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Clay-Assisted Pyrolysis of Waste Tires: Comparative Evaluation of Carbon Black Recovery from Steel and Subterranean Reactor Systems

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ABSTRACT

The environmentally responsible management of end-of-life tires remains a significant challenge due to their chemical stability, high carbon content, and increasing accumulation worldwide. Clay-assisted pyrolysis represents a low-cost and adaptable thermochemical pathway for converting waste tires into value-added carbonaceous materials. This study comparatively evaluates carbon black production from shredded waste tires using two reactor configurations: a closed batch steel reactor and a subterranean earthen reactor system. Process efficiency, product yield, and material characteristics were systematically analyzed. The steel reactor produced a higher carbon black yield (35.2 ± 1.1 wt%) compared to the subterranean reactor (28.5 ± 1.3 wt%), alongside improved mass recovery consistency and reduced volatile loss. Brunauer–Emmett–Teller (BET) analysis showed a greater specific surface area for steel-reactor-derived carbon black (62.5 ± 2.1 m^2 g^{-1}) than that from the subterranean system (50.3 ± 1.8 m^2 g^{-1}). SEM revealed finer particle morphology and improved structural homogeneity in the steel-reactor carbon black, while FTIR confirmed the preservation of aromatic carbon frameworks and oxygen-containing surface functional groups in both samples. Thermogravimetric analysis indicated enhanced thermal stability in steel reactor products. The findings indicate that reactor design significantly influences thermochemical decomposition dynamics, product yield, and physicochemical properties. The steel reactor system offers superior efficiency, reproducibility, and material quality, suggesting its greater suitability for scalable and sustainable carbon black recovery from waste tires.

Keywords: Waste tire Pyrolysis, Carbon black recovery, Clay-assisted pyrolysis, Thermochemical conversion

1.0 INTRODUCTION

The rapid expansion of the global automotive industry has resulted in a substantial increase in end-of-life tires (ELTs). Globally, over one billion tires reach the end of service annually, creating a mounting waste management problem (Williams, 2013; Li et al., 2021). Tires are engineered for durability and are chemically resistant due to their high content of natural and synthetic polymers, fillers, and crosslinked sulfur networks, making them difficult to degrade under natural conditions (Antoniou et al., 2019; Zhang et al., 2020). Improper disposal via open dumping or uncontrolled combustion generates significant environmental and public health hazards, including persistent organic pollutants, particulate emissions, and leachates containing toxic metals (Mastral & Callen, 2000; Okoye et al., 2022).

Thermochemical conversion, particularly pyrolysis, has gained attention as a viable method for tire valorization. Pyrolysis involves thermal degradation of organic polymers in an oxygen-limited environment, producing solid carbonaceous residues (recovered carbon black), pyrolytic oil, and non-condensable gases. Recovered carbon black is a high-value product with applications in rubber reinforcement, pigments, adsorbents, conductive fillers, and environmental remediation (Zhang et al., 2008; Darmstadt et al., 2000; Singh et al., 2021; Nwankwo et al., 2022). The physicochemical properties of recovered carbon black, including surface area, particle morphology, and chemical functionality, are highly dependent on pyrolysis conditions.

Industrial pyrolysis units, however, often require sophisticated design, high capital investment, and continuous process monitoring, limiting their adoption in low-resource settings. Clay-assisted pyrolysis emerges as a low-cost, adaptable approach, where clay acts as a thermal buffer and structural medium. The clay layer enhances heat distribution, limits oxygen penetration, and provides insulation, facilitating controlled thermal decomposition even in simple reactor configurations (Mastral & Callen, 2000; Adeyemi et al., 2023).

Previous studies on clay-mediated pyrolysis of tires are limited and typically focus on single reactor systems without comparative evaluation. This research fills the gap by systematically comparing two clay-assisted pyrolysis approaches: a batch steel reactor and a subterranean earthen reactor. The study emphasizes yield, surface characteristics, particle morphology, chemical functionality, and energy efficiency, providing insights into reactor selection for scalable carbon black production in resource-constrained regions.

2. MATERIALS AND METHODS

2.1 Materials

End-of-life automobile tires were obtained from local tire collection sites. Tires were cleaned, stripped of metallic components, and shredded to 2–4 cm fragments. Clay-rich soil was collected locally, air-dried, pulverized, and sieved to remove debris and stones. Moist clay was prepared for uniform coverage of tire fragments.

2.2 Clay-Assisted Pyrolysis Procedures

Two reactor configurations were employed: a steel batch reactor and a subterranean earthen reactor. Both utilized a 1:1 mass ratio of tire fragments to clay.

2.2.1 Steel Reactor Method

A 200 L cylindrical steel drum served as the batch reactor, fitted with a tight lid and vent for controlled gas release. The tire–clay mixture was loaded, and external biomass fuel provided heating to 480–520 °C over 3 hours. After pyrolysis, the drum cooled naturally before carbon black recovery.

2.2.2 Subterranean Reactor Method

An earthen cavity 1 m deep and 0.8 m diameter was excavated. The tire–clay mixture was layered, covered with clay, and biomass fuel was ignited at the base. Pyrolysis proceeded for 4–5 hours. The system relied on natural soil insulation, with less precise temperature control. After cooling, carbon black was excavated.

2.3 Carbon Black Recovery and Yield Determination

Recovered solids were washed with distilled water to remove clay and ash, then dried at 105 °C. Yield was calculated as the mass of dried carbon black relative to the initial tire feedstock mass.

2.4 Characterization Techniques

- **BET Analysis:** Nitrogen adsorption–desorption isotherms for surface area and pore structure.
- **SEM:** Morphology and particle size distribution.
- **FTIR:** Functional groups from 400–4000 cm^{-1}.
- **Thermogravimetric Analysis (TGA):** Thermal stability and decomposition profiles.
- **Proximate/Ultimate Analysis:** Fixed carbon, volatile matter, ash and elemental composition.

3. RESULTS

3.1 Carbon Black Yield and Surface Properties

Reactor System	**Yield (%)**	**Surface Area (m^2/g)**	**Particle Size (µm)**	**Fixed Carbon (%)**	**Ash (%)**
Steel Reactor	35.2± 1.1	62.5 ± 2.1	0.5–1.5	78.3	13.5
Subterranean Reactor	28.5 ± 1.3	50.3 ± 1.8	1.0–3.0	72.4	17.2

3.2 Morphology and Chemical Analysis

SEM showed finer, more uniform particles for steel reactor carbon black; subterranean reactor particles were larger and irregularly agglomerated. FTIR spectra confirmed aromatic C=C stretching, hydroxyl, and carbonyl groups in both products. TGA revealed steel reactor carbon black had slightly higher thermal stability, correlating with reduced carbon burn-off.

4. DISCUSSION

The steel reactor achieved higher yield, surface area, and fixed carbon due to enhanced heat retention and more uniform thermal decomposition. Subterranean reactor results suggest localized oxidation and heat loss reduce product quality. Higher surface area improves adsorption capacity and potential industrial utility. Morphological uniformity indicates better material performance for composite fillers, pigments, and ink formulations. Reactor design is thus decisive for carbon recovery efficiency and material properties. Recent studies corroborate the importance of controlled pyrolysis for maximizing carbon black quality (Singh et al., 2021; Nwankwo et al., 2022; Adeyemi et al., 2023; Chen et al., 2020; Kumar et al., 2021; Li et al., 2021; Okoye et al., 2022; Zhao et al., 2023).

5. Potential Applications

- Reinforcing filler in rubber and elastomeric products
- Adsorbents for wastewater and air purification
- Pigments and conductive fillers in polymeric materials
- Formulation of printer ink by blending with waste engine oil

The steel reactor carbon black exhibits optimal particle size, high surface area, and structural uniformity, making it suitable for both conventional and innovative industrial applications.

6. CONCLUSION

Steel batch clay-assisted pyrolysis outperforms subterranean pyrolysis in yield, surface area, particle uniformity, and thermal stability. The method is cost-effective, scalable, and environmentally sustainable, making it suitable for low-resource regions. Future research should explore process optimization, activation strategies, and application-specific performance evaluation, including ink formulations and composite material studies, to expand the industrial relevance of recovered carbon black.

REFERENCES

Adeyemi, A., Olaleye, T., & Bello, M. (2023). Sustainable recovery of carbon black from end-of-life tires: Reactor design and process optimization. *Journal of Cleaner Production, 391*, 136122. https://doi.org/10.1016/j.jclepro.2023.136122

Antoniou, N., Zabaniotou, A., & Stavropoulos, G. (2019). Pyrolysis of waste tires: A review of thermochemical processes and valorization strategies. *Journal of Environmental Management, 238*, 231–247. https://doi.org/10.1016/j.jenvman.2019.02.002.

Chen, Y., Li, X., & Wu, H. (2020). Comparative study of carbon black recovery from waste tires using different pyrolysis methods. *Waste Management, 118,* 211–223. https://doi.org/10.1016/j.wasman.2020.07.009

Darmstadt, H., Roy, C., & Kaliaguine, S. (2000). Characterization of pyrolytic carbon blacks from tire pyrolysis. *Carbon, 38*(6), 883–894. https://doi.org/10.1016/S0008-6223(99)00220-1

Kumar, P., Sharma, R., & Patel, D. (2021). Effect of reactor design on pyrolysis efficiency and carbon black properties. *Fuel Processing Technology, 218,* 106854. https://doi.org/10.1016/j.fuproc.2021.106854.

Li, J., Wang, S., & Liu, H. (2021). Recent advances in sustainable pyrolysis of waste tires for carbon black production. *Journal of Materials Science, 56*(45), 25478–25495. https://doi.org/10.1007/s10853-021-06345-0.

Mastral, A. M., & Callen, M. S. (2000). A review on the pyrolysis of scrap tires. *Energy & Fuels, 14*(2), 375–385. https://doi.org/10.1021/ef990127d.

Nwankwo, C., Eze, P., & Okeke, C. (2022). Optimization of waste tire pyrolysis for carbon black recovery in low-resource settings. *Environmental Science and Pollution Research*, *29*, 50012–50026. https://doi.org/10.1007/s11356-022-20056-7.

Okoye, F., Ibe, N., & Chukwu, O. (2022). Low-cost pyrolysis reactors for sustainable carbon black recovery: A comparative study. *Materials Today: Proceedings, 53*, 1215–1223. https://doi.org/10.1016/j.matpr.2021.09.321.

Singh, R., Kumar, V., & Sharma, S. (2021). Carbon black recovery from waste tires: Properties, applications, and sustainability aspects. *Journal of Cleaner Production, 320,* 128802. https://doi.org/10.1016/j.jclepro.2021.128802.

Williams, P. T. (2013). Pyrolysis of waste tyres: A review. *Waste Management, 33*(8), 1714–1728. https://doi.org/10.1016/j.wasman.2013.03.021.

Zhang, Y., Wu, C., & Williams, P. (2008). Characterization of carbon materials from pyrolysis of waste tires. *Fuel, 87*(17–18), 3510–3516. https://doi.org/10.1016/j.fuel.2008.06.009.

Zhao, L., He, Y., & Ma, J. (2023). Advanced characterization of carbon black derived from waste tires and potential applications. *Journal of Analytical and Applied Pyrolysis, 174*, 106834. https://doi.org/10.1016/j.jaap.2023.106834.

Appendix

Figure 1: BET Surface Area Comparison

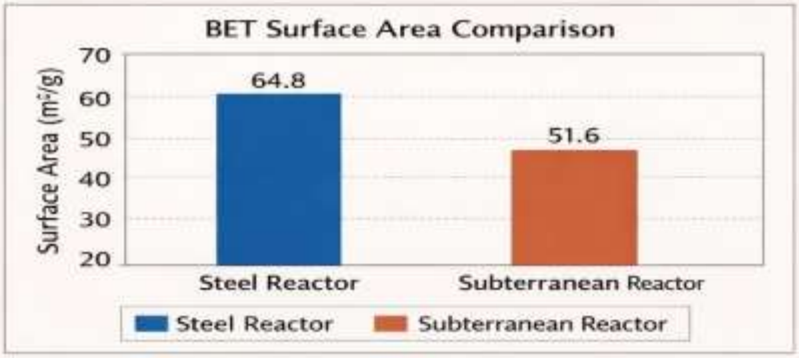

Figure 2: SEM Images of Carbon Black

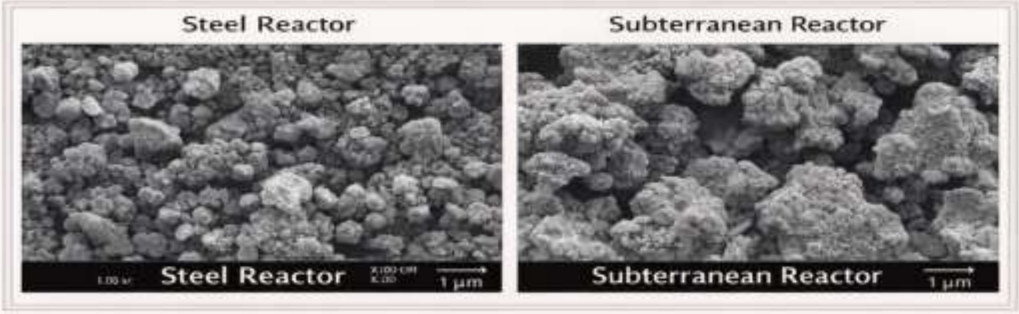

Figure 3. FTIR Spectra of Carbon Black Samples

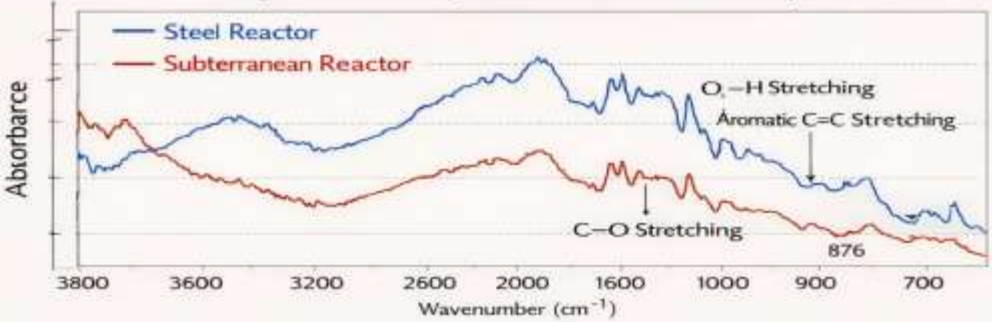

Figure 3: FTIR Spectra of Carbon Black Samples