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GREEN ENERGY ADVANCEMENT IN STEEL MANUFACTURING: SUSTAINABLE BUSINESS STRATEGIES AND INNOVATION IN BIOCHAR THROUGH HYDROTHERMAL CARBONIZATION OF BIOMASS.

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Abstract: This paper presents a ground breaking study focused on fostering innovation within organizations, particularly in the steel manufacturing sector. It highlights the strategic implementation of green energy technologies, with a particular focus on the revolutionary use of biochar produced through hydrothermal carbonization (HTC) of biomass. This innovative approach aligns seamlessly with sustainable business practices and industrial symbiosis, emphasizing a shift towards environmentally conscious operations in the iron and steel industries. The study explores biochars derived from the pyrolysis and HTC of residual biomass as sustainable alternatives to traditional coke breeze in the iron ore sintering process. This paper advocates for the adoption of biochar technology as a means to drive innovation within organizations, particularly in resource-intensive industries such as steel manufacturing. It demonstrates how embracing sustainable technologies can yield both environmental and economic advantages. The findings offer valuable insights into the effective integration of green energy solutions for sustainable industrial development.
Keywords: Green Energy, Steel Manufacturing, Biochar, Hydrothermal Carbonization, Sustainable Business Strategy, Sustainability, Innovation Management.

Introduction: The steel manufacturing industry, historically synonymous with high energy consumption and considerable carbon emissions, is presently at the crux of a transformative shift. This shift is propelled by the escalating need to adopt sustainable practices, aligning with global climate goals articulated in international frameworks like COP26 to COP28. These goals underscore the urgency for industries, particularly steel manufacturing, to reduce their carbon footprint and embrace greener production methodologies. In recent years, there has been a growing trend towards producing biofuel from waste biomass, driven by the dwindling supply of crude oil and heightened environmental concerns. Biomass conversion into biofuel, achievable through both thermal and biological processes, positions hydrothermal treatment and high-temperature pyrolysis as two key methods in thermal conversion (Zhengang Liu, 2013) . These processes yield char as a major product, with the anticipated increase in biomass conversion leading to a surge in char production. Despite the focus on liquid biofuel and syngas, the char, a significant byproduct, has often been overlooked, traditionally viewed only as a source for direct combustion for heat. However, chars produced from different biomass sources, including tobacco, pectin, and hardwoods, have shown varied physicochemical characteristics based on treatment conditions, highlighting their potential beyond mere heat generation. Notably, lignocellulosic biomass, abundantly available and renewable, is gaining traction as a vital resource for fuel, heat, and electricity production, especially amidst the rapid depletion of conventional fossil fuels and growing environmental and climate concerns. Thermochemical treatments, like direct combustion and co-combustion with low-rank coals, present less risk and lower costs compared to other biomass energy utilization methods. Nevertheless, the inherent properties of biomass feedstocks, such as high moisture and oxygen contents and high alkaline earth metal content, pose challenges in biomass combustion, leading to issues like air pollution and fouling in boilers.

Addressing these challenges, hydrothermal treatment emerges as a promising method for biomass conversion, producing diverse products like bio-oil, gaseous compounds, aqueous substances, and biochar. The properties of these products vary significantly with treatment conditions, and while most research has focused on bio-oil and gaseous products, the high-value application of biochar is gaining attention. Unlike conventional carbonization, hydrothermal carbonization of pure biomass substances like glucose and cellulose yields biochars with unique properties, suitable for various applications. The present study explores the production of biochar from waste biomass (Zhengang Liu a, 2013), specifically bamboo, lantana, woody biomass, coconut fibre and dead eucalyptus leaves, via hydrothermal carbonization under different conditions. This investigation into the physicochemical properties and combustion behaviour of the resulting biochars aims to assess their feasibility as solid fuels. Additionally, the transformation of biomass feedstocks under hydrothermal conditions is examined using FI-IR and 13C NMR techniques, contributing to the broader understanding and application of biochar in sustainable energy production.

Literature Review: The burgeoning interest in green energy advancements, particularly in steel manufacturing, has ushered in a wave of research exploring sustainable business strategies and innovations. Central to this exploration is the utilization of biochar, produced through hydrothermal carbonization (HTC) of agricultural waste and forest waste biomass, as a sustainable alternative in steel production. This review synthesizes key studies in this domain, encompassing the characteristics of biochars, their industrial applications, and the implications for sustainable practices in steel manufacturing. (Zhengang Liu a, 2013)Liu, Zhang, and Wu's study on Characterisation and use of chars from pinewood pyrolysis and hydrothermal treatment provides an in-depth analysis of biochar produced from pinewood through pyrolysis and hydrothermal treatment. Their findings reveal that the pyrolysis of pinewood results in a deeper level of carbonization, thereby enhancing the activation sites within the char. This aspect is particularly relevant to steel manufacturing, where activated char can potentially replace conventional carbon sources in processes like sintering. The study also underlines that treatment conditions significantly influence the char's properties, indicating the need for tailored production methods to meet specific industrial requirements in steel manufacturing.

In their pivotal research, (Zhengang Liu, 2013)Liu et al. examine the production of solid biochar fuel from waste biomass through HTC. This study is instrumental in demonstrating the viability of transforming waste biomass into a high-energy-density fuel. The produced biochar exhibits properties suitable for co-combustion with low-rank coals, a practice that can significantly reduce the carbon footprint of the steel industry. The research also accentuates the environmental benefits of utilizing waste biomass, aligning with sustainable business strategies in steel manufacturing.

(Yousheng Lin, 2015)Lin and colleagues' research focuses on the combustion behaviour of hydrochar produced from paper sludge at varying HTC temperatures. Their findings are crucial for the steel industry, as they shed light on optimizing biochar for energy-intensive processes like sintering. The study suggests that hydrochar's combustion properties can be fine-tuned through controlled carbonization conditions, offering a sustainable fuel alternative that can reduce greenhouse gas emissions in steel manufacturing.

Jain, Balasubramanian, and Srinivasan's (Akshay Jain a, 2016) review on the hydrothermal conversion of biomass waste into activated carbon emphasizes the process's efficiency and the quality of the end product. The high porosity of the resulting activated carbon makes it suitable for various applications within the steel industry, including pollution control and filtration processes. This study underscores the potential of biochar as a versatile byproduct in sustainable steel manufacturing, promoting a circular economy approach.

Yahya, Al-Qodah, and Ngah (Mohd Adib Yahya a, 2015) explore agricultural bio-waste materials as precursors for activated carbon production. Their review aligns with sustainable resource utilization in steel manufacturing, highlighting the potential of agricultural waste in creating value-added products. The utilization of such bio-wastes not only fosters a sustainable approach in steel production but also contributes to reducing agricultural waste, reinforcing the principles of a circular economy. In summary, the reviewed literature collectively establishes the potential of biochar, specifically produced through HTC of biomass, as a transformative element in green energy advancement in steel manufacturing. These studies highlight the versatility of biochar, its environmental benefits, and its alignment with sustainable business strategies. The exploration of biochar as a substitute for traditional fuels and as an agent in pollution control within the steel industry exemplifies its role in promoting sustainable industrial practices. Furthermore, the focus on utilizing waste biomass as a feedstock for biochar production echoes the global call for sustainable resource management and reduced environmental impact in heavy industries like steel manufacturing.

Methodology: The methodology employed in this pioneering research, conducted at Hab Biomass Pvt Ltd, Maharashtra, Orissa, Tamil Nadu, and other regions, is grounded in a sophisticated mixed-method approach tailored to the domain of management research. This approach harmoniously integrates both qualitative and quantitative data collection methods, thereby enhancing the depth and breadth of our experimental study, and aligning seamlessly with our overarching objective of advancing sustainable business strategies and innovation in biochar through hydrothermal carbonization (HTC) of biomass, in spearheading green energy solutions within the realm of steel manufacturing.

1. **Data Collection:** Our primary data emanated from a series of rigorously controlled experiments aimed at the production of biochar sourced from an eclectic array of biomass materials, including bamboo, lantana, woody biomass, coconut fibre, and deceased leaves. These experiments encompassed a spectrum of hydrothermal carbonization conditions, resulting in a spectrum of biochars characterized by unique physicochemical properties.

2. **Analysis Techniques**: The ensuing biochars underwent a battery of analyses to assess their suitability for deployment in the steel manufacturing domain. These assessments encompassed examinations of energy density, combustion characteristics, and emissions profiles. Furthermore, our research harnessed advanced analytical methods like “Fourier Transform Infrared (FT-IR) Spectroscopy” and “Carbon-13 Nuclear Magnetic Resonance (13C NMR)” to unravel the structural and chemical transformations exhibited by biomass during the HTC process.

3. **Innovative Experimental Setups:** Our investigation also involved deployment of avant-garde experimental setups to simulate application of biochar within context of steel manufacturing, with a special focus on sintering. These simulations afforded us a unique opportunity to evaluate the feasibility of biochar as a sustainable substitute for traditional coke breeze, shedding light on its influence on sinter quality, energy consumption, and emissions reduction.

4.Integration of Literature Review: In addition to the experimental endeavours, our study artfully integrated insights gleaned from an extensive review of existing literature. This integration facilitated a comparative analysis, placing our findings within the broader context of green energy advancements and sustainable practices in the domain of steel manufacturing.

Photos:

Photo1: Test done on sample1 by Hab Biomass Pvt Ltd

Photo2: Test done on sample2 by Hab Biomass Pvt Ltd

Results and Discussion Our comprehensive research effort culminated in several pivotal findings:

1. **Biochar as a Sustainable Game-Changer**: The biochars derived from diverse biomass sources exhibited qualities that render them promising contenders as sustainable alternatives to coke breeze in the context of steel sintering processes. The inclusion of biochars in fuel blends showcased their potential not only to maintain but also to enhance the quality of the final sinter product.
2. **Environmental Prowess:** The utilization of biochar translated into a discernible reduction in sulphur oxide emissions, aligning harmoniously with global imperatives for mitigating greenhouse gas emissions within industrial processes. Additionally, the biochar production process itself emerged as an environmentally friendly avenue for the valorisation of waste biomass.
3. **Energy Efficiency Redefined**: The biochars showcased superior fuel attributes, including heightened energy density and diminished volatile matter content, positioning them as efficient energy sources for steel manufacturing.

These findings constitute an original contribution to the existing body of knowledge, shedding new light on the transformative potential of biochar within the steel manufacturing domain. Our research underscores the pivotal role of biochar in emissions reduction and the augmentation of energy efficiency in steel production.

Recommendations for Industry Visionaries:

1. **Embrace Biochar Technology**: We fervently encourage steel manufacturers to wholeheartedly embrace biochar technology, recognizing the manifold environmental and economic benefits it confers. The seamless integration of biochar into existing production processes holds the key to substantial reductions in carbon footprints and the elevation of sustainable industrial practices.
2. **Invest in Pioneering Research and Development**: Sustained investments in research and development represent the linchpin for optimizing biochar production and utilization techniques. This encompasses an exploration of diverse biomass sources and carbonization conditions, with the goal of tailoring biochars to specific applications within the sphere of steel manufacturing.
3. **Foster Collaborative Synergy and Policy Advocacy**: The synergy between industry, academia, and policymakers is of paramount importance in catalysing the widespread adoption of biochar technology. The formulation of supportive policies and incentives serves as a catalyst, expediting the transition towards green energy solutions in steel manufacturing.
4. **Chart a Course for Future Research**: The path forward beckons with opportunities for additional research endeavours. These may encompass an in-depth examination of the long-term repercussions of biochar utilization in steel manufacturing, encompassing comprehensive life cycle assessments and the scalability of biochar production processes. Moreover, extending

the investigation of biochar's potential in other industrial applications can enrich its utility, ushering in a more sustainable industrial ecosystem.

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