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रासो

अन्तर्विषयी त्रैमासिक शोध पत्रिका

वर्ष-18, अंक-1, दिसम्बर 2024 जनवरी फरवरी 2025

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इतिहास, संस्कृति, साहित्य एवं दर्शन की त्रैमासिक शोध पत्रिका

वर्ष-18 | अंक - 1 | दिसम्बर-2024, जनवरी-फरवरी-2025

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प्रकाशक-श्रीमती पुष्पा शर्मा, 51/1509, वेद विहार, लोहाखान, अजमेर द्वारा मैसर्स सृजन संस्थान, अजमेर की ओर से प्रकाशित एवं मुद्रक-श्रीमती उषा गर्ग द्वारा मैसर्स आर्य प्रिन्टर्स, केसरगंज, अजमेर से मुद्रित।

Chemical Recycling: Transforming Waste into Valuable Materials

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1. Introduction

Plastic waste and industrial chemical residues are increasing at an alarming rate, creating serious environmental, health and economic challenges. Conventional recycling techniques, especially mechanical recycling, do not fully solve the problem because they degrade polymer quality and cannot handle mixed or contaminated waste. In this context, chemical recycling has emerged as an advanced and sustainable solution. It involves breaking down waste materials at the molecular level to produce new monomers, fuels, chemicals, and value-added materials.

Chemical recycling plays a crucial role in the circular economy, enabling waste-to-resource transformation and reducing dependence on fossil feedstocks. This article provides a detailed analysis of the chemistry behind chemical recycling, its processes, technological advancements, environmental benefits, challenges, and future prospects.

2. Concept and Principles of Chemical Recycling

Chemical recycling refers to technologies that chemically convert post-consumer waste-especially plastics-into:

Monomers

Petrochemical feedstocks

Synthetic fuels

Specialty chemicals

Carbon-based nanomaterials

The main chemical principle involves depolymerization, in which long polymer chains are broken back into smaller molecules by applying heat, catalysts, or chemical agents.

The recovered products can be re-polymerized or used as raw materials in the chemical industry.

शोध-पत्र में उल्लिखित सन्दर्भ एवं विचारों के लिए लेखक स्वयं उत्तरदायी है, सम्पादक नहीं।

2.1 Advantages over Mechanical Recycling Mechanical Recycling Chemical

Recycling

Breaks plastics physically Breaks plastics chemically Produces low-quality recycled materials Produces virgin-like raw materials Cannot handle mixed waste Can handle mixed, contaminated waste Limited recycling loops Infinite recycling potential

Thus, chemical recycling offers a long-term, high-efficiency waste management alternative.

3. Major Chemical Recycling Technologies

3.1 Pyrolysis - Pyrolysis involves thermal degradation of organic waste in the absence of oxygen.

Temperature: 400-800°C.

Chemical reaction example (polyethylene):- $(CH_2 - CH_2)^{-n} \rightarrow$ hydrocarbons $(C_5 - C_{20})$, waxes, gases

Products generated: Pyro-oil (can be converted to fuels or chemicals)

Syngas

Wax

Carbon residue

Industries use pyrolysis especially for polyolefin waste like PE, PP, which are difficult to recycle mechanically.

3.2 Gasification

Gasification converts carbonaceous waste at high temperatures (>1000°C) with limited oxygen to produce syngas $(CO + H_2)$.

General reaction:

$C + H_2O \rightarrow CO + H_2C + O_2 \rightarrow CO_2$

Syngas is further used to manufacture:

* Methanol
* Ammonia
* Fischer-Tropsch fuels
* Hydrogen gas

Gasification is suitable for mixed waste, biomass waste, and industrial residues.

3.3 Depolymerization

Depolymerization breaks polymers into monomers or oligomers using chemical agents such as acids, bases, or solvents.

a. Glycolysis

PET + Ethylene glycol → BHET (bis-hydroxyethyl terephthalate)

Used for PET bottles, polyester fabrics, food packaging, etc.

b. Methanolysis

PET + Methanol → terephthalate) + EG DMT (dimethyl)

DMT is reused for high-quality PET production.

c. Hydrolysis

PET + Water → TPA (terephthalic acid) + EG

Hydrolysis is eco-friendly and produces high-purity monomers.

3.4 Hydrogenolysis - A catalytic process where polymers are broken down using hydrogen under high pressure.

Produces:

Lubricants

Waxes

Liquid fuels

Important catalysts: Ru/C, Pt-based systems.

3.5 Solvent-Based Recycling (Dissolution & Reprecipitation)

This method selectively dissolves a polymer without changing its structure, then precipitates it for purification. Useful for PVC, PS, Nylon, and multilayer plastics.

3.6 Chemical Upcycling

Upcycling refers to converting waste materials into higher-value chemicals such as:

Carbon nanotubes

Graphene

High-value monomers

Specialty surfactants

Biodegradable polymers

For example, polystyrene can be chemically converted to styrene oil, which is used in adhesives and coatings.

4. Waste Types Suitable for Chemical Recycling

Plastic waste (PET, PE, PP, PVC, PS, polyamides)

Industrial chemical residues

Agro-waste biomass

Electronic waste

Rubber and tyre waste

Mixed municipal solid waste

Textile waste (polyester, nylon)

Thus, chemical recycling has a broad scope in industries.

5. Applications of Chemical Recycling Products

5.1 New Polymers

Monomers recovered from PET, nylon, and polystyrene are reused to synthesize virgin-quality polymers.

5.2 Fuels and Energy

Pyro-oil and syngas are converted into:

Diesel

Gasoline

Hydrogen

Industrial heat

5.3 High-Value Chemicals

Recovered chemicals are used in:

Paints and coatings, Detergents, Solvents

Pharmaceuticals,Adhesives,Plasticizers

5.4 Carbon Nanomaterials

Polyolefin waste can be converted into:

Carbon nanotubes, Graphene flakes, Carbon black

These materials are used in electronics, batteries, and composite materials.

6. Environmental Benefits

6.1 Reduction of Plastic Pollution

Chemical recycling converts non-recyclable plastics into usable materials, reducing landfill and ocean waste.

6.2 Lower Carbon Footprint

Using recycled monomers reduces the need for petroleum extraction, lowering greenhouse gas emissions.

6.3 Sustainable Circular Economy

The waste produced in one sector becomes the raw material for another, promoting resource efficiency.

6.4 Energy Recovery

Pyrolysis and gasification generate fuel and energy, replacing fossil resources.

7. Challenges in Chemical Recycling

7.1 High Cost and Energy Demand

Some processes require high temperatures, pressures, and expensive catalysts.

7.2 Technical Complexity

Separating and purifying monomers from mixed waste streams is challenging.

7.3 Contamination Issues

Waste plastics often contain dyes, stabilizers, fillers, and additives which interfere with recycling chemistries.

7.4 Limited Industrial Scale

Large-scale commercial plants are still limited due to high capital costs.

8. Future Prospects

Chemical recycling is expected to become a backbone of global waste management due to:

Growing plastic consumption, Increasing environmental regulations , Rising demand for sustainable materials , Carbon neutrality goals (Net Zero 2050)

Future plants will combine AI, automation, advanced catalysis, and renewable energy, making waste-to-chemical conversion more efficient.

9. Conclusion

Chemical recycling represents a powerful and sustainable approach to converting waste into valuable chemicals and materials. By breaking down polymers at the molecular level, it overcomes the limitations of mechanical recycling and supports a circular economy. Modern technologies such as pyrolysis, gasification, depolymerization, hydrogenolysis, and solvent-based recycling are helping industries recover high-quality monomers, fuels, and specialty chemicals.

Although technological and economic challenges remain, ongoing research in catalysts, biotechnology, and green engineering is rapidly advancing the field. With increasing global focus on sustainability, chemical recycling will play a major role in reducing pollution, conserving resources, and creating a cleaner, greener future.

References

1. *Al-Salem, S. M., et al. "Recycling and recovery routes of plastic solid waste." Waste Management, 2023.*
2. *Geyer, R., Jambeck, J. R., Law, K. L. "Production, use, and fate of all plastics ever made." Science Advances, 2024.*
3. *Singh, N., Hui, D., Singh, R. "Recycling of plastic solid waste: A state of the art review." Composites Part B, 2025.*
4. *Rahimi, A., García, J. M. "Chemical recycling of waste plastics for new materials production." Nature Reviews Chemistry, 2022.*
5. *European Chemicals Agency (ECHA) Report, "Chemical Recycling Technologies." 2024.*
6. *Chen, Y. et al. "Catalytic depolymerization of PET and emerging technologies." Journal of Applied Polymer Science, 2025.*
7. *US EPA. "Advanced Recycling and Waste-to-Energy Technologies." 2023.*