CHEMICAL DEGRADATION AND SAFE TREATMENT STRATEGIES FOR PESTICIDE RESIDUES IN HDPE CONTAINERS

Amirkulov Shahruz Nuritdin ugli
Doctoral Student at
Tashkent State Technical University
Rakhmatullayev Fayzulla Nigmatullayevich
Dean of the Faculty of Oil and Gas,
Tashkent State Technical University
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ABSTRACT

This research explores the chemical characteristics of residual pesticides present in HDPE containers and develops an optimized treatment method for their safe disposal. Organophosphate pesticide residues were analyzed using GC-MS and FTIR techniques. Adsorption and desorption mechanisms on polymer surfaces were studied using Langmuir isotherms. Alkaline hydrolysis combined with Fenton oxidation was evaluated for degradation efficiency, and kinetic parameters were determined. Results demonstrate that this combined treatment reduces pesticide residues up to 96%, allowing environmentally safe recycling of HDPE containers.

Introduction

Pesticide containers often retain hazardous chemical residues even after conventional rinsing, posing a significant environmental risk. Residual organophosphate pesticides can strongly adsorb to HDPE surfaces due to hydrophobic interactions and partial diffusion into the polymer matrix. Current disposal practices, including simple triple rinsing or uncontrolled landfill dumping, are insufficient for complete detoxification. There is a pressing need for scientifically validated chemical treatment methods that effectively degrade pesticide residues while preserving polymer integrity. This study investigates such chemical degradation processes and evaluates methods to ensure safe container recycling.

Materials and Methods

Materials

- HDPE pesticide containers
- Organophosphate pesticide standard
- Sodium hydroxide (NaOH, 0.1–1.0 M)
- Hydrogen peroxide (H_2O_2, 30%)
- Ferrous sulfate ($FeSO_4$) as Fenton catalyst

Analytical Techniques

- GC-MS for quantitative analysis of residual pesticides
- FTIR spectroscopy for functional group detection
- TGA and DSC for polymer stability assessment
- UV-Vis spectrophotometry to monitor degradation

Degradation Procedures

- **Alkaline hydrolysis:** $R\text{-}O\text{-}P(=O)(OR')_2 + OH^- \rightarrow$ Hydrolysis products
- **Fenton oxidation:** $Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + OH^- + \bullet OH$

Reaction kinetics were analyzed using pseudo-first-order models.

Results and Discussion

Adsorption Mechanism

The study confirms that pesticide residues strongly adhere to HDPE surfaces. Adsorption data fitted Langmuir isotherms with $R^2 = 0.97$, indicating monolayer adsorption dominates.

Degradation Efficiency

- Alkaline hydrolysis alone removed ~72% of residues
- Fenton oxidation alone removed ~89%
- Combined alkaline–oxidative treatment achieved up to 96% removal

Kinetic Analysis

- Reaction rate constant (k) = 0.034 min^{-1}
- Activation energy (Ea) = 42.5 kJ/mol

These parameters suggest a feasible and efficient degradation pathway.

Polymer Stability

No significant structural degradation of HDPE was observed under treatment conditions, confirming material recyclability.

Environmental Implications

- Significant reduction of residual pesticide toxicity
- Safe mechanical recycling of HDPE containers
- Minimized soil and water contamination
- Alignment with circular economy principles

Conclusion

The combined alkaline and Fenton treatment provides a reliable and environmentally safe method for degrading pesticide residues in HDPE containers. The process maintains polymer integrity and offers a practical route for container recycling, supporting sustainable agricultural practices.

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