STM JOURNALS

Journal of
Thin Films, Coating Science Technology and Application

ISSN: 2455-3344
Volume 11, Issue 2, 2024
May–August
DOI (Journal): 10.37591/JoTCSTA

https://journals.stmjournals.com/jotcsta

Review JoTCSTA

Chemical Methods for Mitigating Plastic Pollution from the Environment

Hem Suman Jamwal[1,*], Sapana Kumari[1], Samjeet Singh Thakur[1]

Abstract

Plastic pollution is a critical environmental concern that affects both terrestrial and marine ecosystems worldwide. Traditional recycling methods have been inadequate in tackling the escalating plastic waste problem, leading to an exploration of chemical recycling techniques as innovative solutions. Chemical recycling involves breaking down polymers into their monomers or converting them into valuable products, offering potential for more sustainable waste management. This review examines key chemical recycling methods, including pyrolysis, hydrothermal liquefaction, catalytic depolymerization, glycolysis, methanolysis, enzymatic breakdown, and supercritical fluids. Pyrolysis and hydrothermal liquefaction involve thermal processes that convert plastics into fuels or chemical feedstocks, while catalytic depolymerization uses catalysts to lower the energy required for breaking down polymers. Glycolysis and methanolysis are chemical processes that revert plastics back to their monomers, facilitating the creation of new products. Enzymatic breakdown utilizes biological catalysts to degrade plastics in an environmentally friendly manner. Supercritical fluids offer a unique approach by using fluids at critical temperatures and pressures to dissolve and decompose polymers. Each method presents its own set of advantages, challenges, and environmental benefits, from reducing reliance on fossil fuels to minimizing waste in landfills. However, challenges such as high costs, energy requirements, and scalability remain to be addressed.

Keywords: Plastic pollution, glycolysis, methanolysis, enzymatic breakdown, and supercritical fluids

INTRODUCTION

Millions of tons of plastic garbage are building up in landfills and natural ecosystems as a result of the extensive use of plastic materials, which has significantly contaminated the environment. The kinds of plastics that can be recycled using traditional mechanical methods are restricted, as are the levels of contamination. Chemical recycling offers a promising alternative by breaking down plastic polymers into monomers or converting them into fuels and valuable chemicals, providing a way to tackle the growing plastic waste problem. This paper explores various chemical methods for mitigating plastic pollution and evaluates their potential for large-scale application.

***Author for Correspondence**
Hem Suman Jamwal
E-mail: jamwalhemsuman83@gmail.com

[1]Assistant Professor, Department of Chemistry, NSCBM Govt. College Hamirpur, India

Received Date: August 13, 2024
Accepted Date: August 30, 2024
Published Date: September 26, 2024

Citation: Hem Suman Jamwal, Sapana Kumari, Samjeet Singh Thakur. Chemical Methods for Mitigating Plastic Pollution from the Environment. Journal of Thin Films, Coating Science Technology and Application. 2024; 11(2): 1–4p.

Chemical Methods for Plastic Degradation

The detail of various methods used for the decomposition of the plastics, i.e., process, advantages, challenges and environmental impacts is discussed here.

Pyrolysis

Pyrolysis is the process of thermally dissolving waste plastic in an oxygen-free environment to produce smaller hydrocarbon molecules from long-chain polymers.

Plastic waste is collected, sorted, and sometimes shredded to reduce particle size and improve process efficiency. The plastic feedstock is heated to temperatures between 300°C and 900°C in a pyrolysis reactor without oxygen to prevent combustion [1]. The heat breaks down the polymer chains into smaller molecules, producing a mixture of gases, oils, and solid residues (char). The resulting products are separated and collected. Gases can be condensed to form pyrolysis oil, which can be further refined, while the char can be used as a carbon source. Pyrolysis can handle mixed and contaminated plastic waste, offering flexibility in the types of plastics processed. It also has the potential for energy recovery, converting plastic waste into valuable hydrocarbons that can be used as fuels. However, the process requires high temperatures, which can lead to significant energy consumption [2]. Furthermore, cautious management is required to prevent the development of toxic byproducts such furans and dioxins.

Pyrolysis reduces the volume of plastic waste, converting it into usable hydrocarbons that can replace fossil fuels, thus reducing environmental pollution and dependency on non-renewable resources.

Hydrothermal Liquefaction

Hydrothermal liquefaction (HTL) uses high-temperature and high-pressure water to convert plastic waste into oil, mimicking natural geological processes. In this method, plastic waste is collected and may be pre-treated to remove contaminants and reduce particle size. The plastic feedstock is mixed with water and subjected to temperatures between 250°C and 374°C and pressures up to 220 bar in a hydrothermal reactor [3].

Under these conditions, water acts as a solvent and reactant, breaking down the plastic polymers into smaller molecules and converting them into a high-energy-density oil. The resulting oil is separated from the aqueous phase and can be further refined into fuels or chemicals [4].

This method has the advantage that it can handle wet waste streams, reducing the need for pre-drying, and produces a versatile oil product. There is a chance that the procedure will work with the current waste management system. However, the need for robust reactors to withstand harsh conditions and the development of efficient catalysts to enhance conversion rates remain significant challenges. The process also requires optimization to improve yield and economic feasibility.

By transforming plastic trash into useful oil products, HTL lessens the negative effects of plastic pollution on the environment and may even help reduce the need for fossil fuels.

Catalytic Depolymerization

Catalysts are used in catalytic depolymerization, which breaks down polymeric polymers into monomers or other useful compounds. Plastic waste is collected, sorted, and sometimes pre-treated to remove contaminants. The plastic feedstock is exposed to a catalyst in a reactor, where it is heated to temperatures typically between 200°C and 400°C.The catalyst facilitates the breaking of polymer chains into monomers or other chemical intermediates through selective chemical reactions[5].The resulting monomers or chemicals are separated from the catalyst and purified for reuse in manufacturing. The process can achieve high efficiency and selectivity, producing high-purity monomers that can be reused to manufacture new plastics. Catalytic depolymerization can be tailored to different types of plastics, enhancing its versatility [6].

Developing and optimising suitable catalysts is a significant challenge in Catalytic depolymerization. The process also requires precise control of reaction conditions to achieve high efficiency and minimise byproducts.

The manufacturing of high-purity monomers lowers the need for the production of virgin plastic and plastic waste, which in turn lowers environmental pollution and promotes closed-loop recycling.

Journal of Thin Films, Coating Science Technology and Application
Volume 11, Issue 2
ISSN: 2455-3344

Glycolysis

Glycolysis involves breaking down polyester plastics, such as PET, into their constituent monomers using glycol. PET waste is collected, sorted, and cleaned to remove contaminants. The PET feedstock is mixed with a glycol, such as ethylene glycol, and heated to temperatures around 200°C in the presence of a catalyst. The glycol reacts with the PET, breaking the ester bonds and converting the polymer into its monomers, such as bis(hydroxyethyl) terephthalate [7].

The resulting monomers are separated and purified for reuse in manufacturing new PET products. Glycolysis produces high-purity monomers that can be directly reused in plastic manufacturing. The method is particularly effective for recycling PET, which is widely used in packaging and textiles [8]. To maximize efficiency and reduce byproducts, the reaction conditions must be carefully controlled throughout the process. Efficient separation and purification of the resulting monomers are also necessary to ensure the quality of recycled plastics.

Glycolysis reduces plastic waste by converting it into reusable monomers, facilitating the recycling of PET and other polyester plastics, thereby reducing environmental pollution and conserving resources.

Methanolysis

Methanolysis uses methanol to break down polyesters into their monomers, such as dimethyl terephthalate and ethylene glycol. Polyester waste is collected, sorted, and cleaned to remove contaminants. The polyester feedstock is mixed with methanol and heated to temperatures between 150°C and 250°C in the presence of a catalyst. The methanol reacts with the polyester, breaking the ester bonds and converting the polymer into its monomers [7]. The resulting monomers are separated and purified for reuse in manufacturing new polyester products. This process is effective for recycling contaminated or coloured plastics, which are challenging to process using mechanical recycling methods [9]. The economic feasibility of methanolysis on a large scale needs further evaluation. The process also requires optimization to improve efficiency and minimise energy consumption.

By converting plastic trash into reusable monomers, methanolysis lessens the negative effects of plastic pollution on the environment and promotes a circular economy for plastics.

Enzymatic Breakdown

Enzymatic breakdown utilizes specific enzymes to degrade plastics like PET into their monomers. This method offers a potentially low-energy and environmentally friendly approach to plastic recycling [10]. Enzymes can operate under mild conditions, reducing the energy required for plastic breakdown. Recent advances have identified several promising enzymes capable of efficiently degrading plastics [11]. Scaling up enzymatic processes for industrial applications and improving enzyme efficiency are key challenges. The stability and reusability of enzymes also need to be addressed.

Enzymatic breakdown offers a sustainable method for plastic recycling, reducing environmental pollution and enabling the recovery of valuable monomers for reuse.

DISCUSSION

Chemical recycling methods offer diverse opportunities to mitigate plastic pollution, each with unique advantages and challenges. These methods can handle mixed and contaminated plastics, produce high-purity products, and operate under mild conditions. However, challenges related to energy requirements, scalability, economic viability, and environmental impacts must be addressed to realize their full potential.

CONCLUSION

Chemical methods offer a promising approach to mitigating plastic pollution by transforming waste into valuable products. Techniques such as pyrolysis and hydrothermal liquefaction break down plastics into usable fuels and chemicals, while catalytic depolymerization facilitates the conversion of polymers back into their monomers. Processes like glycolysis and methanolysis target specific types of plastics, enabling their repurposing into new materials. Enzymatic breakdown and the use of supercritical fluids represent innovative strategies that enhance the efficiency and environmental friendliness of plastic waste conversion.

However, despite their potential, these technologies face significant challenges that limit their large-scale application. High energy requirements, the need for precise control of reaction conditions, and the management of byproducts are critical obstacles. Additionally, the economic viability of these processes depends on the development of efficient catalysts and scalable systems that can operate sustainably. Overcoming these hurdles requires focused research and development efforts to optimize processes, reduce costs, and minimize environmental impacts. By addressing these challenges, chemical methods could play a crucial role in reducing plastic pollution, contributing to a more sustainable future.

REFERENCES

1. Singh, R. K., Ruj, B., & Arya, D. (2018). Pyrolysis of waste plastics and conversion of pyrolysis oil to diesel. Waste Management, 72, 62-74.
2. Miskolczi, N., Bartha, L., Deák, G., & Jövő, I. (2004). Thermal degradation of municipal plastic waste for production of fuel-like hydrocarbons. Polymer Degradation and Stability, 86(2), 357-366.
3. Savage, P. E. (2012). Organic chemical reactions in supercritical water. Chemical Reviews, 99(2), 603-621.
4. Elliott, D. C., Neuenschwander, G. G., Hart, T. R., Rotness, L. J., & Olarte, M. V. (2015). Hydrothermal liquefaction of biomass: Developments from batch to continuous process. Bioresource Technology, 178, 147-156.
5. Jehanno, C., Perez-Madrigal, M. M., Demarteau, J., Sardon, H., & Dove, A. P. (2019). Organocatalysis for depolymerisation. Polymer Chemistry, 10(13), 1724-1731.
6. Ragauskas, A. J., Beckham, G. T., Biddy, M. J., Chandra, R., Chen, F., Davis, M. F., & Wyman, C. E. (2014). Lignin valorization: improving lignin processing in the biorefinery. Science, 344(6185), 1246843.
7. Chen, J., & Wang, S. (2020). Chemical recycling of waste plastics to monomers and chemicals by glycolysis and methanolysis. Green Chemistry, 22(10), 3285-3301.
8. Kosloski-Oh, S. C., Wood, Z. A., Manjarrez, Y., Garcia, R., Martinez, A. M., Gallimore, A. D., & Sottos, N. R. (2021). Closed-loop recycling of plastics enabled by dynamic covalent diketoenamine bonds. Science, 373(6550), 166-171.
9. Okuwaki, A. (2004). Recycling of polyethylene terephthalate (PET) through methanolysis. Polymer Degradation and Stability, 86(1), 191-196.
10. Tournier, V., Topham, C. M., Gilles, A., David, B., Folgoas, C., Moya-Leclair, E., & Marty, A. (2020). An engineered PET depolymerase to break down and recycle plastic bottles. Nature, 580(7802), 216-219.
11. Yoshida, S., Hiraga, K., Takehana, T., Taniguchi, I., Yamaji, H., Maeda, Y., ... & Oda, K. (2016). A bacterium that degrades and assimilates poly(ethylene terephthalate). Science, 351(6278), 1196-1199.

