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UTILIZATION OF CORN COB WASTE AS AN ALTERNATIVE CATALYST IN CATALYTIC CONVERTERS FOR DIESEL ENGINE CARBON EMISSION REDUCTION

Muhamad Muhajir [1)*], Imron Musthofa [1)], Hajar Isworo[1)]
Muhammad Rezki Fitri Putra [2)], Bayu Agung Wicaksono [2)]

1) Heavy Equipment DepartmentTechnology. Politeknik Negeri Tanah Laut, Kalimantan Selatan
2) Automotive Technology Department. Politeknik Negeri Tanah Laut, Kalimantan Selatan

Correponding email [1)] : muhamadmuhajir@politala.ac.id

Abstract. Catalytic converters function to transform harmful exhaust gases into less hazardous substances through catalytic reactions, primarily oxidation and reduction. This study aims to investigate the potential of corncob waste as an alternative catalytic material in catalytic converters for reducing carbon emissions from diesel engines. The methodology involves synthesizing biochar-based catalysts derived from corncobs via pyrolysis, followed by performance evaluation within a catalytic converter system under varying engine speeds: 700 RPM, 900 RPM, and 1100 RPM. Experimental results demonstrate that catalytic efficiency does not increase monotonically with char content; instead, the 70% char formulation achieved the highest smoke opacity reduction, recording 18.90% at 700 RPM and 14.70% at 900 RPM, outperforming both the 50% and 100% variants at 1100 RPM, where exhaust temperature and flow rate increase substantially, the 100% char catalyst showed comparatively greater stability, achieving a reduction of 5.50%, while the 70% formulation declined to 2.90%. These quantitative outcomes confirm that optimal performance arises from a balanced char loading that maximizes reactive surface area while preserving gas–solid interaction efficiency. Corncob biochar thus represents a viable and sustainable alternative to metal-based catalysts. However, the variability in performance across operating conditions and the need for improved thermal durability underscore the importance of further material optimization for commercial diesel applications.

Keywords: Biochar, Catalyst, Catalytic Converter, Diesel Engine, Emissions.

1. INTRODUCTION

Escalating global concern over environmental degradation, particularly air pollution stemming from vehicular emissions, has catalyzed transformative shifts in industrial paradigms with the automotive sector at the forefront. Diesel engines, despite their operational efficiency and widespread deployment, remain significant contributors to atmospheric contamination through the release of noxious pollutants including particulate matter (PM), nitrogen oxides (NO_x), and carbon monoxide (CO). These emissions are causally linked to deteriorating urban air quality, elevated incidences of respiratory morbidity, and the exacerbation of secondary environmental phenomena such as acid precipitation and photochemical smog. In response, regulatory frameworks worldwide are progressively tightening emission thresholds, thereby intensifying the imperative for sustainable, high-efficiency emission abatement technologies [1], [2] .

Catalytic converters have long served as the principal engineering intervention for mitigating vehicular exhaust toxicity, leveraging catalytic oxidation and reduction reactions to convert hazardous compounds into benign byproducts. Conventional systems predominantly employ platinum-group metals (PGMs) notably platinum, palladium, and rhodium as catalytic agents. While highly efficacious, these materials entail substantial economic costs and pose sustainability challenges due to finite geological reserves and the ecologically deleterious

processes associated with their extraction and refinement. Consequently, the scientific community is increasingly directing efforts toward identifying economically viable and environmentally benign catalytic alternatives, with biomass-derived catalysts emerging as a compelling avenue for innovation [3], [4].

Among biomass feedstocks, agricultural residues particularly corncob have attracted considerable research interest owing to their abundant availability, high lignocellulosic content, and amenability to thermochemical conversion into functional biochar. Corncob-derived biochar exhibits favorable physicochemical attributes, including high specific surface area, hierarchical porosity, and carbon-rich composition, rendering it a promising substrate for catalytic applications. Empirical evidence indicates that such biochar can rival or even surpass conventional catalysts in specific contexts, while simultaneously advancing circular economy principles by valorizing waste streams and minimizing reliance on virgin resource extraction [5], [6], [7].

Notwithstanding these advantages, the practical deployment of biomass-derived catalysts in diesel aftertreatment systems confronts significant technical hurdles. Chief among these is the inherent heterogeneity in catalytic performance, attributable to feedstock variability and the sensitivity of pyrolysis parameters (e.g., temperature, heating rate, residence time) on biochar microstructure and active site distribution. Such inconsistencies compromise catalytic reproducibility and reliability under real-world operating conditions. Moreover, while laboratory-scale assessments often report encouraging results, biomass catalysts frequently exhibit diminished activity relative to PGMs under demanding operational regimes characterized by elevated temperatures and prolonged exposure to complex exhaust matrices [3], [8].

To address these limitations, recent research has explored multifaceted optimization strategies, including feedstock pre-treatment protocols, structural modification via heteroatom doping or surface functionalization, and hybridization with complementary catalytic materials. Metal doping, for instance, has been shown to augment catalytic activity by introducing redox-active centers, while surface engineering enhances gas-phase adsorption kinetics, thereby improving overall conversion efficiency [9]. Although these approaches have yielded measurable performance gains, scalability and long-term durability under industrial conditions remain critical research frontiers. The design and number of catalytic converters also contribute to reducing exhaust emissions [10], [11]

This study advances the field by experimentally evaluating the efficacy of corncob-derived biochar catalysts within a dynamically controlled diesel engine environment. Specifically, it investigates the influence of varying biochar loadings and engine operational parameters on the catalyst's capacity to mitigate smoke opacity and PM emissions. While prior investigations have validated the catalytic potential of corncob biochar under static or idealized conditions, a conspicuous knowledge gap persists regarding its behavior under transient, engine-representative regimes [12], [13].

The primary objective of this work is to bridge this empirical deficit by subjecting biomass-derived catalysts to realistic engine dynamics, thereby assessing their viability as drop in replacements for conventional PGM systems. The study's novelty resides in its explicit focus on dynamic performance metrics an aspect frequently neglected in bench-scale catalysis research. It is hypothesized that corncob biochar, when engineered through optimized synthesis protocols, can achieve catalytic performance commensurate with or exceeding that of noble metal benchmarks, thus offering a sustainable, cost-effective pathway for diesel emission control. The research scope encompasses catalyst synthesis, engine-integrated performance testing, and comparative analysis against standard catalytic converter configurations, contributing actionable insights toward the decarbonization and circularization of automotive aftertreatment technologies.

2. METHODS

This study encompasses material selection, catalyst synthesis, and experimental procedures specifically designed to evaluate the performance of corncob waste-based catalysts in reducing exhaust emissions from diesel engines. The research employs multiple catalyst models derived from corncob waste, processed into biochar and subsequently utilized as alternative catalytic materials in catalytic converter systems. The detailed methodology is outlined as follows:

2.1 Materials and Material Sources

The primary material used in this study is corncob waste (Zea mays), sourced from local agricultural areas in Tanah Laut Regency, near the research site. Only dried corncobs free from decay were selected to ensure optimal quality during processing. A total of 3 kg of dried corncobs was collected and used as the main feedstock for catalyst production.

2.2 Catalyst Preparation

Catalyst fabrication commenced with the carbonization of dried corncobs via pyrolysis. The pyrolysis process was conducted under controlled temperature conditions to yield biochar possessing a porous structure capable of enhancing catalytic activity. The resulting char was then ground into fine powder using a blender (Philips Model HR-2116); crushed corncobs were also finely milled to achieve uniform particle size. A total of 500 grams of char powder, obtained from carbonizing 3 kilograms of dried corncobs (yield ratio approximately 6:1), was used as the active catalytic material. For catalyst fabrication, the char powder was mixed with finely crushed corncob powder

according to the required composition ratios—50:50, 70:30, and 100:0—resulting in mass ratios of 250 g:250 g, 350 g:150 g, and 500 g:0 g, respectively. Each mixture was then blended with epoxy resin, and hardener was added at 10% of the total mixture weight. The mixture was homogenized and molded into cylindrical catalyst units. The mixture was homogenized and molded into cylindrical shapes using plastic molds (8 cm diameter, 10 cm height) with 17 perforations, producing three catalytic converter variants: (Figure 1a) converter with 50% char content, (Figure 1b) converter with 70% char content, and (Figure 1c) converter with 100% char content.

Figure 1. Catalytic converter from dry corn cobs and corn cob charcoal:
a. Charcoal 50%, b. Charcoal 70%, c. Charcoal 100%

2.3 Catalyst Housing Fabrication

The catalyst housing, commonly referred to as the "property tube," was engineered to securely contain the catalyst and ensure proper integration into the exhaust system of the test vehicle. As illustrated in Figure 2, the housing design was initially modeled using AutoCAD software and subsequently fabricated physically at the Automotive Technology Workshop of Politeknik Negeri Tanah Laut (POLITALA). This housing serves to uniformly distribute exhaust gases during testing and to guarantee optimal contact between the exhaust stream and the catalyst surface.

Figure 2. Catalyst housing

2.4 Catalytic Converter Assembly

Upon completion of the housing fabrication, the molded catalysts dried for 48 hours were prepared for installation into the exhaust system of the test vehicle. The catalyst units were mounted at the exhaust outlet of the test engine, ensuring precise alignment and mechanical stability throughout the experimental trials to prevent displacement or leakage during operation.

2.5 Experimental Procedure

The experiments were conducted using a diesel-powered test vehicle (Quick G 1000 Tractor) located at the Automotive Technology Workshop of Politeknik Negeri Tanah Laut (Politala). Three distinct corncob waste-based catalytic converter models, previously fabricated, were evaluated. Each catalyst unit was sequentially installed into the vehicle's exhaust system and tested across three engine speeds: 700 RPM, 900 RPM, and 1100 RPM. Engine speed was monitored using a photo-mode tachometer mounted on the flywheel to ensure accurate and consistent RPM readings throughout data acquisition. Each experimental run was maintained for a minimum of one minute per variable, with smoke opacity measurements repeated at least twice to guarantee data reliability and reproducibility.

2.6 Data Measurement and Analysis

Collected data included smoke opacity levels recorded at each tested RPM. Opacity measurements were performed using a smoke analyzer (Exhaust Gas Tester Model OP-201), which quantifies light extinction percentage (% opacity) of the exhaust stream. The acquired data were subsequently analyzed to compare emission reduction performance between the corncob-based catalytic converter models and a conventional catalytic converter serving as the baseline reference. Statistical evaluation was employed to determine the significance of observed differences

and to correlate catalytic efficiency with engine speed and char content variation [14].

3. RESULTS AND DISCUSSION

The results and discussion presented in this study evaluate the performance of corncob-based catalysts in reducing smoke opacity from diesel engine exhaust emissions. The investigation employed three catalyst models containing varying proportions of corncob char (50%, 70%, and 100%), which were tested across three engine speed conditions (700 RPM, 900 RPM, and 1100 RPM) to systematically assess catalytic effectiveness under dynamic operational parameters.

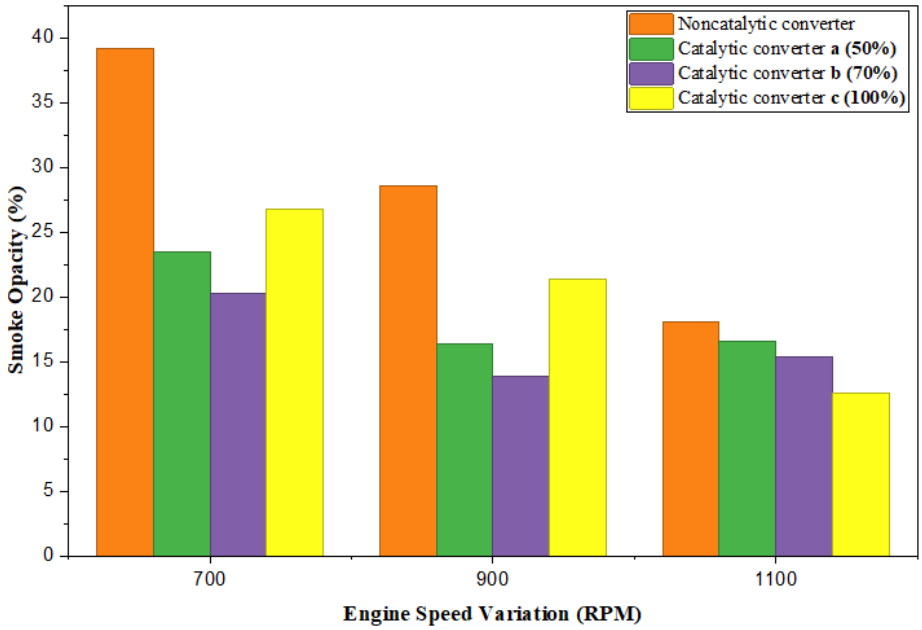

Figure 2. Reduction in smoke opacity across different catalytic converter models

Experimental results show a clear link between the proportion of corncob-derived biochar in the catalyst and smoke opacity reduction. Of the three formulations, the 70% char catalyst cut smoke opacity the most at critical engine speeds of 700 and 900 RPM. This composition achieves the best balance between active surface area and structural integrity. Catalytic performance does not increase linearly with the addition of more char; rather, the 70% formulation is optimal. It offers the most reactive sites while maintaining strong mass transfer. These findings support earlier literature that notes catalytic efficiency depends not just on the number of carbonaceous active sites but on achieving the right microstructure. This structure promotes surface-mediated redox reactions [15]. The high carbon matrix in corncob biochar enhances interactions with exhaust gases, boosting oxidation of particulate matter (PM).

The 50% char formulation resulted in modest reductions in opacity, which were still statistically significant at all engine speeds. The 70% char variant achieved the most reduction and consistently outperformed both the 50% and 100% formulations, especially at 700 and 900 RPM. This suggests that catalytic efficiency does not consistently rise with increased char; rather, the 70% composition strikes the best balance between reactive sites and structural strength. The data show that excessive char, as in the 100% formulation, may block gas–solid interaction or weaken the substrate, thereby reducing efficiency. Thus, it is essential to determine the optimal char content, rather than simply maximizing it, to control emissions while preserving the catalyst's structure and function.

3.1 Impact of Engine Speed on Catalytic Efficiency

Figure 3 demonstrates that engine rotational speed strongly influences catalytic functionality. The data show that smoke opacity reduction decreases progressively as engine speed increases. At 700 RPM, all catalyst models achieve their highest reduction performance. This suggests that the lower engine load and slower exhaust flow enhance gas–catalyst residence time and interfacial interaction, leading to more effective conversion. The 70% char catalyst achieves the greatest reduction at this speed, followed by the 50% and 100% formulations.

As engine speed rises to 900 RPM, catalyst performance drops for all types. The 70% char catalyst still achieves the best reduction, but the loss of efficiency shows that faster exhaust lowers contact time. Note that more exhaust flow increases mixing, but the graph shows that shorter contact at this speed reduces pollutant-catalyst contact [16].

At 1100 RPM, efficiency drops more noticeably. The 50% and 70% char catalysts sharply reduce opacity control, while the 100% char catalyst shows better stability and the highest reduction at this speed. This may result from the greater thermal tolerance of higher carbon content materials. Still, overall reduction remains low, suggesting that high exhaust temperatures and rapid gas flow hinder catalytic activity. These findings align with Yu et al. (2020), who observed that even with improved gas–solid contact at higher speeds, biomass-derived catalysts often face performance limits from structural and thermal constraints [16].

Furthermore, the elevated exhaust temperatures associated with higher engine speeds may trigger thermal degradation pathways, a concern also highlighted by Lott & Deutschmann (2020) [16]. Such thermal stress can compromise the long-term structural stability of biochar-based catalysts, making sustained operation at high RPM challenging. Thus, although biomass-derived catalysts perform effectively at lower engine speeds, the decline in efficiency with increasing RPM underscores the need for further optimization to ensure long-term thermal resilience and practical deployment in real-world diesel applications.

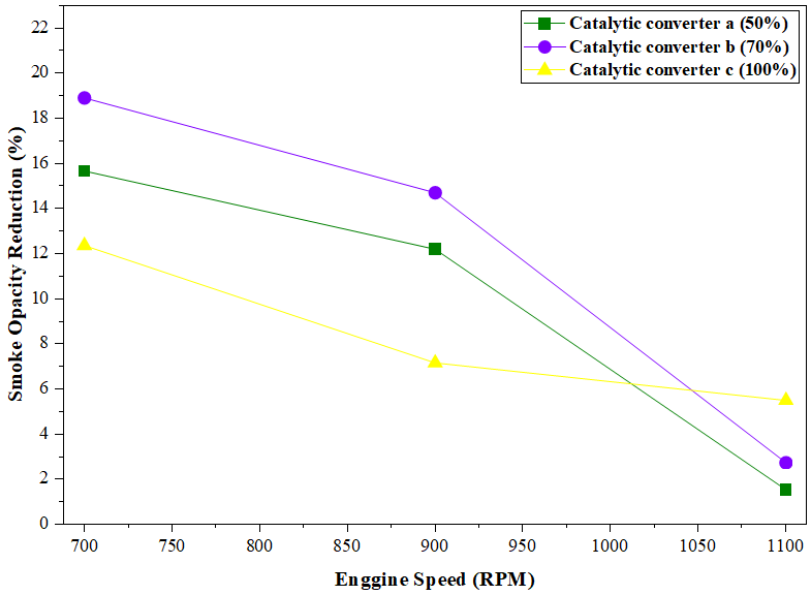

Figure 3. Impact of engine speed on catalytic efficiency

3.2 Thermal Effects on Catalytic Activity

Operating temperature is a key modulator of catalytic kinetics. As engine speed increases, exhaust gas temperature also rises, directly influencing reaction rates by providing the thermal energy required to overcome activation barriers [8]. However, excessive thermal exposure may induce catalyst deactivation, particularly in formulations with insufficient structural reinforcement, through mechanisms such as pore collapse, surface oxidation, or degradation of functional groups.

In this study, the 70% char catalyst demonstrated the most favorable balance between catalytic activity and thermal tolerance, maintaining higher efficiency than both the 50% and 100% formulations across the entire temperature range tested. Although carbon-rich structures can exhibit enhanced thermal stability as noted by Yu et al. (2021), the 100% char catalyst did not outperform the optimized 70% formulation, likely due to reduced structural cohesion or less effective gas–solid interaction at elevated temperatures [17]. While higher temperatures at increased engine speeds can promote more vigorous pollutant–catalyst interactions [18]. Performance declines beyond certain thresholds indicate the onset of thermal stress. Therefore, operational temperature must be carefully optimized within the engine's performance envelope to sustain catalytic efficiency and ensure long-term material durability in real-world applications[19].

3.3 Long-Term Stability and Structural Durability

The viability of corncob derived catalysts in commercial diesel systems hinges critically on their ability to maintain structural and chemical integrity under prolonged, dynamic operating conditions including thermal cycling, oxidative stress, and moisture exposure. Experimental assessments revealed that the 100% char catalyst retained its performance significantly better than lower loading variants following repeated thermal and hygrothermal stress cycles. In contrast, the 50% and 70% formulations exhibited accelerated performance decay, indicating diminished resistance to environmental degradation.

These findings echo Yu et al. (2020), who identified thermal and oxidative instability as key limitations of biomass-based catalysts [20]. Enhancing char content not only amplifies initial catalytic activity but also fortifies long-term durability by improving structural coherence and resistance to active site depletion. To further augment resilience, future formulations may incorporate stabilizing agents such as inorganic binders or metal oxide

promoters or leverage advanced synthesis techniques including controlled activation, heteroatom doping, or hybridization with thermally stable ceramic supports [21]. Such innovations are essential to translate laboratory-scale efficacy into industrially viable, durable emission control solutions.

3.4 Comparative Analysis with Noble Metal Catalysts

When benchmarked against conventional platinum or palladium-based catalysts, corncob-derived systems exhibit competitive though not yet equivalent performance in smoke opacity reduction. Noble metal catalysts remain unmatched in terms of intrinsic activity and reaction selectivity, particularly for complex oxidationreduction pathways [22]. However, their prohibitive cost and geologically constrained supply render them unsustainable for global, long-term deployment [20]. Biomass derived alternatives offer a compelling substitute by leveraging renewable agricultural residues, thereby reducing dependency on critical raw materials and advancing circular economy objectives [7]

Although the corncob catalysts achieved comparable opacity reductions under specific operational windows, inconsistencies in performance across variable loads and evidence of progressive deactivation highlight the need for further material optimization. Strategic enhancements such as metal oxide doping, catalytic pyrolysis, or chemical activation protocols may bridge the efficiency gap while improving thermal and mechanical robustness [23]. These advancements are imperative to enable scalable, reliable integration of biomass-derived catalysts into commercial aftertreatment systems.

4. CONCLUSION

This study demonstrates that corncob-based catalysts can effectively reduce smoke opacity in diesel engine exhaust, with performance governed by both char composition and engine operating conditions. Quantitative results confirm that the 70% char formulation provides the highest reduction, achieving 18.90% at 700 RPM and 14.70% at 900 RPM, reflecting an optimal balance between reactive surface area and structural cohesion. At elevated speeds, the 100% char catalyst exhibits comparatively better thermal stability, recording 5.50% reduction at 1100 RPM, although its overall performance remains below that of the optimized 70% formulation. These trends highlight the dependence of catalytic efficiency on gas–solid residence time and thermal loading, both of which diminish as engine speed increases. Despite the promising performance of biochar-based catalysts, challenges remain regarding consistency and long-term durability under high-temperature exhaust environments. Future studies should focus on enhancing catalyst robustness through improved activation techniques, thermally stable binders, and metal oxide promoters. Extended engine endurance testing and validation across diverse diesel platforms are also recommended to support practical implementation and advance industrial adoption.

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