the enhancement of the gas heater's thermal efficiency.

Figure 3 presents the velocity vectors within the confines of the designed heater, illuminating the impact of the internal blade structure. As depicted in subgraph (A) of Figure 3, upon collision with the initial blade, the flow is seen to bifurcate into two streams, thereby generating two fluid jets on opposing sides of the blade. This Figure distinctly highlights the ensuing formation of vortices and turbulence trailing the blades. In further detail, the right segment of subgraph (B) of Figure 3 showcases the flow subjected to intense rotational activity within the conduits linking the furnace to the adjustment chamber.

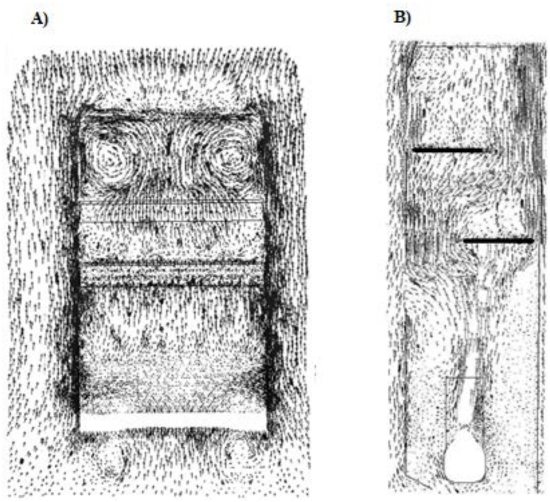

Figure 3. Velocity vectors around blades in cross-section plates of the designed heater

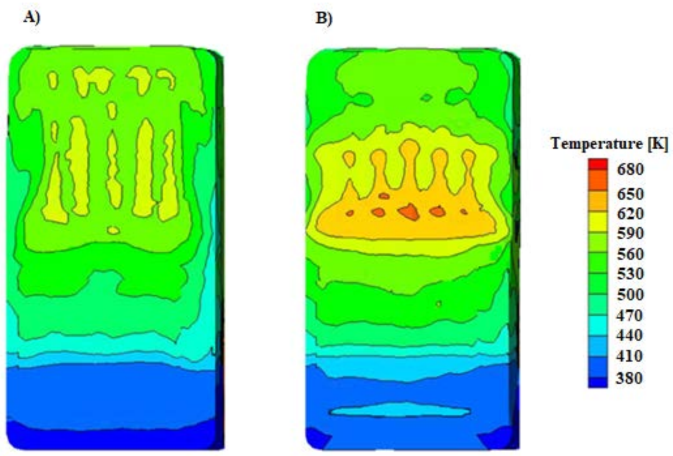

Figure 4. The temperature distribution on the designed heater A) without blades B) with blades

A comparative examination of temperature distribution on the heater, both with and without blades, is exhibited in Figure 4. The outcomes unambiguously underscore the instrumental role of blades in the attainment of elevated temperatures within the designated region. This elevation in temperature is markedly conspicuous in the immediate vicinity of the blades, an area where jet formation is evident. Such an occurrence is indicative of the blades' capacity to amplify both heat transfer and the underlying fluid dynamics within the system. Notably, simulation data disclosed a significant 12-degree augmentation in the average temperature on the heater surface when blades were incorporated.

Within this specific heater configuration, the strategic introduction of obstacles was observed to boost fluid velocity, subsequently instigating vortexes and turbulence. Such flow perturbations were found to disrupt the boundary layer, thereby leading to a surge in heat flux coupled with a rise in surface temperature. Moreover, the curtailment of jet expansion and the ensuing reduction in velocity post-obstacle traversal contributed to the prolongation of hot gas residence within the chamber. This facilitated more effective heat transfer, culminating in the realization of an enhanced overall efficiency for the heater.

The aforestated results lend credence to the hypothesis that the integration of blades within the heater architecture can have a pronounced effect on the thermal efficiency of the system. By modulating fluid dynamics and optimizing heat transfer mechanisms, the blades serve as an effective means to both conserve energy and enhance performance. Further studies could extend this investigation by exploring variations in blade design and material composition to ascertain their effects on system efficiency and reliability. Additionally, real-world experimental validation of the simulation findings may yield further insights into the practical applicability of these design enhancements.

5.2 Efficiency: Maximizing Energy Conversion

Traditional gas-fired heaters, marked by their simplistic design featuring a lone gas burner body without a double-walled chimney, and characterized by separate inlets for air intake and product exhaust, offer a starting point for the study of thermal efficiency. Thermal efficiency, as defined, represents the ratio of the total energy produced by natural gas to the energy loss through the chimney. This ratio is represented by the following expression:

$$\eta = m^{\circ}_{\text{in}}\, LHV/E^{\circ}_{L} \tag{3}$$

where, η symbolizes the thermal efficiency of a conventional heater, m°_{in} is the mass flow rate of the fuel consumed, LHV denotes the fuel's calorific value, and E°_{L} stands for the energy loss through the chimney per unit time. An empirical relationship further quantifies this energy loss as follows [10]:

$$E^{\circ}_{L} = 9.68 + T\,(0.00909 + 0.33/Y_{CO_2}) \tag{4}$$

In Eq. (4), T and Y_{CO_2} are variables representing the temperature difference between the outlet gas temperature and the test site's air temperature, and the mass fraction of carbon dioxide in the chimney exit gas mixture, respectively. These were measured with the TESTO 330-1 LX gas analyzer.

An advance in the understanding of heater efficiency was facilitated through the application of thermodynamic equations and the use of the Engineering Equation Solver (EES) software. By enabling a detailed exploration of variations in chimney temperature and excess air percentage, these tools facilitated quantification of their impacts on overall performance. In this study, a program developed in the EES environment was employed to examine the design heater. Numerical and operational data pertaining to the designed heater are elaborated in Table 1. The efficiency of the designed heater was ascertained employing the below equations:

$$\eta = 100 \times \left[1 - \frac{m^{\circ}_{out}\frac{H_{out,\ total}}{M_{total}}}{Q_{in}\frac{m^{\circ}_{in}}{M_{CH_4}}}\right] \tag{5}$$

$$m^{\circ}_{out} = m^{\circ}_{in} + 17.37 m^{\circ}_{in} \tag{6}$$

$$M_{total} = \frac{M_{CO_2}\cdot n_{CO_2} + M_{H_2O}\cdot n_{H_2O} + M_{N_2}\cdot n_{N_2} + M_{O_2}\cdot n_{O_2,\ out}}{n_{CO_2} + n_{H_2O} + n_{N_2} + n_{O_2,\ out}} \tag{7}$$

$$Q_{in} = n_{CH_4,in}\cdot h_{CH_4} - (n_{CO_2}\cdot h_{CO_2,Flame} + n_{H_2O}\cdot h_{H_2O,Flame} + n_{N_2}\cdot h_{N_2,Flame} + n_{O_2}\cdot h_{O_2,Flame}) \tag{8}$$

$$H_{out,\ total} = Cp_{total}\cdot T_{out,\ 2} \tag{9}$$

where, m°_{out}, m°_{in}, Q_{in}, $H_{out,\ total}$, M, n, h_{Flame}, M_{total}, and $T_{out,2}$ represents mass flow rate of products exiting the chimney, mass flow rate of the inlet gas, heat released from the combustion reaction, total enthalpy of the output products at the chimney temperature, molar mass, number of moles, enthalpy of each product at flame temperature, molar mass of all combustion products, and chimney outlet temperature.

By utilizing Eqs. (3) and (5), efficiencies of 75% and 85% were calculated for the conventional and the designed heaters, respectively. These results represent a notable 10% increase in efficiency for the designed heater, an enhancement attributable to specific design innovations. The incorporation of elements such as a double chimney with an ejector, blades, and meshed plate distinguishes the designed heater from its conventional counterpart. This augmentation in efficiency not only translates into reduced energy consumption and lower operational costs but also yields environmental advantages. The reduction in energy requirements consequentially lowers greenhouse gas emissions, offering a multi-dimensional benefit that spans economic and ecological realms.

Table 1. Numerical and Operational data related to the designed heater

	Numerical	**Operational of Optimized Model**	**Operational of Conventional Model**
Chimney outlet temperature		473 [K]	490 [K]
$\mathbf{Y}_{CO_2}$			4.4%
T			189.85 [K]
LHV			52 $[\mathrm{MJ/m^3}]$
Heater Surface temperature		783 [K]	
Primary air amount		50%	
flame temperature		2000 [K]	
$H_{\text{out,total}}$	522[kj]		
Q_{in}	166646 [kj]		
m°_{out}	9.983 [kg/hr]		
M_{total}	27.63 [g/mol]		
$\eta_{\text{conventional heater}}$ calculated by Eq. (3)			75%
$\eta_{\text{designed heater}}$ calculated by Eq. (5)	85%		

5.2.1 Effect of excess air on efficiency

An increase in the amount of excess air was observed to enhance the mixing of fuel and air, thus facilitating complete combustion. Conversely, negative consequences on the efficiency of the heater were also noted:

• An increase in excess air levels was found to decrease the temperature of combustion products. This phenomenon is attributable to the larger volume of air molecules absorbing the energy released from the fuel reaction, resulting in a decrease in the temperature of the combustion products. A subsequent decline in the furnace walls' temperature was also observed, leading to reduced heat transfer from the heater to the environment via convection and radiation. Cumulatively, these factors contributed to a reduction in the thermal efficiency of the heater.

• Furthermore, a higher percentage of excess air was shown to augment the flow of hot gases in the chimney, culminating in heat loss and a significant diminishment in heater efficiency.

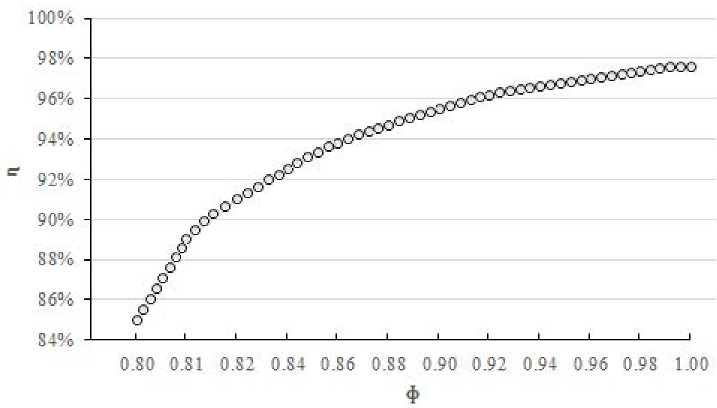

Figure 5. Variation of heater efficiency as a function of ø

Figure 5 illustrates the variation of heater efficiency as a function of equivalence ratio (∅). Under conventional conditions, excess air was observed to adversely affect the efficiency of gas heaters. However, directing the precise amount of air needed for combustion into the heater, and having it exit the chimney under identical temperature conditions, was found to enhance thermal efficiency to approximately 97.50%, as depicted in Figure 5.

5.2.2 Effect of chimney gas exit temperature on efficiency

As depicted in Figure 6, developed in the EES, a decrease in exhaust temperature was found to increase heater efficiency. Nevertheless, a reduction in the draft force of the chimney was also observed, which may pose a risk of combustion products flowing back into the room. Critical consideration must be given to ensure that combustion products do not reach the dew point temperature before exiting the chimney, as the production of corrosive acids may ensue. Consequently, a certain threshold must be maintained for the exit temperature of the output products.

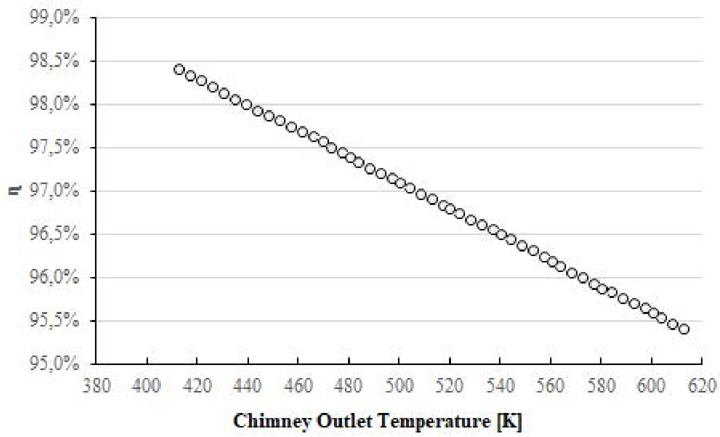

Figure 6. Variation of heater efficiency as a function of chimney outlet temperature

5.3 Investigation of Pollutant Emissions from the Designed Heater: An Environmental Analysis

An emphasis on the environmental aspect of heating systems has emerged in recent years. Among various heating options, conventional gas-fired heaters are often considered greener. Natural gas, due to its cleaner-burning properties, was found to lead to diminished greenhouse gas emissions and a reduced carbon footprint.

The primary pollutants of concern, including NO_x, SO_x, and CO, were investigated. A reduction in SO_x production was achieved through meticulous engineering of modern combustion chambers. CO emissions, which typically occur when oxygen is insufficient or flame temperatures are low, were found to be mitigatable by increasing the supply of primary and excess air. The presence of CO in the combustion byproducts was found to be negligible, even with significant excess air [11]. However, attention was directed towards NO_x.

NO and NO_2 were observed to be produced through reactions involving nitrogen in both primary and secondary air supplies. Elevated flame temperatures or a small amount of primary air were found to foster NO_x formation [12, 13]. A noteworthy reduction in pollutant levels was consistently observed upon increasing the excess air supply, as visually represented in Figure 7.

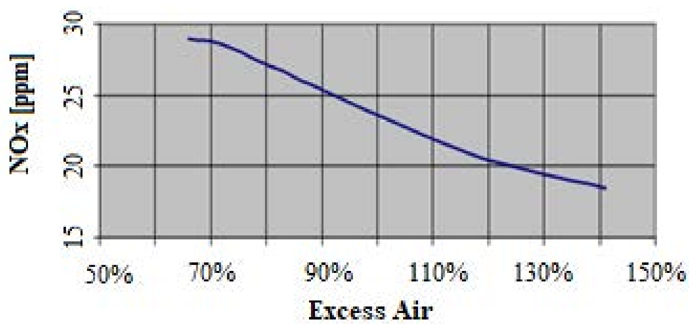

Figure 7. Effect of excess air on NO_x pollutant experimentally [12]

In this study, NO_x concentrations of 32 and 35 ppm were measured for the initial and proposed designs, respectively. Despite a 3 ppm increase in NO_x production in the designed system, an overall reduction in emissions was noted in relation to natural gas consumed for equivalent heating. This reduction was attributed to the 10% efficiency enhancement of the proposed heater. Consistency was maintained with experimental data presented in Figure 7, in terms of the NO_x levels for both conventional and proposed heaters.

6 Conclusions

In this study, a novel design for a gas heater, particularly tailored for residential applications, was introduced. Several innovative features were incorporated to enhance performance, leading to the following key findings:

• Design Advancements: The combustion chamber was equipped with blades that were found to disrupt the boundary layer and prolong the residence time of hot gas. This innovation was observed to enhance heat transfer. Meshed plates were implemented below the burner to ensure better distribution of inlet air for efficient combustion. A double-walled chimney, aimed at preheating the inlet air and minimizing excess air, was also employed, while an ejector was integrated to obviate the need for a fan. Collectively, these design advancements contributed to a 10% increase in the efficiency of the heater, improving the overall efficiency from 75% to 85%.

• Efficiency Considerations: A close correlation between the heater's efficiency, the exit temperature of chimney gases, and the percentage of excess air in the combustion chamber was identified. While an increase in excess air was found to facilitate complete combustion, excessive amounts were noted to negatively impact efficiency. Conversely, a reduction in exhaust temperature was observed to increase efficiency, albeit with potential risks such as a pressure drop and the formation of corrosive acids.

• Safety and Environmental Concerns: The proposed model was designed to mitigate issues such as carbon monoxide leakage and moisture absorption from the room. By providing combustion air exclusively from outside, safer and more reliable operation was achieved, thus rendering the model suitable for residential use. The emissions of pollutants, such as SO_x and CO, were found to be negligible. Despite a 3 ppm increase in NO_x due to lower excess air flow, this factor was overshadowed by the overall increase in efficiency, resulting in lower natural gas consumption.

Conclusion: The novel design elucidated in this study represents a significant advancement in gas heating technology, particularly for residential environments. The innovations incorporated into the design have addressed limitations in conventional gas-fired heaters, resulting in enhanced efficiency, safety, and environmental compatibility. Future studies could focus on further optimizing the design and conducting comprehensive real-world trials to validate the efficacy of the proposed model.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request.

Conflicts of Interest

The authors declare no conflict of interest.

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