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Valorization of Forest Residues as Biomass for Sustainable Industrial Use Energy Properties and Fossil Fuel Substitution Potential

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Abstract

This study investigates the utilization of forest residues for thermal energy generation in industrial processes. Biomass samples were characterized in terms of calorific value, chemical composition, moisture content, and ash content. The tests simulated real combustion conditions in furnaces and boilers. The results showed satisfactory thermal performance, with the potential to partially replace fossil fuels and reduce greenhouse gas emissions. Application in sectors such as ceramics, textiles, and paper industries proved feasible, highlighting the importance of biomass as a renewable resource for sustainable industrial use.

Keywords: Thermal Energy, Industrial Sustainability, Combustion Efficiency, Atmospheric Emissions, Residual Biomass

1. Introduction

Brazil has historically stood out for having a high share of renewable energy sources in its domestic energy supply compared to the rest of the world. Over the past 20 years, the share of renewables in the Brazilian energy matrix has remained stable, exceeding 40%. Variations observed between 2011 and 2014 were due to a reduction in hydroelectric supply. From 2015 onward, renewable sources resumed growth, driven by the expansion of sugarcane derivatives, wind power, and biodiesel, reaching 49.1% in 2023 due to favorable hydrological conditions [1]. According to the industrial sector accounts for about 25% of global greenhouse gas emissions, with energy-intensive thermal processes being the main contributors [2]. Replacing fossil fuels with renewable sources is a crucial step to mitigate environmental impacts, especially in industries such as ceramics, cement, food processing, and pulp and paper. Biomass, an organic material naturally produced, stands out as a clean and renewable energy alternative. Forest residues, often discarded or underutilized, represent an abundant and underexplored biomass source. These materials can be repurposed for energy generation, fostering circular economy principles and reducing environmental impacts associated with fossil fuel use. Therefore, this study aims to evaluate the energy properties of different forest residues and their viability as a partial substitute for fossil fuels in industrial thermal processes.

2. Materials and Methods

Forest biomass, primarily composed of firewood, is considered a clean and renewable energy source, especially when harvested from plantations specifically intended for energy production et al. Previous studies have demonstrated that forest biomass has calorific values comparable to conventional fuels and can offer lower pollutant emissions, provided it is properly processed and combusted. The industrial application of biomass has gained prominence in public policies focused on energy transition and sustainable production processes.

2.1. Biomass Sampling and Preparation

Samples of forest residues (sawdust, bark, and eucalyptus branches) were collected in the Central-West region of Brazil. The samples were dried at 105 °C for 24 hours and ground to a particle size of 2–5 mm.

2.2. Physicochemical Characterization

- Calorific Value: Determined by adiabatic calorimetry (ASTM D5865)
- Elemental Analysis (CHNS): Conducted using a PerkinElmer elemental analyzer
- Ash Content: Measured in a muffle furnace at 550°C (ASTM D1102)
- Moisture Content: Determined using the gravimetric method (ASTM E871)

2.3. Pilot-Scale Combustion Tests

Combustion tests were performed in an indirect combustion furnace with automated feeding and temperature control. The simulation included continuous operating conditions typical of industrial boilers. Gas emissions were monitored using a portable analyzer (Test 350).

3. Results and Discussion

3.1. Biomass Properties

Biomass Type	LHV (MJ/kg)	Ash (%)	Moisture (%)	C (%)	H (%)	N (%)
Sawdust	18,5	0,9	12,0	49.2	6.1	0.2
Eucalyptus bark	17,2	1,8	14,3	47.0	6.3	0.3
Shredded branches	19,1	1,1	11,5	50.1	6.0	0.2

Note: LHV – Lower Heating Value; C – Carbon; H – Hydrogen; N – Nitrogen; S – Sulfur.

Table 1: Physicochemical Characteristics of the Analyzed Biomass Samples

The results indicate that forest residues present energy values compatible with industrial applications. Ash and moisture contents remained within acceptable ranges, which favors clean and efficient combustion [2].

3.2. Combustion Efficiency

Thermal efficiency ranged from 72% to 78%, depending on the biomass type. Partial substitution of fuel oil with biomass led to CO_2 emission reductions of up to 80%, along with low SO_2 and particulate emissions. These findings reinforce the potential of biomass as a strategy for reducing industrial emissions [3].

3.3. Industrial Applications

Biomass demonstrated technical feasibility for use in

- Ceramic kilns and calcination processes
- Low-pressure boilers in the food, textile, and paper sectors
- Hybrid cogeneration systems.

The main limitations observed were related to moisture control and particle size uniformity, which affect combustion stability. Investments in drying and pelletizing systems may mitigate these limitations and expand biomass use in industry.

4. Conclusions

The evaluated forest residues exhibit suitable energy properties for the partial replacement of fossil fuels in industrial thermal applications. The use of biomass as a complementary energy source promotes process sustainability, reduces greenhouse gas emissions, and contributes to environmental impact mitigation. Furthermore, the valorization of forest residues strengthens the circular economy and adds environmental and economic value to the wood production chain. The findings support the development of public policies and incentives for energy recovery from residues, especially in regions with significant forest potential.

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