Thermal Properties of Some African Tropical Woods: Okoume, Bilinga, Movingui, Ozigo and Nove and their Potential as Biofuel Feedstocks

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Abstract

The thermal properties of tropical woods, essential for optimizing biofuel production, were studied using five wood species from Central Africa: Okoume, Bilinga, Movingui, Ozigo, and Nove. Despite their high lignocellulosic potential, data on the thermal behavior of these species under varying conditions remain scarce. This study investigated their thermal conductivity, diffusivity, and specific heat capacity (Cp) using a hot-disk analyser, considering variations in density, porosity, moisture content, and drying temperatures. Results revealed significant interspecies differences. Movingui exhibited the highest thermal conductivity (0.3050 W/mK) and diffusivity, ideal for efficient heat transfer during biofuel production processes such as pyrolysis. Ozigo demonstrated superior Cp (1656 J/kg/K), making it suitable for thermal energy storage and insulation. In contrast, Okoume's lower thermal conductivity suggests limited heat transfer efficiency. Increasing relative humidity significantly impacted thermal properties, particularly in Okoume and Ozigo, which showed substantial conductivity increases of 69% and 58%, respectively. The findings underscore the potential of these wood species as biofuel feedstocks, with Movingui emerging as a standout candidate due to its high heat transfer efficiency. Ozigo's insulating properties offer potential in temperature-stabilized bioenergy applications. This study bridges critical gaps in understanding the thermal behaviour of tropical woods and provides insights into enhancing their bioenergy utilization through pre-treatment and process optimization. Future research should explore their biochemical composition, combustion, mechanical property, and life cycle impacts to advance sustainable biofuel production.

1. Introduction

The global pursuit of sustainable and renewable energy solutions has never been more urgent. Amidst escalating climate change concerns and the depletion of fossil fuel reserves, bioenergy presents an eco-friendly alternative, promising to reduce greenhouse gas emissions while diversifying energy portfolios [1]. Tropical woods, with their abundant lignocellulosic biomass,

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emerge as key players in this transition. Specifically, African tropical woods, such as Okoume, Bilinga, Movingui, Ozigo, and Nove, hold immense potential as biofuel feedstocks due to their unique thermal properties, renewable nature, and geographical availability. Harnessing these resources effectively requires an in-depth understanding of their thermal characteristics to optimize their role in bioenergy production processes [2]. This study focuses on the thermal properties—thermal conductivity, diffusivity, and specific heat capacity (Cp) —of the selected African tropical woods, measured under varying moisture content and drying temperatures using a hot-disk analyser. These properties are critical for understanding the heat transfer, storage, and insulation behaviour of biomass materials during thermochemical conversion processes such as pyrolysis, combustion, and hydrothermal liquefaction [3,4]. By investigating these parameters, the study seeks to determine the suitability of Okoume, Bilinga, Movingui, Ozigo, and Nove as biofuel feedstocks and their potential applications in energy systems.

Despite the recognized bioenergy potential of tropical woods, a significant knowledge gap persists regarding their specific thermal behaviours under different environmental conditions. Previous studies have explored the thermal properties of other woods but rarely address tropical species, particularly those from Central Africa. This oversight limits the optimization of their use in bioenergy applications. Understanding the effects of density, porosity, and moisture on thermal conductivity and heat capacity is crucial for advancing their integration into renewable energy systems. This research aims to address this gap by investigating the thermal transport properties of these woods and their implications for biofuel production. Specifically, the study seeks to answer the following questions: (1) How do thermal conductivity, diffusivity, and Cp vary among Okoume, Bilinga, Movingui, Ozigo, and Nove? (2) How do these thermal properties influence the potential of these woods as biofuel feedstocks? These inquiries are foundational for developing targeted pre-treatment strategies and improving the efficiency of biofuel production from tropical wood species. By providing the first comprehensive analysis of the thermal properties of these African tropical woods, this study will contribute significantly to the field of bioenergy. The findings will not only enhance the understanding of how thermal characteristics influence biofuel production but also inform strategies for optimizing energy yields and reducing processing costs. Furthermore, the research will serve as a cornerstone for sustainable biomass utilization, supporting global efforts to transition towards cleaner energy systems while fostering economic growth and environmental preservation in Central Africa.

2. Methodology

This study examines the thermal properties of five African tropical wood species—Okoume, Bilinga, Movingui, Ozigo, and Nove—sourced from Gabon. These wood samples were prepared by cutting into standardized dimensions (48 mm × 48 mm × 20 mm) and dried at 60°C and 103°C to remove moisture. The transient plane source (TPS) technique, using a hot-disk thermal analyser, was employed to measure thermal conductivity, thermal diffusivity, and Cp. This method, known for its precision and rapid results, eliminates the influence of contact resistance and measures properties across a broad range of materials.

The TPS analyser features a planar sensor sandwiched between two wood layers, serving as both a heat source and temperature sensor. Measurements were conducted with a heating power of 30 mW and duration of 20 seconds, and each test was repeated three times for consistency [5]. Relative humidity and moisture content were controlled to evaluate their effects on the thermal properties. Bulk density and porosity were also determined using mass and volume measurements. This methodology ensures accurate characterization of wood thermal properties under varying conditions, providing insights into their suitability for bioenergy applications. The approach links thermal performance to key variables, such as density and porosity, critical for optimizing biofuel feedstocks.

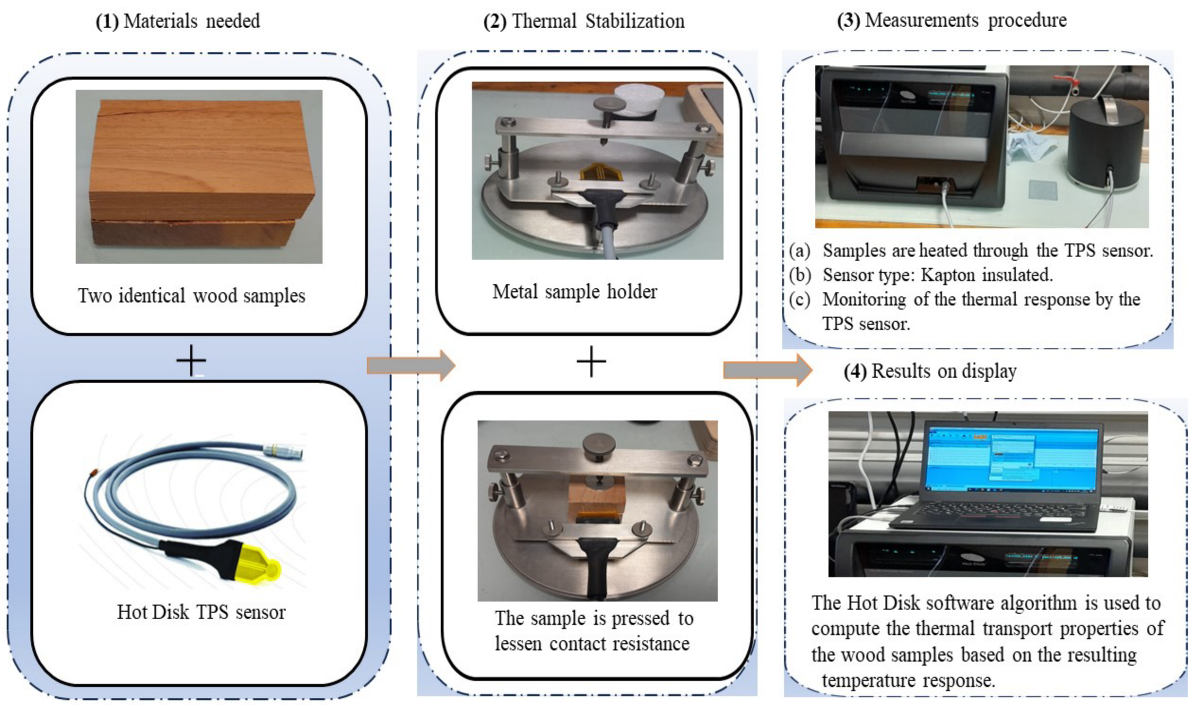

Figure 1: Schematics of the Hot Disk technique

3. Results and Discussion

Thermal conductivity, indicating the efficiency of heat transmission in materials, varied among the wood species studied. From **Figure 2a** and **Figure 2b**, Movingui showed the highest thermal conductivity (0.3050 W/mK), followed by Nove (0.2750 W/mK), while Okoume exhibited the lowest (0.1752 W/mK), suggesting limited heat transfer efficiency. Bilinga and Ozigo displayed intermediate values, comparable to each other but higher than those reported for larch (0.14 W/mK) and spruce (0.12 W/mK) [6]. As shown in **Figure 2a** and **2b**, no significant changes in wood density were observed between drying temperatures of 60°C and 103°C, likely due to insufficient temperature effects, short exposure times, or species-specific characteristics. This aligns with prior research linking higher temperatures to notable density reductions through moisture loss and structural shrinkage [7,8]. Thermal conductivity generally increased with density in Movingui, Bilinga, and Okoume. However, Nove, despite its high density, exhibited relatively low thermal conductivity, possibly due to dense cell walls or extractive content acting as insulators. Similarly, Ozigo's low conductivity may result from high porosity or structural irregularities hindering heat flow. These findings highlight the non-linear relationship between density and thermal conductivity, influenced by wood anatomy, porosity, and microstructure. Variations in moisture content and fibre alignment further underscore the complexity of heat transfer behavior in these tropical woods.

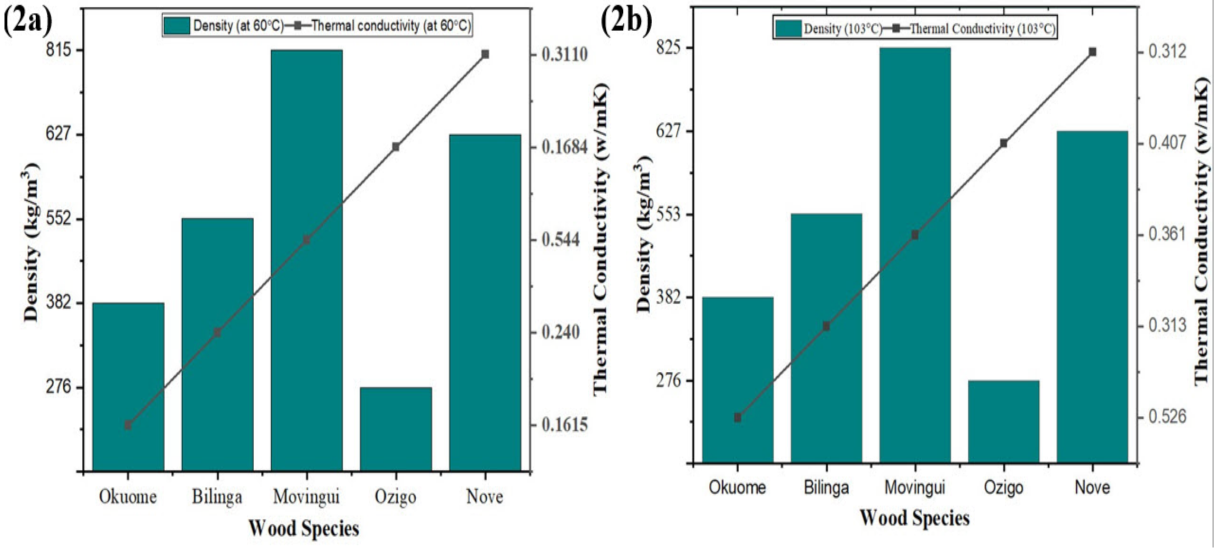

Figure 2: Thermal conductivity and bulk densities of wood species at different drying rates (a) 60ºC (b) 103ºC.

Thermal diffusivity, reflecting the rate of heat propagation, varied significantly among wood species. From **Figure 3**, Nove exhibited the highest diffusivity (0.9317 mm²/s), despite lower thermal conductivity, likely due to its density and structural composition. Movingui and Nove also displayed the highest bulk densities (815 kg/m³ and 627 kg/m³, respectively), indicating superior heat storage capacity per unit volume. In contrast, Ozigo's lower density (276 kg/m³) correlated with reduced thermal conductivity and heat transfer efficiency. Denser woods generally demonstrated higher thermal conductivity due to their lower air content, facilitating more efficient heat transfer. Air, being a poor heat conductor, diminishes conductivity in porous woods like Ozigo. In addition, chemical composition and wood structure, such as cell wall density and fibre alignment, further influenced conductivity, emphasizing the complex interplay of wood properties in thermal performance [9].

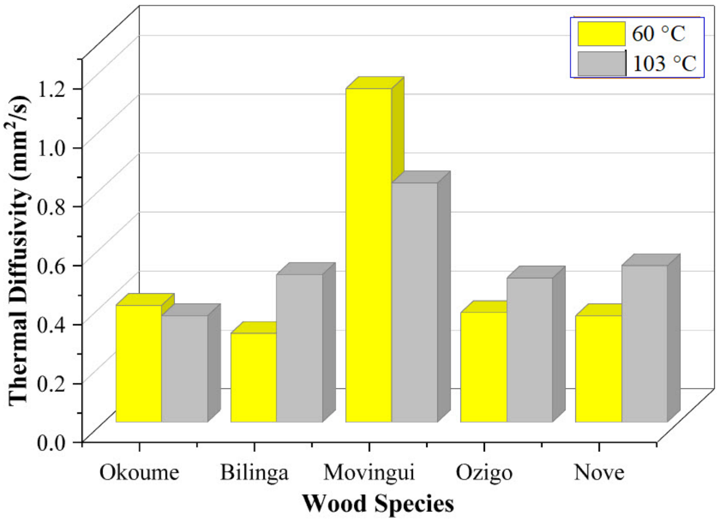

Figure 3: Thermal diffusivity of wood species at different drying rates.

As illustrated in **Figure 4**, Cp and density of wood biomass varied significantly among species and conditions. Ozigo exhibited the highest specific heat capacities (1656 J/kg/K at 60°C and 2124 J/kg/K at 103°C), followed by Bilinga. In contrast, Movingui recorded the lowest values. While Okoume, Bilinga, and Movingui showed reduced Cp with lower moisture content, Ozigo and Nove exhibited increases, likely due to structural or chemical changes during drying, such as enhanced lignin crystallinity or altered cell wall bonding [10]. In comparison, subal pine fir has a Cp of 1400 J/kg/K [11], and for black pine, beech, poplar, and hazelwood, Cp was in the range of 1311–1498 J/kg/K over a temperature range of 313–353 K [12]. High-density woods generally displayed greater Cp due to their higher mass per unit volume, requiring more energy for temperature elevation. These results emphasize the role of density, moisture, and structural composition in determining a wood species' ability to store thermal energy, crucial for bioenergy applications.

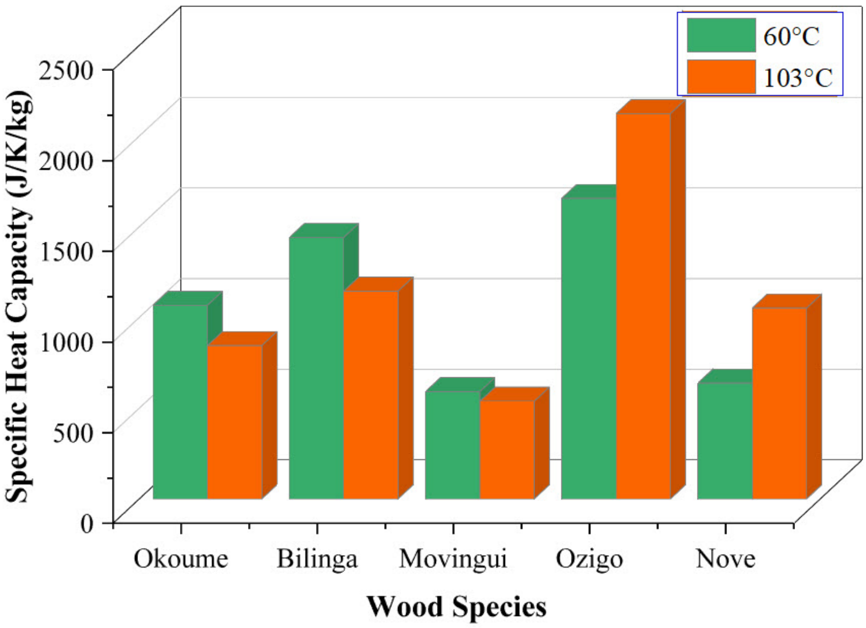

Figure 4: Specific heat capacity of wood species at different drying rates.

The thermal properties of these tropical wood species highlight their diverse suitability for biofuel production. Movingui exhibited the highest thermal conductivity (0.3050 W/mK), making it ideal for processes such as pyrolysis and hydrothermal liquefaction that require rapid and uniform heat transfer [13,14]. Nove had the highest thermal diffusivity (0.9317 mm^2/s), suitable for processes involving heat-sensitive reactions, such as hydrothermal liquefaction. Ozigo demonstrated the highest Cp (1656 J/kg/K), highlighting its potential for energy storage and maintaining stable temperatures during biofuel production. Movingui emerged as the most promising feedstock due to its combination of high conductivity and diffusivity, enhancing the efficiency of thermochemical conversion processes. Ozigo's heat storage capacity complements its use in stabilizing biofuel production cycles. Okoume and Nove, with moderate thermal properties, are suitable as complementary feedstocks in blended biofuel systems. These findings form a basis for optimizing biofuel production by guiding pre-treatment strategies such as drying and pelletization to improve energy yield and reduce processing costs.

Conclusion

This study examined the thermal properties of Okoume, Bilinga, Movingui, Ozigo, and Nove; by assessing their suitability as biofuel feedstocks. Movingui, with its high thermal conductivity and diffusivity, was identified as the most promising species for thermochemical conversion processes such as pyrolysis and hydrothermal liquefaction. Nove demonstrated the highest thermal diffusivity, enabling rapid heat propagation, while Ozigo's superior Cp highlights its potential for energy storage and thermal stability. Okoume and Bilinga, with moderate thermal properties, are viable as complementary feedstocks in blended biofuel systems. These findings provide a foundation for optimizing biofuel production through pre-treatment strategies such as drying and pelletization, which could enhance energy yields and efficiency. Future studies should focus on biochemical analyses and life cycle assessments to evaluate the broader environmental and economic impacts of these woods. In our laboratory, there is an ongoing thermogravimetric analysis of these wood species under varying atmospheric conditions. The aim is to evaluate their thermal degradation behavior, stability, and suitability, providing critical insights into their roles in sustainable biofuel production.

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