Application of Polyhydroxyalkanoates (PHA) in Water Pollution Control[1]

Dr. K. Venkata Krishna

Assistant Professor of Chemistry

Government Degree College for Women (A), Nalgonda, Telangana, India

DOI:10.37648/ijrst.v12i03.010

Received: 10 September 2022; Accepted: 27 September 2022; Published: 03 October 2022

ABSTRACT

Polyhydroxyalkanoates are biodegradable polyesters made by bacteria. These polymers help control water pollution in two ways. First, mixed microbial cultures produce them from wastewater organic matter, turning a waste stream into a useful material. Second, the finished polymer and its composites act as adsorbents for dyes and heavy metals or as filter media that trap bacteria. This paper describes the structure of PHA, the biosynthesis reactions, production from real wastewaters, and direct uses in treatment systems. Tables list removal efficiencies and production yields. Equations show the key steps. The approach reduces plastic pollution while cleaning water when operators match the feedstock and process conditions to the local waste stream.

Keywords: *polyhydroxyalkanoates; PHA; PHB; wastewater treatment; biosorption; biodegradable polymers; resource recovery*

1. Introduction

Conventional plastics persist in rivers and oceans for decades. They fragment into microplastics that enter the food chain. At the same time, many municipal and industrial wastewaters carry high organic loads that require energy-intensive treatment. Polyhydroxyalkanoates offer a link between these two problems. Bacteria store carbon as PHA granules under nutrient-limited conditions. When the carbon comes from wastewater, the process removes organic matter and produces a polymer that can later serve as an adsorbent or filter.

The most common member is poly(3-hydroxybutyrate), or PHB. Copolymers such as PHBV add flexibility. Both polymers break down in soil and water through microbial action. This paper reviews how operators produce PHA from wastewater and how the polymer itself helps remove pollutants. The discussion stays practical: which feedstocks work, what yields appear in the literature, and which treatment roles the material can fill.

2. Chemical Structure of PHA

PHA molecules are linear polyesters of 3-hydroxyalkanoic acids. The repeating unit contains an ester linkage. The side chain R determines the exact polymer. When R is a methyl group, the polymer is PHB. Longer side chains produce medium-chain-length PHA. Natural PHB has the R configuration at the chiral carbon.

[1] *How to cite the article:*
Krishna K.V, Application of Polyhydroxyalkanoates (PHA) in Water Pollution Control, IJRST, Jul-Sep 2022, Vol 12, Issue 3, 58-62, DOI: http://doi.org/10.37648/ijrst.v12i03.010

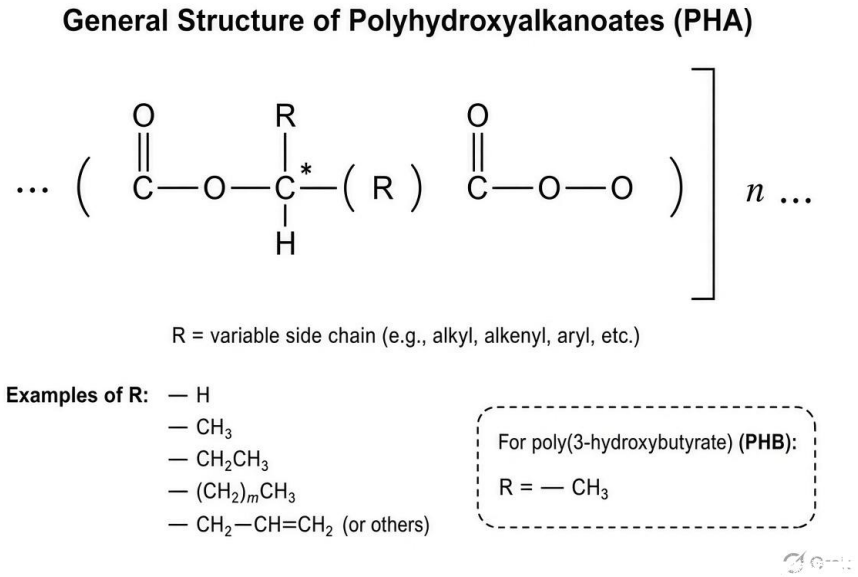


Figure 1. General structure of polyhydroxyalkanoates showing the variable side chain R.

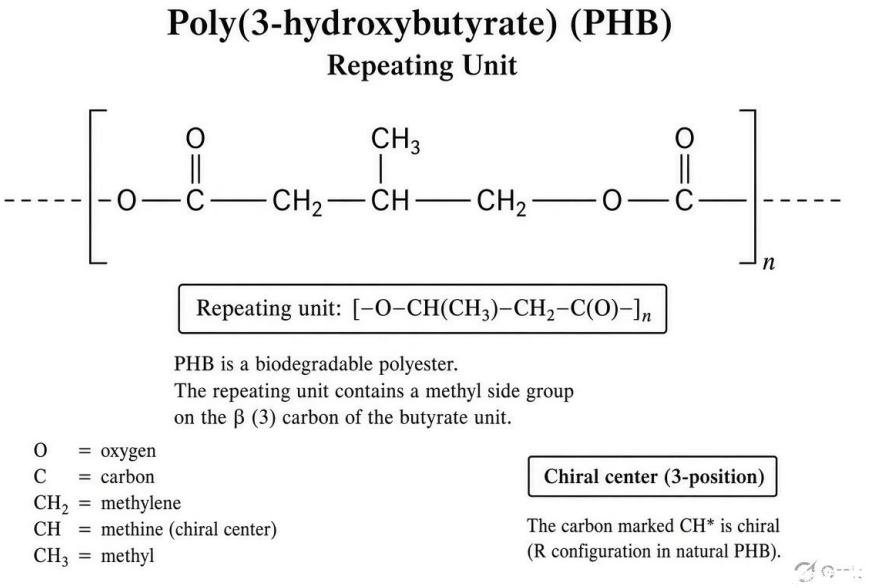


Figure 2. Repeating unit of poly(3-hydroxybutyrate) (PHB).

The ester bond is the site of enzymatic hydrolysis during biodegradation. Microbes secrete PHA depolymerases that cut the chain into soluble monomers. The monomers then enter central metabolism. This cycle returns carbon to the environment instead of leaving persistent fragments.

3. Biosynthesis Pathway

Most bacteria that make PHB use three enzymes. PhaA condenses two molecules of acetyl-CoA into acetoacetyl-CoA. PhaB reduces the ketone to the (R)-3-hydroxybutyryl-CoA using NADPH. PhaC polymerizes the monomers into the growing chain. The overall sequence is:

2 acetyl-CoA → acetoacetyl-CoA → (R)-3-hydroxybutyryl-CoA → PHB

The first step is reversible. High acetyl-CoA and low free CoA favor polymer formation. Nutrient limitation (nitrogen or phosphorus) slows protein synthesis and redirects carbon into storage. In mixed cultures fed with wastewater, operators create a feast-famine cycle to enrich PHA-storing bacteria.

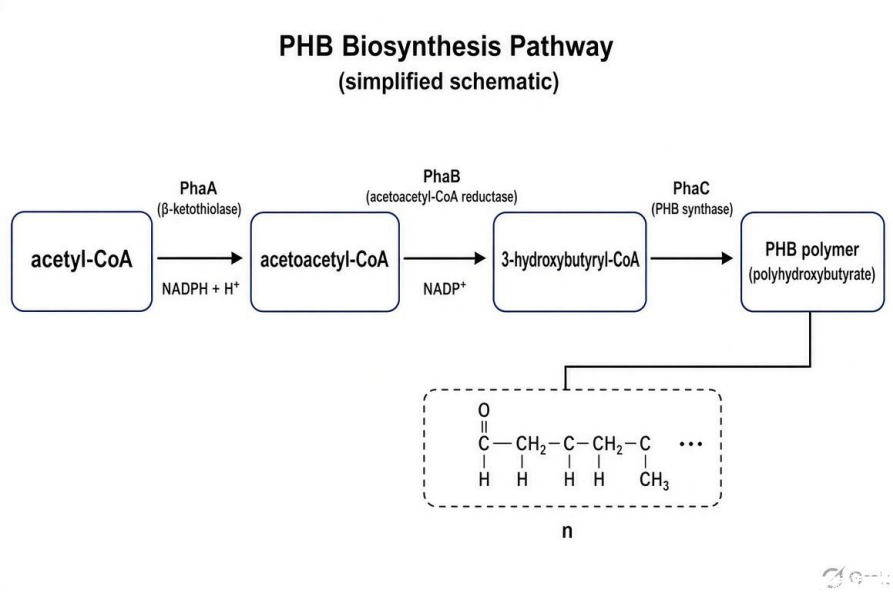


Figure 3. Simplified biosynthesis pathway for PHB from acetyl-CoA.

4. Production of PHA from Wastewater

Municipal wastewater, food-processing effluent, and fermented organic wastes supply the carbon. Mixed microbial cultures avoid the cost of pure-culture sterility. A sequencing batch reactor first selects the storing population under alternating carbon-rich and carbon-poor conditions. A second reactor then accumulates the polymer under nitrogen or phosphorus limitation. Yields of 30–70 % of cell dry weight appear in laboratory and pilot studies published before 2021.

Pilot plants have processed sewage and industrial streams at kilogram scale. The organic load drops during the feast phase because the bacteria store the carbon. The treated water can return to the plant or discharge after polishing. Extraction usually uses solvents or green methods such as surfactant or enzymatic disruption. Residual biomass can serve as fertilizer after polymer recovery.

Table 1. Examples of PHA production from wastewater streams (studies before March 2021)

Feedstock	Culture type	PHA content (% CDW)	Reference note
Municipal wastewater	Mixed culture	30–50	Pilot studies
Food industry effluent	Mixed culture	40–70	Lab and pilot
Fermented sludge	Mixed culture	25–55	Resource recovery

CDW = cell dry weight. Values vary with organic loading rate, feast-famine timing, and nutrient limitation strategy.

5. Direct Applications of PHA in Pollution Control

Once recovered, PHA can serve several treatment roles. Films and porous composites act as filters that retain bacteria and suspended solids. A 2020 study showed that three stacked mcl-PHA films removed 90–92 % of bacteria and yeast from domestic wastewater and lowered biological oxygen demand. The material also reduced solids content enough to meet local discharge standards.

PHA and PHA-cellulose composites adsorb dyes and certain metal ions. The ester and hydroxyl groups provide sites for hydrogen bonding and electrostatic interaction. Capacity depends on surface area and pH. At acidic pH the surface becomes more positive and attracts anionic dyes. At higher pH it favors cationic metals. After saturation the polymer can be regenerated or simply allowed to biodegrade, returning the bound pollutants to a controlled treatment step.

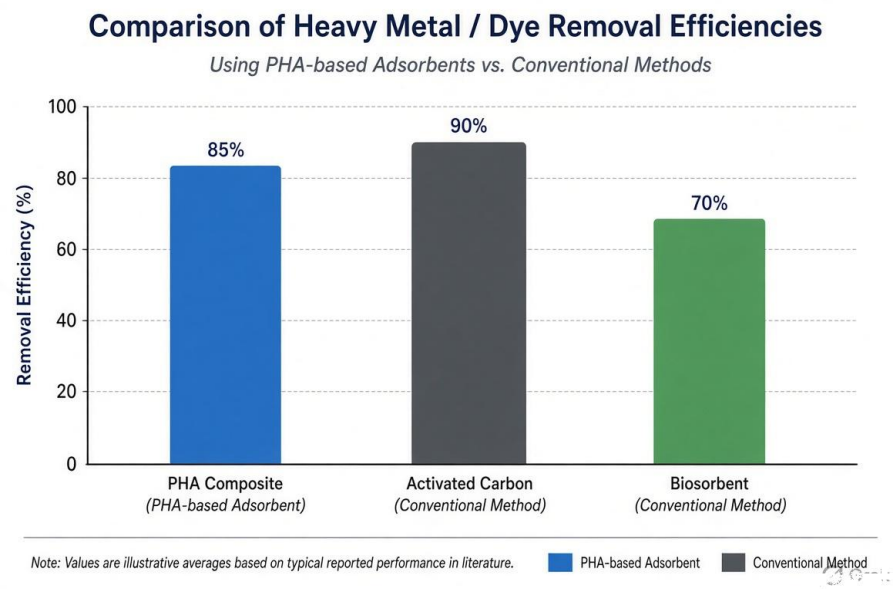


Figure 4. Illustrative comparison of pollutant removal efficiencies (PHA composite versus conventional adsorbents).

Table 2. Reported roles of PHA materials in water treatment

PHA form	Target pollutant	Typical performance
Film or membrane	Bacteria, suspended solids	90 % bacterial reduction
Composite beads	Dyes, heavy metals	70–90 % removal
Biofilm carrier	Organic load	Supports attached growth

Performance values are compiled from laboratory and pilot reports published before March 2021.

6. Mechanisms of Pollutant Removal

Adsorption on PHA follows the same principles as other polymers. Physical entrapment, electrostatic attraction, and hydrogen bonding all contribute. For anionic dyes the equation can be written as:

$$PHA–OH_2^+ + Dye^- \rightleftharpoons PHA–OH_2^+–Dye^-$$

In filtration, the pore size and surface charge retain bacteria. Biodegradation of the polymer itself is slow under normal treatment conditions, so the filter lasts long enough for practical use. After disposal the polymer mineralizes, avoiding secondary plastic pollution.

When PHA production is integrated into a treatment plant, the feast phase removes soluble COD. The famine phase maintains the biomass without additional carbon. The net effect is lower effluent organic load plus a recoverable biopolymer.

7. Advantages and Limitations

PHA production from wastewater reduces the volume of organic waste that must be oxidized or landfilled. The polymer replaces petroleum-based plastics in selected uses and does not leave microplastic residues. Filters made from PHA can be composted after use. These benefits support circular-economy goals.

Costs remain higher than for conventional plastics or activated carbon. Extraction and purification add steps. Yields drop if the feedstock contains inhibitors. Operators therefore combine PHA production with existing activated-sludge or membrane bioreactor systems rather than building dedicated plants. Further work on green extraction and higher-yield mixed cultures is needed before large-scale adoption.

8. Conclusion

Polyhydroxyalkanoates link wastewater treatment with biodegradable material production. Mixed cultures convert organic pollutants into PHB and related copolymers. The recovered polymer then serves as a filter or adsorbent that removes bacteria, dyes, and metals. Both steps reduce environmental load when the process is matched to local waste streams and analytical checks confirm removal. Continued pilot work will clarify the most reliable routes for practical application.

References

1. Mannina, G., Presti, D., Montiel-Jarillo, G., Carrera, J., & Suárez-Ojeda, M. E. (2020). Recovery of polyhydroxyalkanoates (PHAs) from wastewater: A review. Bioresource Technology, 297, 122478.

2. Amadu, A. A., Qiu, S., Ge, S., Addico, G. N. D., Ameka, G. K., Yu, Z., Xia, W., Abbew, A. W., Shao, D., Champagne, P., & Wang, S. (2021). A review of biopolymer (Poly-β-hydroxybutyrate) synthesis in microbes cultivated on wastewater. Science of the Total Environment, 756, 143729.

3. Sagong, H. Y., Son, H. F., Choi, S. Y., Lee, S. Y., & Kim, K. J. (2018). Structural insights into polyhydroxyalkanoates biosynthesis. Trends in Biochemical Sciences, 43(10), 790–805.

4. Madison, L. L., & Huisman, G. W. (1999). Metabolic engineering of poly(3-hydroxyalkanoates): From DNA to plastic. Microbiology and Molecular Biology Reviews, 63(1), 21–53.

5. Sudesh, K., Abe, H., & Doi, Y. (2000). Synthesis, structure and properties of polyhydroxyalkanoates: Biological polyesters. Progress in Polymer Science, 25(10), 1503–1555.

6. Jendrossek, D., & Handrick, R. (2002). Microbial degradation of polyhydroxyalkanoates. Annual Review of Microbiology, 56, 403–432.

7. Albuquerque, M. G. E., Torres, C. A. V., & Reis, M. A. M. (2010). Polyhydroxyalkanoate (PHA) production by a mixed microbial culture using sugar molasses: Effect of the influent substrate concentration on culture selection. Water Research, 44(11), 3419–3433.

8. Valentino, F., Morgan-Sagastume, F., Campanari, S., Villano, M., Werker, A., & Majone, M. (2017). Carbon recovery from wastewater through bioconversion into biodegradable polymers. New Biotechnology, 37, 9–23.

9. Morgan-Sagastume, F., Hjort, M., Cirne, D., Gérardin, F., Lacroix, S., Gaval, G., Karabegovic, L., Alexandersson, T., Johansson, P., Karlsson, A., Bengtsson, S., Arcos-Hernández, M. V., Magnusson, P., & Werker, A. (2015). Integrated production of polyhydroxyalkanoates (PHAs) with municipal wastewater and sludge treatment at pilot scale. Bioresource Technology, 181, 78–89.

10. Raza, Z. A., Abid, S., & Banat, I. M. (2018). Polyhydroxyalkanoates: Characteristics, production, recent developments and applications. International Biodeterioration & Biodegradation, 126, 45–56.

11. Additional studies on PHA production from mixed cultures and wastewater streams and on PHA-based materials for filtration or adsorption published before March 2021.