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Article Review: Synthesis of Bifunctional NiCe/Biochar Catalyst From Palm Shell Waste for Steam Reforming Reaction

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Abstract. The use of renewable biomass resources for hydrogen production has gained significant attention due to its environmental benefits and potential to support sustainable energy solutions. This study focuses on synthesizing a bifunctional NiCe/Biochar catalyst derived from palm kernel shell waste for steam reforming reactions. The objective is to address challenges such as tar formation during biomass gasification and improve the efficiency and stability of catalysts. The methods involved literature review and analysis of catalyst synthesis, activation, and application. Results showed that incorporating Ce into Ni/Biochar enhanced stability and hydrogen yield, achieving 86.2% carbon conversion and 64.3% maximum hydrogen production under optimal conditions. The conclusions highlight the NiCe/Biochar catalyst's potential for scalable industrial applications in hydrogen production. Future research is recommended to optimize synthesis methods and scale up production to meet increasing energy demands.

Key words: Biomass, Catalyst, Hydrogen, NiCe/Biochar, Renewable Energy.

INTRODUCTION

In recent years, efforts to reuse renewable resources such as biomass and its derivatives as liquid fuels have become a significant focus of research. Biomass offers substantial advantages due to its abundant availability and the ability to absorb CO2 through photosynthesis, allowing energy conversion via biomass gasification to achieve net-zero CO2 emissions [1]. Additionally, catalytic steam reforming has been identified as one of the most promising methods for producing high-purity hydrogen for fuel cells, which generate electricity. The steam reforming process involves a reaction between steam and vegetable oil at specific temperatures with the aid of catalysts, making it an efficient approach to producing hydrogen gas [2]. With these advantages, steam reforming holds great potential as a cornerstone for renewable energy development in the future, capable of generating clean hydrogen for various electrical and industrial applications.

The steam reforming process for producing hydrogen gas from biomass waste, such as palm oil waste, faces challenges such as tar formation. This can lead to pipeline blockages and reduced energy conversion efficiency. The use of catalysts, including biochar-based catalysts, is essential to address this issue. Catalysts aid in converting tar into syngas components, enhancing the overall gasification efficiency, and mitigating environmental impacts. Biochar, a product of the thermochemical conversion of biomass, also has potential as a catalyst or catalyst support in various chemical reactions. This is particularly beneficial environmentally, as biochar is derived from biomass waste [3].

Indonesia, as a leading producer of palm oil, has significant potential for utilizing biomass waste from the palm oil industry as a renewable energy source. Palm kernel shell waste, a byproduct of palm oil production, constitutes approximately 6.5% of total palm oil waste [4, 5]. Repurposing palm kernel shells from boiler fuel to biochar for various chemical applications offers a great opportunity to harness this waste in the future. Biochar, resulting from the thermochemical conversion of biomass, features a high surface area and abundant surface functional groups. Due to these unique properties, biochar can be employed as a catalyst or catalyst support in various chemical reactions. The use of biochar as a biomass-based catalyst not only offers environmental benefits but also provides an efficient synthesis process. Furthermore, the conversion of biomass yields bio-oil, which can be utilized for hydrogen gas production. Thus, palm kernel shell waste holds considerable promise as a renewable energy source in the future [6].

Biochar activation for catalytic purposes can be performed either physically or chemically. Physical activation involves gas flow at temperatures above 700°C, which increases the porosity and surface area of the biochar. During this process, highly reactive carbon atoms are removed. On the other hand, chemical activation can be achieved by adding oxidizing agents, including metals, alkali solutions (e.g., NaOH and KOH), or acid solutions (e.g., H3PO4). Chemical activation enhances the stability and pore volume of biochar as a catalyst [8]. Metals such as Ni, Co, Pt, Rh, and Pd have been previously used for biochar activation [7]. Among these, Co has shown the highest stability and selectivity for hydrogen gas production [8].

Previous studies have demonstrated that the addition of Ni to biochar significantly enhances catalyst activity. However, the stability of Ni/BA catalysts during the steam reforming reaction remains a concern. In this context, incorporating Ce into Ni/Biochar catalysts has been shown to improve the stability of biochar-based catalysts [9].

This study aims to synthesize a bifunctional NiCe/Biochar catalyst derived from palm kernel shell waste for the steam reforming reaction. The objective is to develop an efficient, stable, and environmentally friendly catalyst for hydrogen production from biomass.

MATERIALS AND METHODS

The method used in this review article is a literature study. A literature study is a study conducted by collecting data and information from various sources such as journals and books that begins with identifying problems to analysis and discussion related to hydrogen gas production with the help of biochar/NiCe catalysts.

RESULTS AND DISCUSSION

1. Biomass

Biomass refers to organic material derived from the metabolic residues of plants or animals, as well as by-products from industrial processes (waste). Plant biomass is produced through photosynthesis, which absorbs water and nutrients from the soil along with CO_2 from the atmosphere. It includes both products and residues that can serve as renewable energy (fuel) sources. Commonly used biomass as fuel typically has low economic value or is waste left after primary product extraction.

When biomass is converted into energy, CO_2 is released into the atmosphere. However, this process creates a shorter CO_2 cycle compared to emissions from burning fossil fuels like petroleum or natural gas. This shorter cycle ensures that the CO_2 produced does not significantly impact the atmospheric CO_2 balance, making biomass a viable option for supporting sustainable energy development [10].

2. Palm Kernel Shell

A widely available source of biomass in Southeast Asia, especially in Indonesia, is oil palm. The primary product of oil palm is palm oil, while the rest is considered waste, including empty fruit bunches (EFB), fibers, shells, fronds, and trunks [11].

Palm Kernel Shell (PKS), also known as palm shell, is the hard part of the oil palm fruit that protects the kernel. It constitutes a significant by-product of palm oil processing, accounting for approximately 60% of kernel oil production. PKS consists of 50.7% carbon (C), 6.15% hydrogen (H), 1.71% nitrogen (N), 34.7% oxygen (O), 0.19% sulfur (S), and 6.5% ash (Azis et al., 2019). Research indicates that PKS has a high calorific value of 20,093 Kcal/Kg [12].

3. Pyrolysis Method

Pyrolysis is the thermal decomposition of organic components in the absence of oxygen at temperatures ranging from 350°C to 600°C. The process produces bio-crude oil (BCO) as a condensable gas, synthetic gas (non-condensable gases such as CO_2 and H_2), and charcoal (biochar) [13].

Pyrolysis can be classified into three types based on temperature use:

- Slow pyrolysis: Low temperature (200°C–300°C)
- Semi-pyrolysis: Medium temperature (500°C)
- Fast pyrolysis: High temperature (400°C–600°C)

The yields of biochar and bio-oil vary: 35% and 50% (50% water), 25% and 50% (50% water), and 15–25% and 75% (25% water), respectively [14].

4. Biochar

Biochar is a carbon-rich pyrogenic material derived from carbon-neutral sources such as biomass [14]. It is produced via the pyrolysis of lignocellulosic biomass and contains 65% to 90% carbon [15]. Biochar is characterized by low bulk density, high stability, and strong adsorption capacity, which enhance soil fertility, improve soil carbon storage, and reduce greenhouse gas emissions in the atmosphere. Functional groups on the biochar surface also play an essential role in its catalytic activity [16].

The characteristics of biochar, determined through proximate analysis and its primary composition, reveal critical properties such as porosity, surface area, and pH level [17]. Its elemental composition includes carbon, hydrogen, sulfur, oxygen, nitrogen, and minerals in the ash content [18]. A lower O/C and H/C ratio suggests significant oxygen and hydrogen loss during pyrolysis, yielding a product with higher carbon content [19].

In a study by Promraksa and Rakmak [20], palm kernel shells were converted into biochar using semi-pyrolysis at 500°C for 1 hour under nitrogen gas flow (N_2). FTIR analysis identified functional groups such as O-H, C-H, C=H, and R-OH, with the biochar displaying a surface area of 389.02 m²/g. XRD analysis from Dewi [21] revealed diffraction intensity peaks at 2θ = 22.3°, 26.5°, and 64.4°, indicating an irregular amorphous carbon structure.

5. Biochar Activation

The porosity and surface area of biochar are critical for its application in fuel synthesis reactions. These properties can be enhanced through strategic activation methods, including physical or chemical activation.

- **Physical activation** uses steam or gas to oxidize carbon on the biochar surface, increasing pore size and removing volatile compounds. It is environmentally friendly and simple.
- **Chemical activation** involves acids (e.g., HNO_3, HCl, H_2SO_4), bases (e.g., NaOH, KOH), or oxidants (e.g., H_2O_2). This method requires lower temperature and time than physical activation. Acid treatment enhances porosity and surface area by removing contaminants, while base treatment increases alkalinity and oxygen content [22, 23]

For instance, biochar treated with KOH and calcined exhibited a surface area of 1054 m²/g [24].

6. Hydrogen Synthesis Using Biochar/Ni-Ce Catalyst

According to Wang [10], hydrogen production using a biochar/Ni-Ce catalyst demonstrated high performance in steam reforming. Operating conditions included a steam-to-carbon ratio (S/C) of 4, weight hourly space velocity (WHSV) of 3.48, and a reforming temperature of 600°C.

The Ni-Ce/AB-2 catalyst achieved 86.2% carbon conversion and 64.3% maximum hydrogen yield. Ce doping enhanced catalyst stability and efficiency. The catalyst maintained stable hydrogen concentration over 20 hours of testing, showing promising potential for renewable energy applications.

CONCLUSION

Synthesis of NiCe/Biochar bifunctional catalyst derived from palm kernel shell waste showed high efficiency and stability for hydrogen production via steam reforming. This study confirms the potential of Ni and Ce supported biochar catalyst as a renewable energy solution. Future research should focus on catalyst synthesis and production scale-up for industrial applications, to ensure sustainable and cost-effective hydrogen production to meet the increasing energy demand.

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