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Mini Review

The Pyrolysis of Plastics in Kitchen Waste

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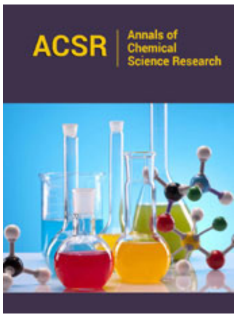

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Abstract

Kitchen waste (KW) and plastic waste pose significant environmental challenges due to their increasing generation and non-biodegradability. Pyrolysis, a thermochemical process conducted in an inert atmosphere, offers a sustainable solution by converting these wastes into valuable products like bio-oil, syngas, and char. This mini review comprehensively analyzes the pyrolysis of plastics in KW, covering fundamental principles, characteristics, kinetic mechanisms, synergistic effects, catalytic applications, and product distributions. Key findings indicate that co-pyrolysis of KW with plastics (e.g., polyethylene, polypropylene) enhances efficiency through synergistic interactions, reducing activation energies by 15-40kJ/mol and increasing bio-oil yields up to 66%. Catalysts such as zeolites and natural materials (e.g., seashells) further improve product selectivity by promoting deoxygenation and cracking. Challenges include waste heterogeneity and economic viability, but advancements in microwave-assisted pyrolysis and integrated systems show promise for scalability. This review highlights the potential of pyrolysis to contribute to circular economy goals by transforming waste into renewable energy sources. Future research should focus on process optimization and life-cycle assessments.

Keywords: Pyrolysis; Kitchen waste; Plastics; Co-pyrolysis; Kinetics; Catalysis; Synergistic effects; Bio-oil

Abbreviations: KW: Kitchen Waste; PE: Polyethylene; PP: Polypropylene; PS: Polystyrene; TGA: Thermogravimetric Analysis; Ea: Activation Energy; MSW: Municipal Solid Waste; ABS: Acrylonitrile Butadiene Styrene

Introduction

Kitchen waste (KW) constitutes a major portion of municipal solid waste (MSW), with global generation exceeding 1.3 billion tons annually, of which 40–60% is organic matter including food residues and packaging plastics [1,2]. The persistence of non-biodegradable plastics like polyethylene (PE), polypropylene (PP) and polystyrene (PS) exacerbates environmental issues such as landfill overflow and greenhouse gas emissions [3,4]. Pyrolysis, a thermal decomposition process at 300-900 °C in oxygen-free conditions, has emerged as a promising technology for converting KW and plastics into value-added products (e.g., bio-oil, syngas), thereby promoting waste-to-energy recovery and circular economy principles [5,6]. This review aims to synthesize recent advances in pyrolysis of plastics in KW, focusing on process characteristics, kinetic insights, synergistic effects and catalytic applications to guide future research and implementation.

Pyrolysis characteristics of kitchen waste and plastics

Pyrolysis involves stages such as drying (100-200 °C), active decomposition (200-500 °C) and char formation (>500 °C). KW components (e.g., starch, proteins) decompose at lower temperatures, yielding oxygenated compounds like aldehydes and ketones, while plastics (e.g., PP, PS) require higher temperatures (300-600 °C) and produce hydrocarbons due to their polymer structure [2,7]. Thermogravimetric analysis (TGA) shows that KW has high moisture (up to 53.3%) and ash content, leading to mass losses of 60-85%, whereas plastics exhibit near-complete volatilization with minimal residue [1,8]. Co-pyrolysis of KW and plastics alters decomposition profiles; for instance, blending KW with PP shifts onset temperatures lower and enhances volatile release through hydrogen transfer, increasing bio-oil yields by up to 20% [5,7].

Kinetic mechanisms and synergistic effects

Kinetic analysis using model-free methods (e.g., Kissinger-Akahira-Sunose, Flynn-Wall-Ozawa) reveals activation energies (Ea) of 25-271kJ/mol, with plastics showing higher Ea due to stable carbon-carbon bonds [9-12]. Co-pyrolysis reduces Ea by 15-40kJ/mol through synergistic effects, where hydrogen radicals from plastics deoxygenate KW-derived intermediates, improving hydrocarbon production [13]. Studies on KW-PP mixtures demonstrate increased aliphatic hydrocarbons (up to 44.6%) and reduced carboxylic acids, with synergy peaking at 300-500 °C [2,7]. Microwave-assisted pyrolysis further enhances kinetics by providing uniform heating; for example, Fe/SiC catalysts lower Ea for ABS plastic from 140.5kJ/mol to 63.7kJ/mol [10].

Catalytic pyrolysis and product enhancement

Catalysts like zeolites (ZSM-5) and natural materials (seashells, cuttlebone) improve pyrolysis efficiency by promoting cracking and deoxygenation. ZSM-5 increases aromatic hydrocarbons in bio-oil by up to 40%, while $CaCO_3$-based catalysts reduce Ea by 28.5% for KW-plastic blends [14]. Product analysis shows that KW-derived bio-oil has a lower heating value (LHV) of 14-18MJ/kg due to oxygen content, whereas plastic-derived oil achieves LHV of 30-42MJ/kg, resembling diesel [15]. Co-pyrolysis optimizes product quality by balancing hydrogen and oxygen, with potential applications in fuel production and chemical synthesis [16,17].

Conclusion

Pyrolysis of plastics in kitchen waste effectively addresses waste management challenges while producing renewable energy sources. Key advancements include synergistic co-pyrolysis reducing activation energies, catalytic methods enhancing product selectivity, and microwave technology improving efficiency. However, challenges such as waste heterogeneity and economic scalability remain. Future work should focus on integrated processes, advanced catalysts and life-cycle assessments to enable commercial adoption. Pyrolysis represents a critical step toward achieving sustainability goals through circular economy practices.

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Credit Authorship Contribution Statement

Bin Kuang: Writing-Original draft preparation, Methodology; Yang Cai: Formal analysis oversight, Validation oversight; Dahai Zheng: Supervision, Funding acquisition, Conceptualization, Writing-Review & Editing, Supervision, Project administration.

Conflict of Interest

The authors declare no competing financial interest.

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