UDC 662
DOI: 10.15587/1729-4061.2023.288834

EVALUATION OF A BIOMASS COMBUSTION FURNACE USING DIFFERENT KINDS OF COMBUSTION CHAMBER CASING MATERIALS

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This research systematically evaluates a biomass combustion furnace, focusing on the influence of varying combustion chamber casing materials. The study employs controlled laboratory experiments to investigate the impact of different casing materials on combustion performance, thermal efficiency, and practical applications such as water boiling capacity. The research uses distinct materials, including clay, steel, and aluminum, for combustion chamber casings while maintaining consistent dimensions. The central experimental apparatus, an aluminum stove, was meticulously crafted, adhering to precise measurements. Coconut shell briquettes served as the primary fuel source for this investigation. The results reveal intriguing dynamics in combustion behavior. Notably, the choice of combustion chamber casing material significantly affects fire temperature, sleeve wall temperature, thermal efficiency, and the ability to boil water. Clay emerges as a standout performer, achieving high thermal efficiency (56.8 %), substantial water boiling capacity (25 liters), and efficient fuel consumption (1.28 kg of burnt briquettes). However, steel casing materials excel in generating the highest fire temperatures (up to 557 °C), underscoring their exceptional heat-conducting properties. Aluminum has fast temperature responses but may not retain heat like clay. The findings help optimize biomass combustion furnaces and associated applications. Material selection is crucial to attaining combustion goals like efficiency, temperature generation, or practical heat. These discoveries could lead to more efficient and ecologically friendly biomass combustion systems for sustainable energy and resource use

Keywords: coconut shell briquettes, cylindrical shapes, household briquette stoves, thermal characteristics

Received date 18.08.2023
Accepted date 20.10.2023
Published date 30.10.2023

***How to Cite:** Suluh, S., Lorenza, D., Sampelolo, R., Pongdatu, G., Ramba, D., Widyianto, A. (2023). Evaluation of a biomass combustion furnace using different kinds of combustion chamber casing materials. Eastern-European Journal of Enterprise Technologies, 5 (8 (125)), 6–15. doi: https://doi.org/10.15587/1729-4061.2023.288834*

1. Introduction

The world's reliance on fossil fuels, particularly petroleum-based fuel oils, has highlighted decreasing stocks. Despite ongoing investigation, these limited deposits have decreased over time, making replenishment difficult. Paradoxically, petroleum reserves depletion corresponded with a considerable increase in fuel oil prices, contrary to original projections. This shows the fragility of energy dependence. Depleting fuel resources makes biomass a possible answer. Biomass from wood, agricultural wastes, and organic waste might solve the home energy dilemma. This resource is vital since it is renewable and can be used locally, giving communities energy sovereignty [1]. Communities may escape fuel oil depletion and rising costs by using biomass as an alternate energy source. This shift might provide a reliable and long-term option for addressing daily energy needs, including cooking. Compared to fossil fuels, biomass burning reduces greenhouse gas emissions, making it an environmental priority.

Biomass is a valuable source of organic material that is produced through the process of photosynthesis. It includes both useful products and waste materials. The research in question centers around a specific biomass source: the residue obtained from the plantation sector. The study focuses on using coconut shells, a byproduct of the coconut industry, as a potential candidate for biomass. The research focuses on transforming coconut shells into charcoal briquettes, highlighting their multifaceted benefits. The conversion described in this text is highly innovative and has multiple uses. It not only repurposes waste material but also has the potential to reduce harmful emissions, address deforestation, and increase energy resources [1].

Coconut shell investigations reveal a fascinating picture. Coconut shell-derived briquettes have a 71.7 % efficiency grade and a 4996 cal/g calorific value [2]. Coconut shells and rice husks mixed 50:50 have a calorific value of 4966 Kcal/kg [3]. Coconut shells surpass rice husks at 17 MJ/kg vs. 10.01 [4]. Snake fruit with coconut shells at 40:60 creates a 6062 cal/g combustion-calorific value [5]. Coconut shells provide 4667 kcal/kg [6]. This study concludes with a calorific value of 4580.5 Kcal/kg. The 20 %:80 %:0 % blend of straw, coconut shell, and rice husk achieve this peak [6]. This astonishing achievement shows that biomass components may work synergistically.

An efficient direct combustion furnace is the key to unlocking the briquettes' potential energy and converting it into usable heat for cooking. However, briquette furnaces still have an opportunity for development in terms of thermal efficiency. As a result, there is an urgent requirement to improve the architecture of the combustion chamber to increase efficiency. Several research projects have attempted to solve this problem by updating the conventional biomass stove. Previous studies have notably advanced this quest for efficiency enhancement [7]. These efforts have improved the combustion chamber of briquette stoves, especially steel models. This change produced a noticeable performance gain, with an increased efficiency of 52.14 percent being the new standard.

Exploring materials in cylinder-shaped biomass burners yielded intriguing findings [7]. Clay, steel, and aluminum combined with a 180 mm sleeve to provide a thermal efficiency peak. Clay stoves dominated this constellation with 73.66 % thermal efficiency. Following clay stove experiments with a redesigned 180 mm diameter sleeve, heat efficiency was still 52.87 % [8]. Another effective modification of clay stove combustion chambers with a 90 mm diameter sleeve yielded 70.73 % thermal efficiency [9]. Interestingly, minor improvements like secondary air duct adjustments can boost efficiency by 68 % [9]. A novel insulin cylinder integrated inside the stove's combustion chamber achieved 57.2 % thermal efficiency [10]. With a broader view, exergy and energy assessments revealed the consequences of extensive combustion chamber alterations on four stove models. The Envirofit stove type led this evaluation with 23.50 % thermal efficiency [11].

Experiments using a wide variety of materials for the combustion chamber casing are now being carried out as part of many research projects to evaluate the efficiency of a biomass combustion furnace. The ultimate goal here is to obtain the highest possible level of thermal efficiency. In addition, it is essential to note that clay has been used as the material for the stoves in the majority of the research that has been done. There is still an obvious need for more investigation into the modification of the form of the briquette stove utilizing materials such as clay, steel, and aluminum. Therefore, research devoted to developing sleeve stove materials for analysis of briquette stove performance is relevant.

2. Literature review and problem statement

The biomass stove can increase the barrel's temperature, which is necessary for the production of briquettes. The furnace generates barrel die heat rather than relying on electric heating. The test results indicate the performance of the 6-kW electric heater in this study when it was replaced. The rice husk briquette machine requires approximately 76 kg of rice husk briquettes and consumes around 80 kWh of electricity to produce one ton of rice husk briquettes. The user suggests modifying the Updraft gasifier stove by implementing top lighting and combining eucalyptus briquettes, sawdust, bamboo, and cow dung as fuel sources. The combustion test results indicated that the gasifier stove achieved a maximum efficiency of 32.3 % when using eucalyptus charcoal briquettes [12, 13]. The performance of cooking stoves can be enhanced by using sawdust as an insulating material, specifically with a layer thickness of less than 6 cm. The combustion test results indicate a thermal efficiency of 32.25 %, suggesting potential reductions in fuel consumption and pollutant emissions [14].

The paper [15] explores the concept of a dual-purpose improved cookstove designed to cater to the needs of low-income communities in Ghana. The study aims to address both efficient cooking methods and the production of biochar, a byproduct with potential agricultural and environmental benefits. The study mentions benefits like reduced cooking time, increased energy efficiency, and biochar production. However, the paper lacks robust quantitative data to substantiate these claims. While biochar production is highlighted as a significant aspect, the report does not delve deeply into the potential uses and benefits of biochar. Connecting the dots between biochar production and its application in agriculture and its potential contribution to carbon sequestration would enrich the paper's relevance and impact.

The research [16] explores the viability of using pyrolysis biomass char in blast furnace injection and tuyere simulation combustion. The study delves into the potential of biomass char as a sustainable alternative fuel source in industrial processes. The paper presents experimental data on the combustion characteristics of biomass char, including ignition temperature, combustion rate, and thermal behavior. The article lacks a comprehensive introduction that contextualizes the significance of blast furnace injection and the challenges associated with traditional fuels. While the study presents simulation results and experimental data, the discussion section could provide a more in-depth analysis of these findings.

The article [17] assesses the performance of an improved biomass cook stove against traditional stoves in Iran. The study highlights the potential benefits of transitioning to improved stove technology. The paper directly compares the improved biomass cook stove and traditional stoves, allowing for a clear understanding of the differences in efficiency, fuel consumption, and emissions. The paper lacks an in-depth description of the technical specifications and design features of the improved biomass cook stove and traditional stoves. This omission limits the readers' understanding of the stoves' actual configurations and how they contribute to their respective performances.

The study [18] aims to enhance the efficiency of waste briquetting processes. The study focuses on optimizing equipment and technology to improve the conversion of waste materials into briquettes. The study's focus on optimizing equipment and technology for waste briquetting has practical implications for industries and waste management systems, potentially leading to more effective and eco-friendly waste conversion practices. The paper lacks sufficient technical details regarding the equipment, techniques, and technologies used for waste briquetting. The methodology section is brief and lacks comprehensive explanations of the experimental setups, data collection procedures, and analytical methods. This reduces the transparency and replicability of the study.

In another study, a wood stove underwent modifications by incorporating a catalytic combustion chamber, utilizing materials like coconut shell charcoal briquettes, sawdust, and bagasse [19]. The findings from combustion tests revealed that the wood stove achieved its highest thermal efficiency of 63.63 % with coconut shell charcoal briquettes, followed by 61.62 % with sawdust briquettes, and a comparatively lower 53.85 % with sugarcane bagasse. A separate comparison was conducted involving gasifier stove tests and modified household stoves, performed in triplicate [20]. The results unveiled a trend of lower thermal efficiency in the gasifier stove, at a mere 22.1 %. However, this household stove demonstrated a twofold reduction in emissions compared to the gasifier stove. Furthermore, an innovative approach involved the development of a biomass stove powered by refractory bricks and clay, utilizing rice husk briquettes. This stove harnessed the heat generated from the briquettes as a substitute for electric heating [21].

Previous studies have examined different facets in this field, such as improving the efficiency of briquette printing by utilizing the heat from biomass stoves, optimizing stove designs to reduce harmful emissions, modifying the insulation properties of combustion chambers, replacing stove materials, and using simulations to evaluate the effects of insulation materials. However, there is a lack of comprehensive research in the existing literature regarding integrating three different insulation materials in the combustion chamber of an aluminum stove. Therefore, this study aims to compare the performance of three insulation materials, specifically steel, aluminum, and clay. The combustion procedure involves the utilization of coconut shell briquettes and necessitates modifications that involve the integration of sleeves into the combustion chamber of the furnace. These sleeves are characterized by a diameter of 180 mm and a height of 150 mm.

3. The aim and objectives of the study

The study aims to identifying the performance of different combustion chamber casing materials within the biomass combustion furnace. The casing materials, including steel, aluminum, and clay, are integral components that influence heat transfer, insulation, and combustion stability within the furnace.

To achieve this aim, the following objectives are accomplished:

– to analyze the thermal characteristics of briquette stoves that are built using clay, steel, and aluminum cylinders;

– to conduct a performance analysis of briquette stoves by comparing the use of different stove cylinder materials such as clay, steel, and aluminum.

4. Materials and methods of experiment

4. 1. Object, hypothesis of the study and materials

The object of this study is a biomass combustion furnace, which plays a crucial role in sustainable energy solutions and biomass utilization. A biomass combustion furnace is purpose-built device that enables the controlled and efficient combustion of biomass materials. These materials can include wood, agricultural residues, or coconut shells. The primary purpose of this furnace is to generate heat energy for various applications, such as heating, cooking, and electricity generation. The biomass combustion furnace is a crucial component of biomass energy systems. It plays a central role in converting the chemical energy stored in organic materials into thermal energy through combustion. Biomass combustion furnaces are crucial in meeting energy demands and reducing environmental impacts by effectively harnessing and directing thermal energy for various purposes.

The study's primary hypothesis is that biomass combustion furnace performance, efficiency, and combustion dynamics depend on combustion chamber casing material. The research hypothesizes that the clay, steel, or aluminum casing material determines essential combustion parameters and combustion chamber thermal behavior. The idea also argues that case materials affect combustion temperature profiles, ignition characteristics, and efficiency. It expects each material's thermal conductivity, heat retention capacity, and biomass fuel interaction to affect combustion sustainability, temperature distribution, and energy conversion efficiency. The study's premise suggests that changing case materials can improve or hinder combustion efficiency, pollution reduction, and energy use. It posits that the complexities of casing materials and biomass combustion affect peak fire temperatures and combustion sustainability.

The study made several assumptions to support the research design, methodology, and analysis. The research assumes that combustion occurs under steady-state conditions, disregarding any transient effects or variations that may arise during real-world operation. Simplifying allows for a more concentrated analysis, although it may not encompass all the intricacies found in real-world scenarios. The study analyzes and compares three primary casing materials: clay, steel, and aluminum. The materials chosen are believed to cover a range of thermal conductivity and behavior without considering alternative casing materials. The assumption is that the combustion chamber exhibits homogeneity regarding temperature distribution and airflow patterns. The premise of simplifying the analysis of casing material effects is beneficial, but it may not fully consider localized variations.

The core of this research endeavor involved a meticulous exploration of the effects of varying materials within the furnace cylinder while maintaining uniform dimensions – specifically, a diameter of 180 mm and a height of 150 mm. This deliberate manipulation aimed to unravel the distinct impacts that different materials could wield within the confines of this standardized environment. For a visual exposition of the components central to this study, Fig. 1 stands as an elucidating guide. Herein, the images of the cylinder variants and the meticulously crafted stove provide tangible insights. The cylinder materials of clay (Fig. 1, *a*), steel (Fig. 1, *b*), and aluminum (Fig. 1, *c*) are distinctly represented, offering observers a visual gateway into the diverse landscapes of this research exploration.

A critical instrument in this investigation was the stove, meticulously fashioned from aluminum, which served as the stage for these material variations. This stove, characterized by its relentless craftsmanship, stood resplendent with a diameter of 200 mm and an imposing height of 300 mm. These precise measurements were imperative to provide a consistent platform for evaluating the changes introduced within the furnace cylinder.

The bedrock of combustion enhancement lay in the selection of coconut shell briquettes, each measuring 65 mm in diameter and 45 mm in height. These briquettes, chosen with discernment, represented this study's prime fuel source. Their specific properties promised to interlace intriguing nuances into the combustion process, pivotal in deciphering the multifaceted interactions between fuel characteristics and the varying cylinder materials.

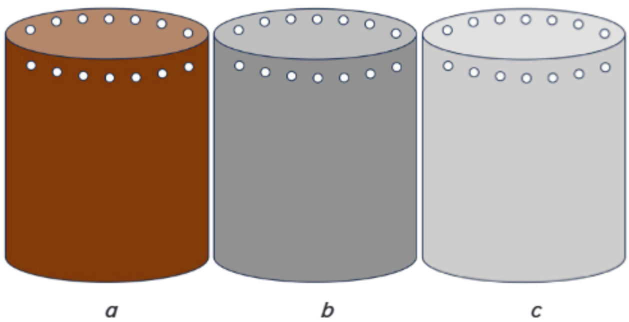

Fig. 1. A sketch of three types of sleeve materials: *a* — clay; *b* — steel; *c* — aluminum

4. 2. Cylindrical briquette stove shapes

The briquette stove used in this study featured a distinctive cylindrical shape, contributing to its efficient design and performance. The stove's dimensions were carefully engineered for optimal combustion and heat distribution. The inner diameter of the cylinder measured 200 mm, while the inner height extended to 290 mm, as depicted in Fig. 2. To ensure durability and heat retention, the side walls of the cylinder were designed to be 20 mm thick, providing excellent insulation. Meanwhile, the stove sections had a slightly reduced thickness of 10 mm, maintaining structural integrity while minimizing material usage. The body of this furnace is made from clay. This well-thought-out design resulted in a combustion chamber volume of approximately 9.11×10^6 mm^3, providing ample space for the combustion process to take place effectively.

A strategically positioned hole with a diameter of 40 mm at the base of the stove allowed for proper air intake, facilitating efficient and controlled combustion. This intake ensured a steady flow of oxygen, promoting better burning of the briquettes and enhancing the stove's overall performance. Additionally, the furnace was equipped with four sturdy legs, each with a height of 40 mm. These legs served the dual purpose of providing stability and elevating the stove slightly above the ground. This elevation prevented direct contact with the surface below, reducing the risk of heat transfer and potential damage.

The research method employed in this study was an experimental approach to evaluate the performance and efficiency of coconut shell charcoal briquettes when used as a honeycomb structure on an aluminum stove. To assess the stove's capabilities and compare its performance under different conditions, inner cylinder tests were conducted using various materials, including aluminum, steel, and clay. The experimental setup involved alternately placing inner cylinders made of aluminum, steel, and clay on the stove, each containing the coconut shell charcoal briquettes. This allowed researchers to observe and analyze the stove's behavior and heat transfer characteristics when subjected to different materials.

During the testing process, the researchers carefully monitored the water boiling process on the stove. The water boiling process served as a standard performance metric for the furnace, as it directly correlated with the stove's ability to generate and transfer heat efficiently. By observing the boiling time, heat distribution, and fuel consumption under varying cylinder materials, the researchers could draw valuable insights into the stove's effectiveness and suitability for different applications. Using coconut shell charcoal briquettes as a honeycomb structure was a deliberate choice, as it could potentially enhance the combustion process and increase heat retention due to its unique shape and composition. This novel design could improve burning characteristics, reduce smoke emissions, and ultimately contribute to sustainable and eco-friendly cooking practices.

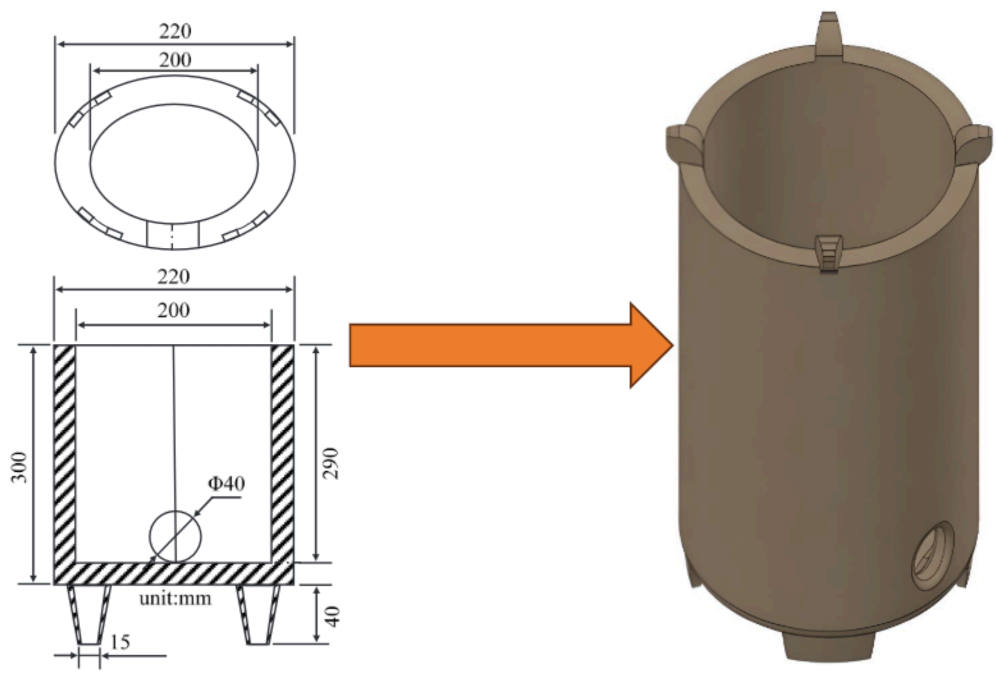

Fig. 2. Dimensions of a cylindrical briquette stove

4. 3. Briquette stove performances test method

Testing the quality of briquette stoves from the three types of materials (aluminum, clay, steel) involves a carefully designed procedure to assess their combustion efficiency. The primary goal is determining how effectively each type of stove converts fuel (coconut shell charcoal briquettes) into heat, which is crucial for evaluating their overall performance and practicality. The testing begins by measuring and recording the initial volume of water in a pot with a capacity of 5 kg. This water-filled pot is then placed on the respective briquette stove for testing. The same amount of water is used for each stove evaluation to ensure consistency across all tests.

Fig. 3 provides a clear schematic illustration of the data collection process for temperature measurements during the water boiling. The researchers utilized Type K thermocouple sensors, which are well-known for their accuracy and reliability in temperature monitoring. These sensors were strategically placed at various points within the test equipment to capture essential temperature data accurately. A total of 13 thermocouple sensors were carefully positioned at critical locations within the briquette stove to record temperature readings. These sensors were selected to cover critical areas relevant to the stove's performance and combustion process. The measured temperatures included flame temperature, sleeve wall temperature, combustion chamber temperature, and stove wall temperature.

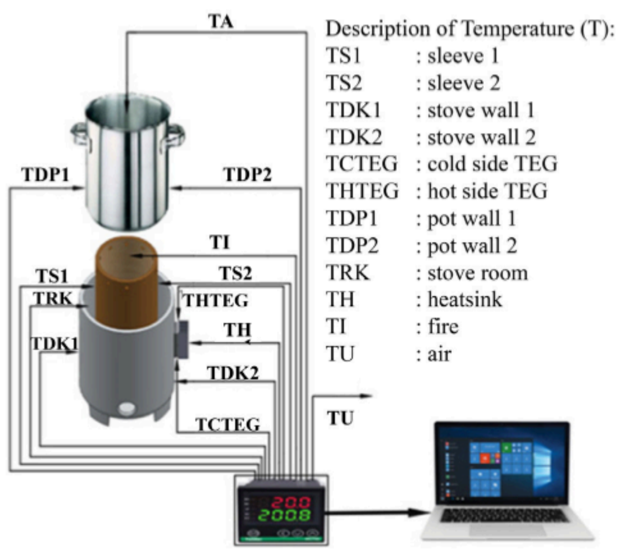

Fig. 3. Illustration scheme of temperature data collection

The data collection was carefully orchestrated using data acquisition techniques integrated into the LabView program. LabView is a powerful software platform for data acquisition, analysis, and visualization. By leveraging this program, the researchers could simultaneously capture and log temperature readings from all the thermocouple sensors. Throughout the water boiling process, the thermocouples collected temperature data offered comprehensive insights into the stove's performance, heat distribution, and efficiency. Detailed temperature measurements and data acquisition facilitated a thorough understanding of how the different stove cylinder materials (aluminum, clay, steel) influenced heat transfer, combustion behavior, and overall stove performance.

The choice of experimental research methodologies utilized in this study was made after great deliberation to ensure the strength and applicability of the research. Several significant variables influenced the selection of these strategies. The choice of a controlled laboratory environment was motivated by the need for meticulous control over variables, hence enabling the isolation and accurate measurement of the effects of combustion chamber case materials. Implementing this control is crucial to establish causal linkages between the properties of the materials and the results of combustion. Furthermore, replicating laboratory tests contributes to the increased reliability of the obtained data. The concept of reproducibility holds significant importance within the scientific method, as it enables fellow researchers to validate and expand upon the obtained results. Lastly, laboratory equipment and apparatus offer a considerable level of precision in the acquisition of data. The importance of accuracy becomes evident when measuring variables such as temperature, combustion efficiency, and fuel consumption, as even minor discrepancies can provide substantial effects on the outcomes.

5. Results of the experiment on the briquette stove performance of various stove cylinder materials

5. 1. Thermal characteristics of briquette stoves

The combustion methodology employed in this research centers on boiling 5 kg of water within a pot, meticulously tracking the temperature variations across several vital points. These points include the stove wall, stove chamber, sleeve, water, flames, and the pot, all meticulously recorded at one-minute intervals until the water attains boiling point. Upon reaching the boiling point (100 °C), the heated water is extracted from the pot, and its weight is recorded for subsequent analysis. Subsequently, the pot is replenished with fresh water, poised for the next boiling cycle. This procedure is conducted iteratively until the briquettes cease to generate a sustained flame.

The evaluation continues by quantifying the residual briquette weight post-combustion, juxtaposed against the weight of the water subjected to boiling. Notably, the quantity of briquettes employed within each trial was constant, comprising nine briquettes for each combustion instance. Concurrently, the aluminum pot's standardized weight remained fixed at 0.4 kg.

Displayed prominently in Fig. 4, the chronological progression of fire temperatures, fueled by the combustion of coconut shell briquettes, becomes a compelling visual narrative. A resounding crescendo mark the pinnacle of this fiery chronicle – the fire's intensity peaked at an impressive 556 °C. This remarkable feat was accomplished during the 10^{th} minute of experimentation, a testament to the unique dynamics brought about by the variation in the cylinder's composition, specifically when utilizing clay as the constituent material.

However, the historical arc of temperature fluctuations is far from linear or predictable. The intricate dance of temperatures unfolds in a manner that often eludes expectations. Swift ascents and sudden descents create a dynamic tableau, each marked point representing a fleeting moment in the ever-changing thermodynamic landscape. An intriguing observation arises when examining the ignition process across the spectrum of cylinder materials. Time and again, a pattern emerges – an inclination toward elongated ignition times across the board. This phenomenon resonates irrespective of the cylinder's material makeup. However, a notable trend appears: materials boasting low thermal conductivity values tend to exhibit a propensity for extended ignition processes. This curious phenomenon finds its explanation in the materials' innate capability to retain heat over prolonged periods.

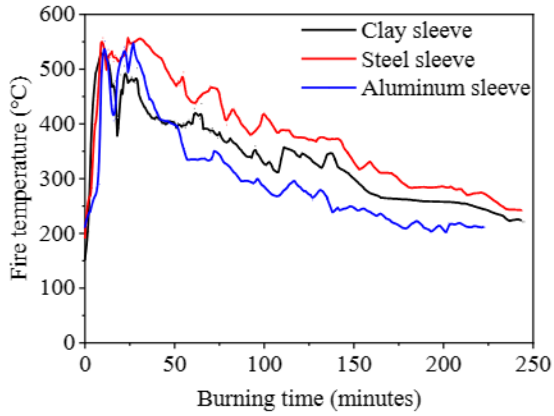

Fig. 4. History of fire temperatures

Displayed in Fig. 5, the temperature trajectory along the sleeve wall during the combustion of coconut shell briquettes paints an illuminating picture. The choice of sleeve material significantly influences the temperature profile, an observation that can be aptly illuminated through a closer analysis of the results. Notably, in the scenario wherein the clay sleeve material is employed, a remarkable peak temperature of 431 °C is recorded, distinctively observed during the 69th minute. This outcome sets this variation apart, as it outshines the other four variations regarding achieved temperature heights. It's equally intriguing that the steel cylinder material registers a peak temperature of 402 °C, marking its zenith during the 46th minute. Conversely, the aluminum cylinder material manifests a relatively swift rise, reaching a temperature peak of 348 °C as early as the 23rd minute of the trial.

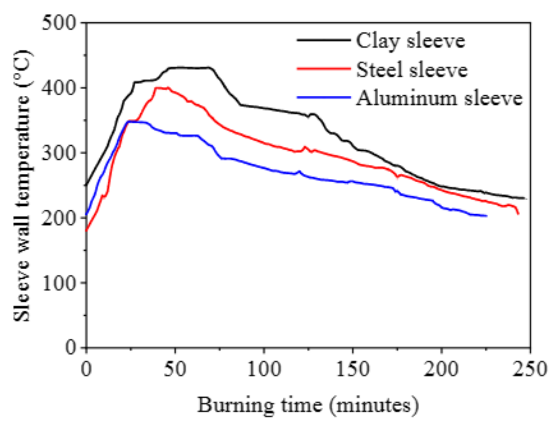

Fig. 5. History of sleeve wall temperatures

Fig. 6 is a pivotal juncture in this analytical journey, offering a panoramic view of the zenith temperatures attainable through the various sleeve wall materials. The data it presents provides a crystalline understanding of the peak thermal performances these materials can yield, illuminating the dynamic heat landscapes they forge. The steel sleeve material is prominent in this thermal saga, achieving a commendable crescendo of 557 °C – the pinnacle of fire temperature. This milestone, a testament to steel's unique heat-handling attributes, showcases its capacity to stoke the flames to remarkable heights.

In the continuum of thermal prowess, the spotlight gracefully shifts to aluminum and clay sleeve materials. These materials exhibit their thermal symphony, achieving sequential peaks with a maximum fire temperature of 551 °C and 529 °C, respectively. This evolving thermal panorama reflects the diverse ways each material interacts with the combustion process, imparting its distinctive thermal signature to the flames. However, the realm of sleeve wall temperatures unfurls another intriguing chapter. The clay sleeve material takes the lead in this domain, boasting the highest summit with a maximum sleeve wall temperature of 431 °C. This outcome underscores clay's thermal resilience and showcases its ability to envelope and retain heat effectively, shaping a robust thermal environment within the sleeve.

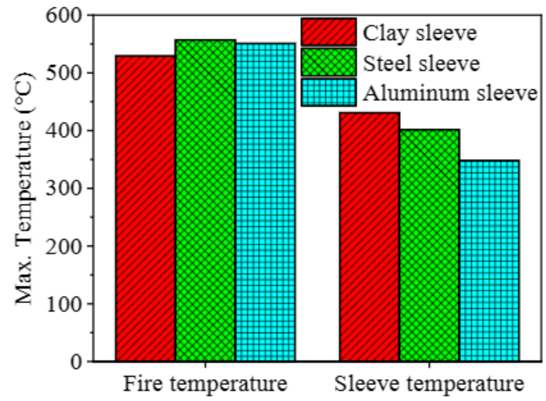

Fig. 6. The maximum temperature on various sleeve wall materials

As the narrative unfolds, the steel and aluminum sleeve materials follow suit, each contributing to the spectrum of temperature dynamics. Steel's maximum sleeve wall temperature scales up to 402 °C, a noteworthy achievement in its own right. On the other hand, aluminum, with its distinct heat-conducting properties, achieves a maximum sleeve wall temperature of 348 °C, lending a unique signature to the thermal landscape.

5. 2. Performance of briquette stoves

Fig. 7 comprehensively depicts the outcomes derived from the rigorous briquette-burning experiments conducted across three distinct cylinder materials. Notably, a distinctive trend emerges – one that warrants a closer examination. Specifically, the trial associated with the 170 mm clay material cylinder stands out significantly, showcasing the most pronounced level of briquette consumption. This variation attains a substantial 1.28 kg of burnt briquettes, thereby underscoring the notable impact of the clay material configuration on the combustion process.

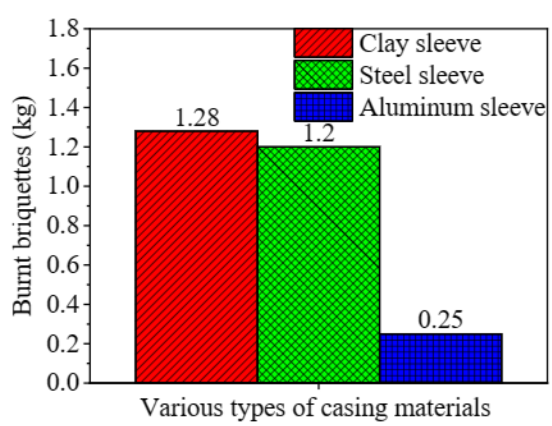

Fig. 7. Burn Mass Of Briquette

Perusing the insightful bar chart in Fig. 6, an additional layer of significance emerges. Integrating a clay material cylinder proves to be a pivotal factor in sustaining the fiery vigor of the briquettes. This inherent resilience translates into a remarkable reduction in the residual matter left in the aftermath of combustion. Therefore, it is evident that the addition of the clay material cylinder effectively fosters an environment where the briquettes' flames persistently burn, generating minimal combustion residue.

Fig. 8 stands as a pivotal gateway, offering a panoramic view into the experimentation realm – a gateway that unlocks insights into the ability of distinct cylinder materials, when nestled within the combustion chamber, to catalyze water's boiling. Within this visual narrative, a captivating saga unfurls, revealing the exceptional prowess of certain materials in harnessing the power of combustion for valuable ends.

A star emerges from the tableau of findings – none other than the clay cylinder material. In concert with the potent energy of coconut shell briquettes, this versatile medium takes center stage by showcasing the highest capacity to transform combustion heat into a practical outcome. With an impressive feat, it boils water not once, twice, or thrice but an astounding five times, amounting to a remarkable 25 liters. This resounding achievement underscores clay's extraordinary ability to channel heat effectively, making it a formidable catalyst for boiling water and harnessing thermal energy for practical applications.

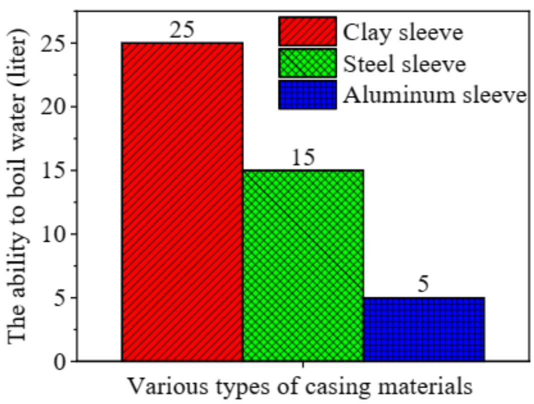

Fig. 8. The ability to boil water

The combustion results that Fig. 8 brings to life signify a significant advancement in thermal efficiency. Incorporating a clay material cylinder, synergizing harmoniously with coconut shell briquettes, yields an extended period of sustained combustion. The flame's unwavering endurance for over four hours is a remarkable testament to the intricate dance between material, fuel, and combustion dynamics. This virtuoso performance paves the way for an impressive sequence – five rounds of water boiling, each standing as a testament to the cumulative efforts in elevating stove efficiency.

Fig. 9 takes on a journey of thermal efficiency, a landscape where various cylinder materials, when harnessed in conjunction with coconut shell briquettes, showcase their distinct capabilities in transforming heat into a helpful triumph – boiling water. This visual representation encapsulates the thermal ballet of combustion and material dynamics, opening a window into the fascinating world of energy conversion. At the forefront of this thermal symphony stands the clay cylinder material, exuding an exceptional prowess in thermal efficiency. When paired with the potent energy of coconut shell briquettes, this stalwart material unveils a resounding achievement – an impressive thermal efficiency of 56.89 %. This milestone signifies not only the clay material's intrinsic heat-retaining capacities but also its ability to channel and maximize the transformative potential of combustion heat into tangible outcomes.

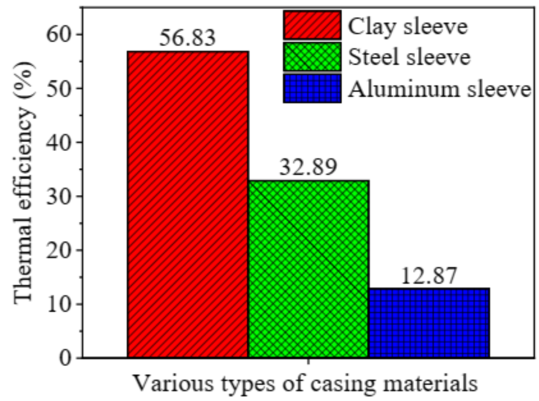

Fig. 9. Thermal Efficiency

The term «Thermal Efficiency», as depicted in Fig. 9, generally pertains to the quantification of the efficiency with which a combustion system transforms the thermal energy derived from the fuel into productive work or heat output. The present study focuses on evaluating the performance of the combustion chamber and its casing material to optimize the conversion of heat produced during combustion, namely from the combustion of biomass briquettes, for practical purposes such as water boiling. Thermal efficiency is used to measure the effectiveness of a combustion system in capturing and utilizing the available heat energy. A higher thermal efficiency signifies a more significant fraction of the heat produced during combustion is efficiently used. In contrast, a lower efficiency implies more heat dissipating or squandering.

Parallel to this, the bar chart accompanying Fig. 9 brings a pivotal insight. A remarkable discovery surfaces through judicious manipulation of cylinder materials, particularly leaning toward those with lower thermal conductivity values. This strategic adjustment, resonating with the pursuit of optimal heat isolation, extends the duration of briquette flames, fortifying their endurance beyond the four-hour mark. This revelation underscores the intricate synergy between material attributes and combustion dynamics, highlighting the role of heat confinement in orchestrating sustainable combustion.

6. Discussion of the experiment on the briquette stove performance of various stove cylinder materials

According to the findings of a historical study of fire temperatures, the steel sleeve material employed in briquette stoves shows the greatest temperature compared to other materials (Fig. 3). This occurrence occurs due to the radiative heat transfer of the briquettes, which is directed toward the combustion chamber of the stove wall. As a consequence of this, there is no loss of any energy throughout the process. The study mentioned in this article [22] found that the stove's thermal efficiency is improved due to the larger geometry of the furnace, which results in the lack of energy loss. This was found to be the case. According to the information presented in the article [23], the processes of heat transfer and fluid movement are improved, increasing the temperature of the fire contained within the combustion chamber. This is made possible by the material that the stove is constructed out of, which has a low thermal conductivity, and the shape of the stove, which was intended to minimize gaps on its surface to reduce energy loss. Experiments involving combustion were carried out on stoves fitted with one of six distinct types of burners. In addition, jet flames or forced air blasts were delivered into the rectangular furnaces in the stove's combustion chamber. As a result of these alterations, an enhanced air jet directed towards the flame zone was achieved, which reduced smoke residue and improved thermal efficiency by up to 34 % [24].

The sleeve wall temperature history displayed clear patterns, indicating that the briquette stove with a clay sleeve material had the highest temperature. The stoves with steel and aluminum sleeve materials followed but at lower temperatures (Fig. 4). The combustion chamber's heat distribution and efficiency are improved by increasing its surface area. The article [25] discusses a research study that examines the effects of various pin-fin shapes and the use of nanofluid coolers on heat transfer and fluid flow characteristics in heat sinks. The study examines how variations in shape impact these characteristics. According to the study, using cylindrical pin fins resulted in a notable enhancement of the Nusselt number, exhibiting an improvement of approximately 23.1 %.

Moreover, the research findings indicate that the broader configuration of the sharp-angled pin-fins has a detrimental effect on heat transfer compared to rectangles and triangles. The use of battery pack aluminum sleeves at different heights has the potential to improve temperature consistency within the battery pack. This can be beneficial in maintaining optimal performance and prolonging battery life. Additionally, implementing these sleeves can contribute to reducing the system's overall weight, which can have advantages in terms of portability and energy efficiency [26].

According to the findings of evaluating the briquette stove's performance results, the clay sleeve material utilized in the furnace demonstrates remarkable performance in several respects. Specifically, it displays exceptional capabilities in boiling water, efficiently using briquettes, and maximizing thermal efficiency (Fig. 6–8). The broad shape of the steeply inclined pin fin contributes to the worsening of the convective heat transfer [25]. The utilization of cylindrical geometry for heat transfer provides a number of benefits, one of the most important of which is the increased rate of efficiency and effectiveness in the heat transfer process. Because of its cylindrical shape, the geometry provides a more significant surface area than other geometries, making the heat transmission process more efficient. Because of the increased surface area, the pace at which heat is transferred can be enhanced, making the process both quicker and more efficient.

In addition, the cylindrical shape of the object facilitates consistent heat distribution (Fig. 1), which helps to ensure A research investigation was carried out to analyze the heat transfer process in a cylindrical microchannel geometry involving two-phase duplet flow. According to the research findings, the Nusselt value experienced a significant increase, specifically by a factor of two. This increase led to a growth of 40 % and 50 % [27]. The heat transfer flow is convective because of a wake with a significant angular deviation caused by a pin-fin-wide [25]. The steel sleeve material is highly regarded and ranked second in advantages, following the clay sleeve material. The primary reason for this is its ability to modulate thermal transfer and its high thermal effectiveness. According to reference [28], using a steel sleeve material can lead to a notable 32.9 % enhancement in the heat transfer rate.

The results of this study demonstrate considerable potential for practically integrating these findings into real-world contexts. The study's findings and data offer a robust basis for enhancing combustion processes within the realm of biomass combustion furnaces. By utilizing the acquired knowledge from this research, professionals such as engineers, designers, and practitioners in the realm of combustion technology can actively investigate potential avenues for augmenting combustion systems' efficiency and overall performance. The findings of this study have the potential to provide valuable insights for the enhancement of biomass combustion furnaces in terms of efficiency and environmental impact. Consequently, this research can contribute significantly to the progress of sustainable energy solutions and resource usage optimization. Based on our research results, let's propose using a cylindrical configuration for domestic stoves, incorporating certain measurements that have exhibited improved combustion efficiency.

The study may be limited since it focuses on certain materials, situations, and characteristics. This constraint may limit its application. Specifically, the research does not analyze the environmental impact of various materials on emissions, sustainability, and resource use. Using coconut shells as a biomass feedstock without addressing feedstock qualities may limit the study's scope. Add new materials, biomass kinds, combustion settings, and furnace designs to expand future studies. Increased generalizability would be good. Comparing combustion chamber casing materials' environmental impacts requires a detailed LCA. Consideration of resource usage and environmental effects helps determine their ecological footprint. Analyze how biomass feedstocks affect combustion performance and how casing materials interact with biomass.

The progress of this research might be improved by conducting further research. Many other angles may use some further investigation. The impact of the fuel's content and its properties on the behavior of the combustion process may be uncovered if the scope of the study was expanded to include a variety of biomass fuels. It's possible that understanding material interactions can be gained by researching different biomass sources. If the research were expanded to include an examination of emissions, such as particulate matter, gases, and contaminants, it would give a more comprehensive review of the performance of combustion and its effect on the environment. Investigating optimization methodologies for casing materials depending on specific objectives, such as optimizing efficiency, lowering emissions, or tolerating various fuel sources, would contribute to realizing the concept.

Several weaknesses may be seen in the study. One example is the possible reduction in combustion conditions' complexity compared to real-world situations. There may be fewer unintended consequences due to the simplicity of factors like moisture content, particle size distribution, and combustion reaction rates. These real-world challenges associated with biomass combustion can significantly impact research outcomes. It's also possible that the study didn't consider the complexities of the interplay between casing materials, biomass quality, and combustion conditions. The kinetics of combustion might be misunderstood if the intricate connection between these parts is ignored.

Additionally, the findings may not adequately evaluate combustion reaction dynamics. Variable oxygen levels, heat dispersion, and biomass heterogeneity affect combustion performance. The study may marginalize delicate interactions in complex real-world environments, missing hidden challenges and opportunities. The investigation may overlook secondary processes like ash production and particulate matter buildup in the combustion chamber. Secondary effects can affect combustion and casing material performance. Therefore, this adds complexity that the previous study may not have thoroughly investigated. The study's restrictions must be considered to comprehend the research findings fully. Applying results to practice requires prudence. These potential limits can guide future research and applications to improve biomass combustion processes completely and nuancedly.

7. Conclusions

1. The study shows steel sleeves are very good at transferring heat. The flames from these sleeves reached a very impressive 557 °C, the highest temperature during the tests. This shows how well steel can move heat around, which raises the temperature inside the burning chamber. Because of this, steel is a good choice for uses where quickly reaching high temperatures is very important. On the other hand, when the focus moves to clay sleeves, a different story is told. Steel wants to get to even higher temperatures, but clay plates do an excellent job by getting to a maximum wall temperature of 431 °C. This result shows that clay's unique strength comes from the way it keeps heat for a long time. Clay materials are good insulators, so they create an environment inside the combustion chamber that spreads heat evenly along the walls of the tube. This even applied heat can have big effects on the efficiency of combustion and the steady release of thermal energy.

2. The study of the performance of the briquette stove with different sleeve wall materials produced compelling and convincing results. The clay material was the best performer across all key performance measures. The study found that clay was the most thermally efficient material, with an impressive thermal efficiency rating of 56.8 %. This high-efficiency level shows how well clay can turn energy from burning into heat. Clay showed its practical use by boiling up to 25 liters of water. This proves that clay is an excellent way to turn energy from burning into real-world benefits, such as boiling water, for different reasons. Clay bands worked well as fuel burners, using 1.28 kg of briquettes. This shows how vital clay is as a fuel-saving catalyst, ensuring that a large part of the fuel is used effectively during combustion. The study shows that clay has a remarkable combustion synergy, meaning it works well with the combustion process. This makes the stove work better as a whole.

Conflict of interest

The authors declare that they have no conflict of interest in relation to this research, whether financial, personal, authorship or otherwise, that could affect the research and its results presented in this paper.

Financing

The study was performed without financial support.

Data availability

Data will be made available on reasonable request.

Acknowledgments

This research is supported by the Mechanical Engineering Laboratory, Hasanuddin University.

References

1. Njenga, M., Karanja, N., Karlsson, H., Jamnadass, R., Iiyama, M., Kithinji, J., Sundberg, C. (2014). Additional cooking fuel supply and reduced global warming potential from recycling charcoal dust into charcoal briquette in Kenya. Journal of Cleaner Production, 81, 81–88. doi: https://doi.org/10.1016/j.jclepro.2014.06.002
2. Yuliah, Y., Kartawidjaja, M., Suryaningsih, S., Ulfi, K. (2017). Fabrication and characterization of rice husk and coconut shell charcoal based bio-briquettes as alternative energy source. IOP Conference Series: Earth and Environmental Science, 65, 012021. doi: https://doi.org/10.1088/1755-1315/65/1/012021
3. Amoako, G., Mensah-Amoah, P. (2018). Determination of calorific values of coconut shells and coconut husks. Journal of Materials Science Research and Reviews, 2 (2). Available at: https://ir.ucc.edu.gh/xmlui/handle/123456789/6153
4. Lukas, A. G., Lombok, J. Z., Anom, I. D. K. (2018). Briquettes Made with Mixtures of Salak Seed (Salacca zalacca) Charcoal and Coconut Shell Charcoal and the Potential as an Alternative Energy Source. International Journal of Applied Engineering Research, 13 (12), 10588–10592. Available at: https://www.ripublication.com/ijaer18/ijaerv13n12_64.pdf
5. Musabbikhah, Saptoadi, H., Subarmono, Wibisono, M. A. (2016). Optimization of temperature and time for drying and carbonization to increase calorific value of coconut shell using Taguchi method. AIP Conference Proceedings. doi: https://doi.org/10.1063/1.4943430
6. Sagdinakiadtikul, T., Supakata, N. (2016). The application of using rice straw coconut shell and rice husk for briquette and charcoal production. International Journal of Energy, Environment and Economics, 24 (2/3), 283–292. Available at: https://www.proquest.com/docview/1903095179?fromopenview=true&pq-origsite=gscholar
7. Djafar, Z., Suluh, S., Amaliyah, N., Piarah, W. H. (2022). Comparison of the Performance of Biomass Briquette Stoves on Three Types of Stove Wall Materials. International Journal of Design & Nature and Ecodynamics, 16 (6), 145–149. doi: https://doi.org/10.18280/ijdne.170119
8. Djafar, Z., Amaliyah, N., Suluh, S., Isra, M., Piarah, W. H. (2020). The Performance of Clay Furnace with Variation in the Diameters of the Briquette Burning Chamber. IOP Conference Series: Materials Science and Engineering, 875 (1), 012068. doi: https://doi.org/10.1088/1757-899x/875/1/012068

9. Wang, J., Lou, H. H., Yang, F., Cheng, F. (2016). Development and performance evaluation of a clean-burning stove. Journal of Cleaner Production, 134, 447–455. doi: https://doi.org/10.1016/j.jclepro.2016.01.068
10. Orhevba, B. A., Olatunji, O. I., Obasa, P. A. (2018). Performance evaluation of a modified briquette stove. Nigerian Research Journal of Engineering and Environmental Sciences, 3 (2), 898–908. Available at: https://www.researchgate.net/publication/334330905_Performance_evaluation_of_a_modified_briquette_stove
11. Tyagi, S. K., Pandey, A. K., Sahu, S., Bajala, V., Rajput, J. P. S. (2012). Experimental study and performance evaluation of various cook stove models based on energy and exergy analysis. Journal of Thermal Analysis and Calorimetry, 111 (3), 1791–1799. doi: https://doi.org/10.1007/s10973-012-2348-9
12. Hailu, A. (2022). Development and performance analysis of top lit updraft: natural draft gasifier stoves with various feed stocks. Heliyon, 8 (8), e10163. doi: https://doi.org/10.1016/j.heliyon.2022.e10163
13. Bokov, V., Sisa, O., Mirzak, V., Medvedieva, O. (2020). Pressing technology and burning quality of spherical fuel briquettes made from autumn leaves. Eastern-European Journal of Enterprise Technologies, 2 (1 (104)), 60–72. doi: https://doi.org/10.15587/1729-4061.2020.198724
14. Okino, J., Komakech, A. J., Wanyama, J., Ssegane, H., Olomo, E., Omara, T. (2021). Performance Characteristics of a Cooking Stove Improved with Sawdust as an Insulation Material. Journal of Renewable Energy, 2021, 1–12. doi: https://doi.org/10.1155/2021/9969806
15. Akolgo, G. A., Essandoh, E. O., Gyamfi, S., Atta-Darkwa, T., Kumi, E. N., Maia, C. M. B. de F. (2018). The potential of a dual purpose improved cookstove for low income earners in Ghana – Improved cooking methods and biochar production. Renewable and Sustainable Energy Reviews, 82, 369–379. doi: https://doi.org/10.1016/j.rser.2017.09.044
16. Dang, H., Wang, G., Wang, C., Ning, X., Zhang, J., Mao, X. et al. (2021). Comprehensive Study on the Feasibility of Pyrolysis Biomass Char Applied to Blast Furnace Injection and Tuyere Simulation Combustion. ACS Omega, 6 (31), 20166–20180. doi: https://doi.org/10.1021/acsomega.1c01677
17. Rasoulkhani, M., Ebrahimi-Nik, M., Abbaspour-Fard, M. H., Rohani, A. (2018). Comparative evaluation of the performance of an improved biomass cook stove and the traditional stoves of Iran. Sustainable Environment Research, 28 (6), 438–443. doi: https://doi.org/10.1016/j.serj.2018.08.001
18. Bondarenko, I., Kutniashenko, O., Toporov, A., Anishchenko, L., Ziuz, O., Dunayev, I. et al. (2020). Improving the efficiency of equipment and technology of waste briquetting. Eastern-European Journal of Enterprise Technologies, 6 (10 (108)), 36–52. doi: https://doi.org/10.15587/1729-4061.2020.220349
19. Murali, G., Channankaiah, P., Hasan, I. E., Anbarasan, P. (2015). Performance study of briquettes from agricultural waste for wood stove with catalytic combustor. International Journal of ChemTech Research, 8 (1), 30–36. Available at: https://sphinxsai.com/2015/ch_vol8_no1/1/(30-36)%20V8N1.pdf
20. Panwar, N. L. (2010). Performance Evaluation of Developed Domestic Cook Stove with Jatropha Shell. Waste and Biomass Valorization, 1 (3), 309–314. doi: https://doi.org/10.1007/s12649-010-9040-8
21. Ahiduzzaman, Md., Islam, A. K. M. S. (2013). Development of Biomass Stove for Heating up Die Barrel of Rice Husk Briquette Machine. Procedia Engineering, 56, 777–781. doi: https://doi.org/10.1016/j.proeng.2013.03.194
22. Kumar, M., Kumar, S., Tyagi, S. K. (2013). Design, development and technological advancement in the biomass cookstoves: A review. Renewable and Sustainable Energy Reviews, 26, 265–285. doi: https://doi.org/10.1016/j.rser.2013.05.010
23. MacCarty, N., Bryden, K. M. (2013). A Heat Transfer Model for the Conceptual Design of a Biomass Cookstove for Developing Countries. ASME 2013 International Design Engineering Technical Conferences and Computers and Information in Engineering Conference. doi: https://doi.org/10.1115/detc2013-12650
24. Bentson, S., Evitt, D., Still, D., Lieberman, D., MacCarty, N. (2022). Retrofitting stoves with forced jets of primary air improves speed, emissions, and efficiency: Evidence from six types of biomass cookstoves. Energy for Sustainable Development, 71, 104–117. doi: https://doi.org/10.1016/j.esd.2022.09.013
25. Ambreen, T., Saleem, A., Park, C. W. (2019). Pin-fin shape-dependent heat transfer and fluid flow characteristics of water- and nanofluid-cooled micropin-fin heat sinks: Square, circular and triangular fin cross-sections. Applied Thermal Engineering, 158, 113781. doi: https://doi.org/10.1016/j.applthermaleng.2019.113781
26. Wang, J., Gan, Y., Liang, J., Tan, M., Li, Y. (2019). Sensitivity analysis of factors influencing a heat pipe-based thermal management system for a battery module with cylindrical cells. Applied Thermal Engineering, 151, 475–485. doi: https://doi.org/10.1016/j.applthermaleng.2019.02.036
27. Li, X., He, L., Qian, P., Huang, Z., Luo, C., Liu, M. (2021). Heat transfer enhancement of droplet two-phase flow in cylindrical microchannel. Applied Thermal Engineering, 186, 116474. doi: https://doi.org/10.1016/j.applthermaleng.2020.116474
28. Ikram, M. Md., Saha, G., Saha, S. C. (2023). Unsteady conjugate heat transfer characteristics in hexagonal cavity equipped with a multi-blade dynamic modulator. International Journal of Heat and Mass Transfer, 200, 123527. doi: https://doi.org/10.1016/j.ijheatmasstransfer.2022.123527