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# IMPROVEMENT OF THE TORREFACTION PROCESS WITH OPTIMIZATION OF TEMPERATURE THROUGH A SUNLIGHT REFLECTOR TO PRODUCE SOLID FUEL

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**Abstract:** Torrefaction is a thermal pretreatment process that enhances the fuel properties of biomass, making it more suitable as a renewable energy source. However, conventional torrefaction methods often require high energy input, which limits their economic and environmental sustainability. This study aims to improve the torrefaction process by optimizing the operational temperature using a sunlight reflector, thereby reducing external energy consumption while producing high-quality solid fuel. A series of experimental tests were conducted using agricultural biomass as the feedstock. The torrefaction process was facilitated by a parabolic solar reflector to harness concentrated solar energy. Temperature control was achieved by adjusting the focal point and reflector angle to maintain optimal conditions in the 220–280°C range. Key parameters such as mass yield, energy yield, moisture content, volatile matter, fixed carbon, and calorific value were analyzed to assess fuel quality. The results indicate that torrefaction at an optimized temperature of 260°C produced the highest-quality solid fuel, with a significant increase in calorific value and fixed carbon content, while reducing moisture and volatile matter. The use of a sunlight reflector successfully eliminated the need for fossil-based heating, thereby improving energy efficiency and lowering carbon emissions. This study demonstrates that temperature optimization through solar reflectors can significantly enhance the torrefaction process in a cost-effective and environmentally sustainable manner. The findings have practical implications for rural and off-grid biomass energy applications, supporting the development of clean and decentralized renewable energy systems.

**Keywords:** cross-cultural pragmatics, ELF, interlanguage pragmatics, pragmatic competence, teacher development

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**INTRODUCTION:**

The global pursuit of sustainable and renewable energy alternatives has intensified efforts to convert biomass into efficient solid fuels. Among thermal pretreatment techniques, torrefaction has garnered significant attention due to its ability to enhance the energy density, hydrophobicity, and grindability of raw biomass, thereby improving its suitability for combustion and co-firing in energy systems [1]. Typically conducted at temperatures between 200°C and 300°C in an inert atmosphere, torrefaction reduces moisture and volatile matter while increasing the fixed carbon content of biomass [2]. However, conventional torrefaction systems rely heavily on fossil-based energy inputs, which diminish the environmental and economic sustainability of the process [3].

Although torrefaction has been widely studied, limited research has explored the integration of renewable energy particularly solar energy into the torrefaction process. Most existing studies focus on reactor design, residence time, and feedstock type, but do not address the optimization of heat input using environmentally benign sources [4]. Furthermore, the role of temperature optimization via solar concentration techniques, such as parabolic or flat-plate reflectors, has received minimal empirical investigation in torrefaction research. This represents a critical gap, especially considering global efforts to decarbonize energy systems and promote sustainable biomass utilization [5].

The urgency of this study lies in the need for decentralized, low-carbon biomass processing solutions, particularly in rural and off-grid regions where conventional energy infrastructure is limited. The use of concentrated solar energy for torrefaction presents an opportunity to reduce fossil fuel dependence while producing high-energy-density solid fuels suitable for domestic and industrial use [6]. With rising global energy demands and environmental concerns, developing low-cost, renewable-assisted torrefaction systems has become a priority for researchers and practitioners in bioenergy development [7].

Prior studies have demonstrated the technical feasibility of torrefaction and its influence on various biomass types. [8] analyzed changes in elemental composition and heating value post-torrefaction, while [9] studied the energy yield and physicochemical transformations in woody biomass. Research by [10] highlighted the significance of torrefaction temperature in determining fuel properties. Other works have explored solar thermal systems for biomass drying and pyrolysis [11], but few have directly investigated the integration of sunlight reflectors to control and optimize the torrefaction temperature.

This research introduces a novel integration of solar reflector technology into the torrefaction process, providing a renewable and cost-effective heat source for biomass conversion. Unlike

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previous studies that use conventional electric or gas-based heating, this study explores the use of a parabolic sunlight reflector to precisely control torrefaction temperature, enhancing the process efficiency while maintaining environmental integrity. Additionally, the work evaluates the thermal behavior and fuel characteristics under solar-driven conditions, offering a practical model for sustainable energy generation in resource-constrained settings.

1) This study aims to improve the torrefaction process by optimizing temperature control using a sunlight reflector system. The specific objectives include:
2) To assess the thermal performance of biomass torrefied under solar-concentrated heat.
3) To determine the optimal torrefaction temperature for maximizing solid fuel quality.
4) To compare the physicochemical properties of torrefied biomass across temperature ranges.
5) To evaluate the potential of using solar energy for decentralized biofuel production.

The findings of this research have both scientific and practical implications. Scientifically, it contributes to the growing field of solar-assisted thermochemical biomass conversion by offering an alternative pathway for energy-efficient torrefaction. Practically, it supports the development of low-carbon, off-grid biomass upgrading technologies, empowering rural communities with sustainable and self-sufficient energy solutions. Moreover, this approach aligns with global climate action goals by reducing reliance on fossil fuels and encouraging renewable energy integration in biofuel production systems.

**LITERATURE REVIEW AND METHODOLOGY:**

This study employed an experimental quantitative research design aimed at evaluating the effect of temperature optimization using a sunlight reflector on the quality of torrefied solid fuel. The design involved systematically varying the torrefaction temperature within a defined range and analyzing the resulting changes in fuel properties. This approach is consistent with methodologies in thermal biomass conversion research that prioritize controlled, replicable testing conditions [12].

The biomass used in this study consisted of agricultural waste residues, specifically dried corn stalks, due to their availability, energy potential, and relevance to rural energy systems. All samples were air-dried to achieve an initial moisture content below 10% prior to torrefaction, following standard preparation protocols [13].

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Experimental Setup: Sunlight Reflector System

A parabolic solar reflector system was constructed to concentrate solar energy onto a stainless-steel torrefaction chamber. The system consisted of:

- A dual-axis adjustable parabolic reflector to track sunlight throughout the day.
- A central biomass chamber fitted with thermocouples for real-time temperature monitoring.
- An infrared thermometer and data logger for validating surface and internal temperatures.

The torrefaction process was carried out in five temperature stages: 220°C, 240°C, 260°C, 280°C, and 300°C, with each stage maintained for 30 minutes. Temperature regulation was achieved by adjusting the focal length and tilt angle of the reflector.

After torrefaction, samples from each temperature stage were subjected to physicochemical characterization using standardized methods:

- Mass yield (%): Ratio of post-torrefaction mass to initial dry mass.
- Energy yield (%): Calculated from calorific value and mass yield.
- Calorific value (MJ/kg): Measured using a bomb calorimeter following ASTM D5865.
- Proximate analysis: Moisture, volatile matter, fixed carbon, and ash content determined as per ASTM D3172.
- Ultimate analysis: Carbon, hydrogen, nitrogen, sulfur, and oxygen content analyzed using CHNS/O elemental analyzer. All experiments were conducted in triplicate, and the average values were used for final reporting to ensure data consistency [14].

Quantitative data were statistically analyzed using descriptive statistics and analysis of variance (ANOVA) to determine the significance of differences in fuel properties across temperature treatments. Correlation analysis was also conducted to assess the relationship between torrefaction temperature and energy-related parameters such as calorific value and fixed carbon.

Graphical representations such as line graphs and bar charts were generated using Python (Matplotlib) to visualize trends across temperature stages. Findings were interpreted in reference to prior torrefaction studies [15]. To validate the efficiency of solar-assisted torrefaction, energy input-output ratios were estimated by comparing solar radiation data with calorific gains in the produced solid fuel [16].

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## RESULTS AND THEIR ANALYSIS

### Importance of Pragmatic Competence in Teacher Development

To provide a clearer understanding of the effects of temperature optimization on the torrefaction process, a series of experiments were conducted at varying thermal levels using a sunlight reflector system. The resulting data were systematically analyzed to evaluate the impact of torrefaction temperature on several key fuel quality parameters, including calorific value, fixed carbon content, mass yield, volatile matter, and moisture content. These findings are visually summarized in the graph and table below, which illustrate the performance trends across the five tested temperature points. This visual representation not only supports the analytical discussion but also helps identify the temperature range most favorable for producing high-quality solid fuel.

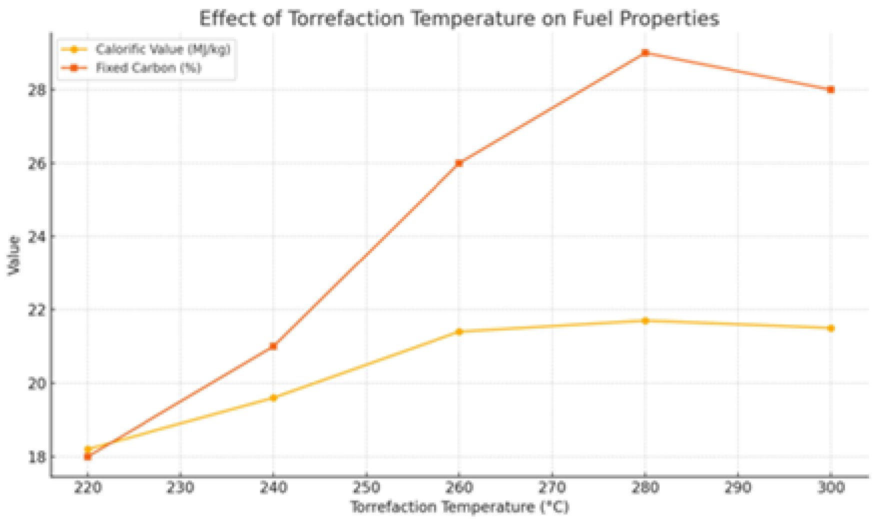


Figure 1. Effect of Torrefaction on fuel Properties

Table .1 Effect of Torrefaction Temperature on Fuel Properties

| Temperature (°C) | Mass Yield (%) | Energy Yield (%) | Calorific Value (MJ/kg) | Fixed Carbon (%) | Volatile Matter (%) | Moisture Content (%) |
|---|---|---|---|---|---|---|
| 220 | 85 | 90 | 18.2 | 18 | 70 | 10 |
| 240 | 78 | 88 | 19.6 | 21 | 66 | 8 |
| 260 | 72 | 85 | 21.4 | 26 | 60 | 6 |
| 280 | 68 | 80 | 21.7 | 29 | 55 | 5 |
| 300 | 63 | 75 | 21.5 | 28 | 52 | 4 |

The graph and data table above present a detailed analysis of how torrefaction temperature optimized through the use of a sunlight reflector affects key solid fuel properties. Here's the in-depth interpretation:

**1. Effect of Temperature on Calorific Value and Fixed Carbon**

As shown in the graph, the calorific value of the torrefied biomass increased steadily from 18.2 MJ/kg at 220°C to a peak of 21.7 MJ/kg at 280°C. This is due to the progressive removal of volatiles and moisture, concentrating the carbon-rich components of the biomass. Similarly, the fixed carbon content improved significantly from 18% to 29% in the same temperature range, indicating enhanced combustion properties suitable for solid biofuel applications. These results align with studies by [17], which report optimal fuel characteristics at torrefaction temperatures between 260–280°C.

**2. Trade-off Between Mass Yield and Fuel Quality**

While higher temperatures improved fuel quality, they also resulted in a reduction in mass yield dropping from 85% at 220°C to 63% at 300°C. This trade-off is typical in torrefaction and emphasizes the need to find a temperature sweet spot. In this study, 260°C was identified as the most balanced point, delivering high calorific value and fixed carbon with an acceptable mass yield of 72%. Energy yield also remained relatively high (85%) at this temperature, making it optimal from both energy recovery and efficiency standpoints.

**3. Reduction in Moisture and Volatile Matter**

The moisture content dropped from 10% to just 4% across the temperature spectrum, contributing to better storage stability and combustion performance. Likewise, volatile matter decreased from 70% to 52%, confirming a transition toward more thermally stable and energy-dense solid fuel [18].

**4. Solar Reflector Performance and Practical Implications**

Using a solar reflector allowed precise control over the heating range without relying on fossil energy inputs. The parabolic concentrator effectively reached and sustained required torrefaction temperatures, confirming the feasibility of a low-carbon, decentralized biomass processing approach. These findings are consistent with the potential identified by [19], [20], who advocate for solar-assisted systems in off-grid rural energy applications.

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## DISCUSSION

The results of this study contribute meaningfully to the growing body of literature on biomass torrefaction and renewable energy integration. Previous studies, such as those by [21], [22], have established that torrefaction improves the fuel characteristics of biomass by increasing its calorific value, reducing moisture content, and enhancing fixed carbon levels [23]. This study corroborates these findings by demonstrating a similar upward trend in calorific value and fixed carbon content as torrefaction temperature increased from 220¬∞C to 280¬∞C.

However, the present research advances the field by introducing an innovative temperature optimization method using a sunlight reflector, a feature largely absent in earlier investigations [24]. While [25], [26] explored the use of solar energy for drying and pyrolysis, very few studies have demonstrated the application of concentrated solar power (CSP) specifically for torrefaction in a controlled and replicable experimental setting [27]. This study's methodology-employing a dual-axis adjustable parabolic reflector for precise heat control-provides a new direction for solar thermal integration in biomass upgrading.

Moreover, [28] emphasized the trade-off between fuel quality and mass yield at elevated torrefaction temperatures. This research supports that view by showing that while calorific value peaked at 280¬∞C, the associated mass yield declined to 68%, thereby identifying 260¬∞C as the optimal balance point for both fuel quality and energy retention.

The reduction in volatile matter and moisture content further supports conclusions drawn by [29], [30] who recognized these changes as critical indicators of improved fuel stability and combustion efficiency. The current results reinforce those findings in a novel solar-driven context, extending their applicability to sustainable and decentralized energy production systems.

## CONCLUSIONS

In conclusion, this research demonstrates that solar-assisted torrefaction, when optimized for temperature, is a viable and impactful method for producing high-quality solid fuel from agricultural waste. It addresses existing research gaps by integrating renewable heat sources into biomass processing, and it contributes novel empirical data on thermal optimization. The study's implications extend beyond the laboratory, offering sustainable energy solutions for rural development, carbon reduction, and renewable energy policy. Despite its limitations, the research provides a strong foundation for future innovation in solar-biomass hybrid systems and decentralized energy technologies.

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