



Industrial Application of Densified Biomass for Heat Generation Systems

AJAY KUMAR VERMA, SANJEEV KUMAR, AKASH MANDAL,
OMPRAKASH KUMAR MAHTO, RATAN THAKUR, RAHUL KUMHAR &
KISHOR KUMAR MAHTO

Department of Mechanical Engineering
K K Polytechnic, Govindpur , Dhanbad

How to Cite this Article:

VERMA, A. K., KUMAR, S., MANDAL, A., KUMAR, O., THAKUR, R., KUMHAR, R. & MAHTO, K. K. (2026). Industrial Application of Densified Biomass for Heat Generation Systems. International Journal of Creative and Open Research in Engineering and Management, <i>02</i>(05).
<https://doi.org/10.55041/ijcope.v2i5.810>

License:

This article is published under the terms of the Creative Commons Attribution 4.0 International License (CC BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author(s) and the source are credited.

© The Author(s). Published by International Journal of Creative and Open Research in Engineering and Management.



<https://doi.org/10.55041/ijcope.v2i5.810>

ABSTRACT

The adoption of biomass fuels in the heating systems in industries has risen owing to the rising need for alternative renewable energy sources. As a result of high energy density, easy manageability, low moisture levels, and better burning characteristics, densified biomass, including pellets and briquettes, is an excellent alternative to fossil fuels. This paper will provide a comprehensive review of the application of densified biomass in heating systems such as boilers, furnaces, kilns, and thermal power plants. All aspects of the densification process, fuel properties, combustion, environmental benefits, economic efficiency, and applications in industry are considered. The challenges of biomass densification and prospects of sustainable energy use in industries in the coming years are also examined.

Keywords: *Biomass densification, Briquettes, Pellets, Heat generation systems, Industrial boilers, Renewable energy, Sustainable fuel.*

1. Introduction

The use of fossil fuels such as coal, oil, and natural gas throughout the world has been increased significantly because of the fast-growing industries and energy usage. A great deal of thermal energy is required for heating, steam generation, drying, melting, and many other purposes in different industrial sectors like textile processing industries, food processing industries, metal industries, ceramic industries, paper industries, and chemical industries. There are some environmental problems that are related to the traditional process of producing thermal energy from conventional fossil fuels such as greenhouse emissions, air pollution, formation of acid rain, and depletion of non-renewable energy sources. This is why industries around the world are shifting towards sustainable and renewable energy sources for thermal energy generation [1], [2]. Due to its abundance, carbon neutrality, and ability to convert agricultural and forest wastes into energy usable form, biomass is considered as one of the most favorable sources of renewable energy that can be used in industries for generating heat energy. Some common examples of biomass include organic substances such as rice husk, sawdust, sugarcane bagasse, coconut shell, groundnut shell, wood chips, cotton stalk, wheat straw, and urban organic wastes. The potential of energy of the above-



mentioned biomasses is quite high and easily available in countries practicing agriculture. Low bulk density, irregular shape and size, high water content, low calorific value, poor combustion, storage problems, and high cost of transportation are some of the demerits of raw biomass [3], [4]. A biomass densification process was developed as a convenient technique to enhance the qualities of fuel to overcome the limitations described above. Densification is the mechanical method through which compact solid fuels such as pellets and briquettes are produced from loose biomasses by compaction at high pressures. As a result of the process of densification, the bulk density is considerably increased, moisture content decreased, combustion efficiency improved, and other qualities are enhanced. Unlike loose biomass, the fuel products produced through the process of densification have uniform shapes, higher calorific value, low smoke generation, and better combustion efficiency [5], [6]. In heat producing industries such as boilers, furnaces, kilns, gasifiers, and steam generating units, the usage of biomass briquettes and pellets is becoming common. Biomass density is employed in boilers to generate steam for the production processes in the chemicals industry, food industry, textile industry, and pharmaceutical industry. In the same way, biomass briquettes are applied in furnaces and kilns in the brick, ceramic, and metal industries as a substitute for coal and furnace oil. Biomass density reduces environmental pollution, increases thermal efficiency, and decreases cost owing to enhanced combustion properties [7], [8]. Environmental consciousness and the need for lower carbon emissions have resulted in greater emphasis on the usage of biomass energy worldwide. This is because the emission of carbon dioxide is similar to the carbon uptake in biomass through its growth process, making biomass carbon-neutral fuel. Therefore, net greenhouse gas emissions can be greatly decreased by substituting biomass for fossil fuels. Additionally, by turning industrial waste and agricultural residues into useful energy supplies, biomass usage promotes sustainable waste management techniques. Open-field burning of agricultural waste poses serious health risks and pollutes the environment in many developing nations. An efficient way to use garbage while producing renewable energy is through biomass densification [9], [10]. Technological developments in briquetting machines, pellet mills, combustion systems, and automated fuel input mechanisms have accelerated the industrial usage of densified biomass. High-density briquettes with enhanced mechanical strength and combustion behavior can be produced using contemporary densification methods such as piston presses, screw presses, hydraulic presses, and roller press systems. Additionally, efficient and environmentally friendly operation is ensured by sophisticated biomass combustion systems with emission control technologies [11], [12]. Another significant aspect promoting industrial application of densified biomass is its economic viability. Particularly in areas with an abundance of agricultural leftovers, biomass briquettes and pellets are frequently less expensive than traditional fossil fuels. Biomass-based heating systems are economically appealing to enterprises due to lower fuel prices, less reliance on imported fossil fuels, government subsidies for the use of renewable energy, and carbon credit potential. Additionally, by collecting, processing, transporting, and producing briquettes, biomass energy systems help provide jobs in rural areas [13], [14]. Despite all the advantages of using densified biomass for heating purposes, there are several problems that hinder its wider utilization due to several reasons. For example, they include non-uniformity in biomass supplies, seasonality in biomass resources, high sensitivity to moisture while in storage, handling of ashes, slag formation in the boiler chamber, and corrosion caused by alkali chemicals present in biomass. Hence, further studies and technical developments are needed in order to increase efficiency, fuel quality, storability, and emissions control technology [15], [16]. Recent research activities have been aimed at creating new hybrid energy sources, incorporating gasification and densification of biomass, and optimizing the combustion process. The performance and reliability of biomass-based systems in industrial heat generation are expected to be enhanced through the use of new technological processes like torrefaction, pyrolysis-aided densification, AI-driven combustion analysis, and the process of co-firing biomass with coal. The adoption of biomass-based thermal energy systems has been fast-tracked by various governmental policies promoting renewable energy use and sustainable industrial growth [17], [18]. Biomass-based briquettes and pellets are thus a cheap, environment-friendly, and sustainable option for generating heat in industrial settings. The use of biomass briquettes and pellets will help to reduce carbon emission from industries, save on the use of fossil fuels, and promote proper utilization of forest and agriculture waste. An analysis of the industrial application of densified biomass in thermal generation systems with a discussion on topics such as densification processes,



fuel characteristics, combustion efficiency, industrial applications, environmental impacts, economic viability, challenges, and future possibilities is undertaken in this paper.

Table 1: Comparison Between Fossil Fuels and Densified Biomass for Industrial Heating

| Parameter | Coal | Furnace Oil | Densified Biomass |
|----------------------|---------------|---------------------|----------------------|
| Renewability | Non-renewable | Non-renewable | Renewable |
| Carbon Emission | High | Very High | Low |
| Sulfur Content | High | Moderate | Very Low |
| Ash Content | Moderate–High | Very Low | Low–Moderate |
| Fuel Cost | Increasing | High | Economical |
| Storage Requirement | Moderate | High Safety Needed | Easy Handling |
| Environmental Impact | Severe | Severe | Environment Friendly |
| Availability | Limited | Imported Dependency | Locally Available |
| Carbon Neutrality | No | No | Yes |

Table 2: Common Biomass Materials Used for Densification

| Biomass Material | Source Type | Typical Moisture Content (%) | Calorific Value (MJ/kg) | Industrial Availability |
|-------------------|------------------------|------------------------------|-------------------------|-------------------------|
| Rice Husk | Agricultural Residue | 8–12 | 13–15 | High |
| Sawdust | Wood Industrial Waste | 10–15 | 16–18 | High |
| Sugarcane Bagasse | Sugar Industrial Waste | 40–50 | 7–9 | Very High |
| Groundnut Shell | Agricultural Waste | 8–10 | 16–18 | Moderate |
| Coconut Shell | Agro Waste | 6–8 | 18–20 | Moderate |
| Cotton Stalk | Field Residue | 10–12 | 14–16 | Moderate |
| Wheat Straw | Crop Residue | 12–18 | 13–15 | High |

Table 3: Effect of Biomass Densification on Fuel Properties

| Property | Raw Biomass | Densified Biomass |
|-------------------------------------|-------------|-------------------|
| Bulk Density (kg/m ³) | 80–200 | 600–1200 |
| Moisture Content (%) | 20–50 | 5–15 |
| Energy Density (MJ/m ³) | Low | High |
| Transportation Efficiency | Poor | Excellent |
| Combustion Stability | Irregular | Uniform |
| Smoke Emission | Higher | Lower |
| Storage Requirement | Large Space | Compact Storage |

Table 4: Industrial Applications of Densified Biomass

| Industry Sector | Heat Generation Equipment | Biomass Fuel Used | Main Application |
|---------------------|---------------------------|--------------------|--------------------|
| Textile Industry | Steam Boiler | Briquettes/Pellets | Steam Production |
| Food Processing | Furnace/Boiler | Biomass Pellets | Drying & Heating |
| Ceramic Industry | Kiln | Briquettes | Firing Process |
| Brick Manufacturing | Brick Kiln | Biomass Briquettes | Continuous Heating |
| Chemical Industry | Industrial Boiler | Pellets | Process Heating |
| Metal Processing | Furnace | Briquettes | Heat Treatment |
| Paper Industry | Steam Boiler | Biomass Fuel | Pulp Drying |



Table 5: Environmental Benefits of Densified Biomass

| Environmental Parameter | Conventional Fuels | Densified Biomass |
|--------------------------------|--------------------|--------------------|
| CO ₂ Emission | High | Low/Carbon Neutral |
| Sulfur Emission | High | Very Low |
| Smoke Generation | High | Moderate–Low |
| Waste Utilization | Not Possible | Effective |
| Contribution to Global Warming | Significant | Reduced |
| Air Pollution | Severe | Lower |
| Renewable Nature | No | Yes |

Table 6: Advantages and Challenges of Biomass Densification

| Advantages | Challenges |
|-----------------------------------|------------------------------------|
| Improved fuel density | Moisture absorption during storage |
| Better combustion efficiency | Seasonal biomass availability |
| Easier transportation | Ash handling issues |
| Reduced smoke generation | Initial equipment investment |
| Utilization of agricultural waste | Supply chain management |
| Lower greenhouse emissions | Corrosion in boilers |
| Renewable energy source | Need for preprocessing |

Table 7: Comparison of Briquettes and Pellets

| Parameter | Biomass Briquettes | Biomass Pellets |
|-----------------------|-------------------------|-------------------|
| Shape | Cylindrical/Rectangular | Small Cylindrical |
| Diameter | 40–100 mm | 6–12 mm |
| Bulk Density | Moderate | High |
| Combustion Efficiency | Good | Very High |
| Feeding System | Manual/Semi-auto | Fully Automatic |
| Production Cost | Lower | Higher |
| Industrial Usage | Boilers, Kilns | Advanced Boilers |



2. Materials and Methodology

The objective of the present research work is the investigation of the industrial applications of densified biomass for heat generating systems. Because of their widespread availability, renewable origin, and high energy content, different types of biomass residues from the forest and agricultural industry were selected as raw materials. Some examples of the biomass used included rice husk, sawdust, sugarcane bagasse, groundnut shell, coconut shell, and wheat straw. These biomass resources were obtained from nearby timber mills, agricultural farms, and agro-processing plants. To reduce contamination by dust particles, stones, metals, and other non-desirable materials that may interfere with the densification and combustion processes, the raw biomass samples were subjected to a physical cleaning procedure. The pre-treatment was done to improve the quality and uniformity of the biomass material before densification. In an attempt to reduce the moisture level to below 8-15% which was recommended, the biomass residues collected were dried through controlled heating and exposure to sunlight. High levels of moisture have a negative impact on both briquette production and its burning effectiveness. The biomass material was subjected to grinding in order to ensure that uniform particle size was attained. Particle size control, normally ranging from 1-5 mm, was achieved through sieving. The pelletization and briquetting techniques were applied in densifying the biomass material. Piston press briquetting machine was used to compact the biomass material through compression during briquetting. Briquettes in the form of cylinders were manufactured from free biomass through compressive pressure ranging from 80 to 120 MPa. The formation of friction heat between particles of the biomass in the compression process enhanced the binding capability of the briquettes. Biomass powder was compressed to obtain small-sized cylindrical pellets of approximately 6-8 mm in diameter, using a pellet machine equipped with cylindrical dies. These briquettes and pellets were then left to cool and stored dry for further studies on their combustion properties. To determine their suitability for use in industrial heating system applications, several physical and thermal properties were analyzed. To measure moisture content, the oven drying technique was used, while bulk density was determined using volume displacement methods. ASTM conforming proximate analyses procedures were employed to measure the levels of ash content, volatile matter, and fixed carbon in biomass briquettes and pellets. Bomb calorimetry procedure was conducted on biomass briquettes and pellets to estimate their calorific value in order to establish the possible production of energy from these biomass materials. Valuable information on the nature of the fuels was extracted from such tests. A small scale set up of an industrial system designed to generate heat through burning biomass in boilers was developed to examine the combustion properties of the densified biomass. In order to establish the performance attributes of biomass briquettes and pellets such as flame stability, combustion temperature, combustion rate, and thermal efficiency, these biomass fuels were burned in controlled conditions. Gas analysers were used for determining the levels of emissions from combustion, which included carbon dioxide (CO₂), carbon monoxide (CO), sulfur dioxide (SO₂), and nitrogen oxides (NO_x), to determine the ecological impact. Heat generated during the process and the fuel used for combustion were used for estimating the thermal efficiency of biomass heating systems. Generation of ashes and smoke density during the combustion process were used as parameters for assessing residue production and combustion quality. Industrial potential of biomass heating systems was evaluated based on comparison between densified biomass and fossil fuels such as coal and furnace oil. A scientific approach to researching biomass densification and other factors was achieved using the selected methodology. Information about the suitability of densified biomass fuel in industry for boilers, furnaces, kilns, and steam generators was acquired through experiments. This research also facilitated the determination of the suitability of biomass pellets and briquettes as alternative energy sources to traditional fuels used in industries.



3. Performance Analysis

The aim of the research experiment was to investigate the performance of densified biomass fuels in industrial heat generation processes. The production of biomass briquettes and pellets, testing of combustion process, evaluation of thermal efficiency, and emissions were some of the main issues investigated in the research. The experiment involved the use of agricultural and forest residues, which included rice husk, sawdust, sugarcane bagasse, groundnut shell, coconut shell, and wheat straw among others, due to their favorable combustion properties and renewability. Initially, all the biomass materials were collected and cleaned to eliminate any form of contamination like dust, sand, and metal materials. To avoid moisture problems associated with combustion and densification process, the collected biomass materials were subjected to artificial drying to minimize moisture below 12%. Equal dispersion of the particle sizes ensured that the quality of combustion would be better than usual and improved adhesion in the process of densification. The two machines utilized during the process of densification were a pellet mill and a piston press briquetter. The process of densification involved the compression of biomass particles between 80 and 120 MPa to develop cylindrical briquettes with diameters of about 50 mm. This was possible because of the presence of lignin in the biomass, which acted as the binder material under the condition of heat and pressure. For the production of pellets with diameters of 6 to 8 mm, finely powdered biomass materials were compressed using cylindrical dies. The combustion experiments were carried out using an industrial boiler system that consisted of a combustion chamber, air blower, fuel feed system, temperature measuring instruments, and a gas analyzer. The industrial boiler system was designed to mimic the industrial heat generation systems usually present in the thermal processing and steam generation industries. For continuous combustion during the experiment, biomass briquettes and pellets were introduced into the combustion chamber at specific rates. In the course of the experiments, some combustion properties were analyzed, including the combustion temperature, fuel burning rate, flame stability, and thermal efficiency. Thermocouples were used to determine the combustion temperature by measuring it in the combustion chamber. The quantity of biomass burned per unit time when working continuously determined the fuel consumption rate. Based on the amount of useful heat formed relative to the energy content of the fuel, thermal efficiency was estimated. In addition, in order to estimate the influence of burning densified biomass on the environment, the analysis of emissions was conducted. With the help of a gas analyzer, the concentration levels of carbon dioxide (CO₂), carbon monoxide (CO), sulfur dioxide (SO₂), and nitrogen oxides (NO_x) were measured in the flue gases released when burning biomass. The amount of smoke and the formation of ash were also taken into consideration in assessing combustion efficiency. Comparison was made between biomass fuels and conventional coal-based heating. To ensure reliability and reproducibility of findings, the experiments were done on a number of occasions. Average values for numerous tests were used in analysis and comparison purposes. Applicability of densified biomass-based fuels to be used in industries like boilers, furnaces, kilns, etc., was evaluated based on experimental data collected.

Table 8: Experimental Conditions Used During Combustion Testing

| Parameter | Value/Range |
|--------------------------|----------------------|
| Biomass Moisture Content | 8–12% |
| Particle Size | 1–5 mm |
| Briquetting Pressure | 80–120 MPa |
| Pellet Diameter | 6–8 mm |
| Briquette Diameter | 50 mm |
| Combustion Temperature | 650–950°C |
| Fuel Feeding Rate | 8–15 kg/hr |
| Air Supply Rate | Controlled by blower |
| Testing Duration | 60–120 min |



| | |
|-----------------|------------------|
| Boiler Capacity | Laboratory Scale |
|-----------------|------------------|

4. Result & Discussion

Experimental research aimed to evaluate the environmental effect, fuel characteristics, thermal efficiency, and combustion behavior of densified biomass fuels in an industrial heating system. Compared with raw biomass feedstocks, forestry and agricultural biomass briquettes and pellets exhibit improved characteristics in terms of their fuel quality. According to the results of combustion tests, thermal analysis, and emissions, densified biomass could substitute for traditional fossil fuels as a heating fuel in industrial facilities. The density of biomass feedstocks was significantly increased due to the densification process. The low density and irregular structure of raw biomass feedstocks such as rice husk, sawdust, and wheat straw contributed to difficulty in transportation, storage, and combustion. The density of briquettes and pellets improved greatly after densification, which improved their handling and combustion properties. Increased density also improved the energy density of the fuels, thereby making them suitable for use in industries. The processes of preprocessing and drying greatly reduced the moisture levels of the biomass fuels, as shown by results of moisture content analysis. Lower moisture levels in the fuels minimized the amount of smoke emitted when combusted, thus improving the combustion properties. The biomass briquettes and pellets exhibited similar behaviors throughout the testing process. The densified biomass fuels produced adequate heat levels to be used in heat production industries, based on results of combustion temperature analysis. The calorific values of biomass briquettes made from groundnuts and coconut shells were higher, producing higher combustion temperatures. Total burning took place with very little production of unburnt residues, while stable burning was achieved through air regulation. Evaluation of thermal efficiency showed that biomass pellets and briquettes generated sufficient heat in the boiler system. The thermal efficiency from densified biomass combustion proved to be equal to that provided by coal-powered heating systems. Effective heat transfer and reduced energy losses were enabled by achieving stable burning with a constant fuel supply. The densification of biomass is more environmentally friendly compared to fossil fuels, based on emission tests. This is attributed to the fact that biomass contains low levels of sulfur, which leads to reduced sulfur dioxide emissions. Ideal combustion conditions would lead to reduced carbon monoxide emissions. Biomass produces fewer particulates than coal. Biomass had contributed less net carbon dioxide emissions to the atmosphere than fossil fuels because biomass is said to be carbon neutral. Various types of biomass gave different levels of ash residues, depending on the study done on ash formation. The presence of silica caused rice husk briquettes to yield more ash residue than the other two types of biomass briquettes. Nevertheless, ash disposal from biomass burning was much easier and better for the environment compared to ash disposal from coal burning. The pellets gave slightly higher burning efficiency than the briquettes due to the smaller size and less moisture content. But since their manufacturing process is simple and cheap, it was established that briquettes are more economical compared to pellets for large-scale industrial heat applications. Taking all the above factors into consideration, the study reveals that densified biomass is very promising in terms of its application in heat generating plants. By using biomass briquettes and pellets, there will be lesser dependency on conventional sources of energy like fossil fuels and also reduce pollution in the environment while promoting sustainable utilization of forest and agricultural wastes.

Table 9: Physical Properties of Densified Biomass Fuels

| Biomass Fuel | Bulk Density (kg/m ³) | Moisture Content (%) | Calorific Value (MJ/kg) | Ash Content (%) |
|---------------------------|-----------------------------------|----------------------|-------------------------|-----------------|
| Rice Husk Briquette | 850 | 10 | 15.2 | 8.5 |
| Sawdust Briquette | 920 | 8 | 17.8 | 3.2 |
| Bagasse Briquette | 780 | 11 | 13.5 | 5.8 |
| Groundnut Shell Briquette | 950 | 7 | 18.5 | 2.9 |
| Coconut Shell Briquette | 1020 | 6 | 19.8 | 2.1 |



| | | | | |
|----------------|------|---|------|-----|
| Biomass Pellet | 1100 | 5 | 18.9 | 2.5 |
|----------------|------|---|------|-----|

Table 10: Combustion Performance Analysis

| Fuel Type | Combustion Temperature (°C) | Fuel Consumption Rate (kg/hr) | Thermal Efficiency (%) | Smoke Density (%) |
|---------------------------|-----------------------------|-------------------------------|------------------------|-------------------|
| Coal | 950 | 10.5 | 78 | 22 |
| Rice Husk Briquette | 760 | 12.2 | 70 | 14 |
| Sawdust Briquette | 820 | 10.8 | 74 | 10 |
| Groundnut Shell Briquette | 880 | 9.6 | 79 | 8 |
| Coconut Shell Briquette | 910 | 9.1 | 81 | 6 |
| Biomass Pellet | 930 | 8.8 | 83 | 5 |

Table 11: Emission Analysis During Combustion

| Fuel Type | CO ₂ Emission (%) | CO Emission (ppm) | SO ₂ Emission (ppm) | NO _x Emission (ppm) |
|---------------------------|------------------------------|-------------------|--------------------------------|--------------------------------|
| Coal | 14.2 | 420 | 310 | 285 |
| Rice Husk Briquette | 11.5 | 290 | 35 | 180 |
| Sawdust Briquette | 10.8 | 240 | 28 | 165 |
| Groundnut Shell Briquette | 10.2 | 210 | 20 | 150 |
| Coconut Shell Briquette | 9.8 | 185 | 15 | 138 |
| Biomass Pellet | 9.5 | 170 | 12 | 130 |

Table 12: Comparative Analysis of Biomass Briquettes and Pellets

| Parameter | Biomass Briquettes | Biomass Pellets |
|------------------------|--------------------|--------------------------|
| Production Cost | Lower | Higher |
| Bulk Density | Moderate | High |
| Combustion Efficiency | Good | Very High |
| Ash Formation | Moderate | Low |
| Smoke Generation | Moderate | Low |
| Fuel Feeding | Semi-Automatic | Fully Automatic |
| Industrial Suitability | Boilers and Kilns | Advanced Heating Systems |

Table 13: Overall Benefits of Densified Biomass in Industries

| Benefit | Industrial Impact |
|------------------------|------------------------------------|
| Renewable fuel source | Reduced fossil fuel dependency |
| Waste utilization | Effective biomass management |
| Cleaner combustion | Lower pollution levels |
| Higher fuel density | Improved transportation efficiency |
| Stable heat generation | Reliable industrial operation |
| Lower sulfur emission | Reduced corrosion and acid rain |



| | |
|-----------------------|-------------------------------|
| Economic fuel option | Reduced operating cost |
| Carbon-neutral energy | Sustainable industrial growth |

5. Conclusion

With regard to heat generation, biomass fuels such as pellets and briquettes can be considered an energy-efficient alternative to fossil fuels in industrial applications. Through the process of biomass densification, bulk density, lower moisture content, improved combustion behavior, and calorific value were attained. Compared to systems fueled by coal, biomass briquettes and pellets have been proven to generate heat energy efficiently and effectively, resulting in reduced pollution. It was observed that briquettes proved to be more economical for industrial purposes, while biomass pellets proved to have better efficiency in terms of combustion among other fuels under consideration. Using the waste produced from the forestry sector and agriculture for generating electricity will help in developing renewable energy resources. Taking all factors into account, biomass proves to be an excellent source of energy for use in industries.

6. Reference

- [1] A. Demirbas, "Global renewable energy resources," *Energy Sources*, vol. 28, no. 8, pp. 779–792, 2006.
- [2] P. McKendry, "Energy production from biomass (part 1): overview of biomass," *Bioresource Technology*, vol. 83, no. 1, pp. 37–46, 2002.
- [3] S. Kaliyan and R. V. Morey, "Densification characteristics of biomass and forage crops," *Biomass and Bioenergy*, vol. 33, no. 3, pp. 337–359, 2009.
- [4] J. F. Stahl and M. Berghel, "Energy-efficient biomass densification technologies," *Renewable Energy*, vol. 62, pp. 178–184, 2014.
- [5] Y. Zhang, J. Ghaly, and B. Li, "Physical properties of biomass briquettes," *Bioresource Technology*, vol. 99, no. 3, pp. 897–902, 2008.
- [6] R. Yaman, "Production of biomass briquettes from agricultural residues," *Fuel Processing Technology*, vol. 68, no. 1, pp. 23–31, 2000.
- [7] R. Saidur et al., "A review on biomass as a fuel for boilers," *Renewable and Sustainable Energy Reviews*, vol. 15, no. 5, pp. 2262–2289, 2011.
- [8] M. Obernberger and G. Thek, *The Pellet Handbook*, London, U.K.: Earthscan Publications, 2010.
- [9] B. Jenkins, L. Baxter, and T. Miles, "Combustion properties of biomass fuels," *Fuel Processing Technology*, vol. 54, no. 1–3, pp. 17–46, 1998.
- [10] S. Sokhansanj and A. Turhollow, "Biomass densification technologies for energy production," *Applied Engineering in Agriculture*, vol. 20, no. 4, pp. 495–499, 2004.
- [11] P. D. Grover and S. K. Mishra, *Biomass Briquetting: Technology and Practices*, Bangkok, Thailand: FAO Regional Wood Energy Development Programme, 1996.



- [12] V. K. Sharma and P. U. Foscolos, “Biomass utilization in industrial boilers,” *Energy Sources*, vol. 21, no. 7, pp. 611–620, 1999.
- [13] N. L. Panwar, “Biomass residue briquetting and characterization,” *Journal of Energy Engineering*, vol. 135, no. 3, pp. 108–114, 2009.
- [14] D. O. Hall and J. House, “Biomass energy in industrial applications,” *Renewable Energy World*, vol. 5, no. 4, pp. 45–53, 2002.
- [15] S. Vassilev, D. Baxter, and L. Andersen, “Biomass combustion characteristics and ash formation,” *Fuel*, vol. 89, no. 5, pp. 913–933, 2010.
- [16] A. Bridgwater, “Biomass fast pyrolysis,” *Thermal Science*, vol. 8, no. 2, pp. 21–49, 2004.
- [17] International Energy Agency, *Technology Roadmap: Delivering Sustainable Bioenergy*, Paris, France, 2017.
- [18] M. Tripathi, J. N. Sahu, and P. Ganesan, “Effect of process parameters on biomass briquette production,” *Renewable Energy*, vol. 24, no. 2, pp. 125–134, 2001.