

# NANO-BIOREMEDIATION FOR WASTEWATER TREATMENT

Edited By

Gajendra Singh Vishwakarma,  
Narendra Kumar, Alok Pandya  
and Zinia Mohanta

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# Nano-Bioremediation for Wastewater Treatment

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# Nano-Bioremediation for Wastewater Treatment

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## Preface

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The exponential growth of industrialization and urbanization over the past century has led to unprecedented environmental challenges, particularly in water pollution. Contaminants ranging from heavy metals and organic compounds to pathogenic microorganisms have rendered wastewater treatment a critical global priority. Traditional methods of wastewater treatment, while effective to an extent, often fall short in addressing the multifaceted and complex nature of modern pollutants. This scenario necessitates innovative and sustainable solutions, driving the scientific community to explore the potential of advanced technologies in environmental remediation.

One such promising frontier is nano-bioremediation. This emerging field synergistically combines nanotechnology principles with biological processes to develop cutting-edge solutions for wastewater treatment. Nanotechnology offers tools at an atomic and molecular scale that can enhance the efficiency, speed, and scope of bioremediation processes. The unique properties of nanomaterials, such as their high surface area-to-volume ratio, tuneable surface chemistry, and exceptional reactivity, make them ideal candidates for removing contaminants that are otherwise challenging to degrade or extract.

This book aims to provide a comprehensive overview of the state-of-the-art advancements and future directions in this dynamic field. It brings together contributions from leading experts and researchers, offering readers an in-depth understanding of the principles, methodologies, and applications of nano-bioremediation.

Structured to guide the reader through a logical progression of topics, this book starts with the fundamental concepts of nanotechnology and bioremediation, followed by detailed discussions on the synthesis and characterization of nanomaterials, their interaction with biological systems, and the mechanisms underlying their role in pollutant degradation and removal. Case studies and practical applications are presented to

illustrate the real-world impact and potential of these technologies in various settings.

Special emphasis is placed on the sustainability and safety aspects of employing nanomaterials in environmental applications. The potential risks associated with nanotechnology, including toxicity and environmental impact, are critically evaluated alongside the benefits, ensuring a balanced perspective on the use of these advanced materials.

As we move towards a future where clean water resources become increasingly scarce, the integration of nanotechnology in bioremediation processes represents a promising pathway to sustainable water management. This book aspires to serve as a valuable resource for researchers, practitioners, policymakers, and students, providing them with the knowledge and tools needed to harness the power of nano-bioremediation for a cleaner and healthier environment.

We hope that this book will inspire further research and innovation in this exciting field and contribute to the development of practical solutions that can be implemented on a global scale. The journey towards effective and sustainable wastewater treatment is ongoing, and we are optimistic that the insights and discoveries shared in this book will play a significant role in advancing this vital area of environmental science. Finally, our gratitude goes to Martin Scrivener and the team at Scrivener Publishing for their support in bringing this volume to light.

Editors

**Gajendra Singh Vishwakarma**  
**Narendra Kumar**  
**Alok Pandya**  
**Zinia Mohanta**

# Nano-Bioremediation and Scale-Up Techniques for Wastewater Treatment

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## **Abstract**

Providing enough affordable, clean water for everyone is the biggest challenge of the twenty-first century. In the past few decades, many techniques for treating wastewater have been investigated; however, their application is limited by a number of issues, such as the use of chemicals, the production of disinfection by-products (DBPs), time commitment, and cost. Advances in nanotechnology have led to the development of products and processes used in wastewater treatment, such as magnetic nanoparticles, nanofiltration, nanobiocides, nanoadsorbents, and nanozero valent iron. Also, in the scenario of wastewater treatment, the production of bioengineered nanoparticles (BNPs) through microbial interaction plays a significant role. Being less costly and dangerous than traditional approaches, BNPs have been employed as biocatalysts, adsorbents, oxidants, and reductants in the removal of contaminants from drinking water and wastewater because they contain a special bacterial carrier matrix. Moreover in this regard, the use of microbial fuel cells (MFCs) has garnered importance due to the features of simultaneous power production and wastewater treatment. There is a need to scale-up all the available techniques in this aspect, at a large scale. For that, development is required in pilot or large-scale water treatment plants. In this regard, different studies are available in which various processes and parameters have been demonstrated that can be considered during the scale-up techniques and designing principles for optimum wastewater treatment. In this particular book chapter, we have discussed each and every aspect of the same in detail and also sheds light on the most recent developments in nanotechnology in light of the pressing need

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to investigate and manage the emerging hazardous wastes with reduced prices, less energy, and greater efficiency.

**Keywords:** Wastewater treatment, nano remediation, reverse osmosis, nanofiltration, ultrafiltration, microfiltration, fabrication, scale-up

### 1.1 Introduction

The ever-increasing demand for clean water necessitates the development of innovative and efficient water treatment technologies. Traditional methods, while effective, often struggle with emerging contaminants and require significant resources. This has led researchers to explore the exciting potential of microbes and nano-conjugates in wastewater treatment and water purification systems.

In the field of wastewater treatment and water purification, the integration of microbes and nanotechnology has shown great promise. Microbes, with their diverse metabolic capabilities, offer a biological approach to pollutant degradation. By harnessing their natural ability to break down organic matter and certain inorganic compounds, we can create targeted bioremediation solutions. Nano-conjugates, on the other hand, present a unique physicochemical approach. These engineered structures, on a scale of billionths of a meter, possess remarkable properties like high surface area and tunable reactivity. They can be designed for specific functionalities such as adsorption of contaminants, photocatalysis for pollutant degradation, or even sensing of specific pollutants. Various nanomaterials, including zeolites, chitosan, Multi-walled carbon nanotubes (MWCNT), nano-composites, and nano-oxides, have been employed in water treatment processes [1]. The microbial synthesis of nanoparticles has emerged as a cost-effective and environmentally friendly method, offering high absorbent capabilities due to their nanoscale size and unique properties. Additionally, the bioinspired production of nanomaterials through microorganisms has gained attention for its efficiency in treating wastewater and decontaminating pollutants, providing a sustainable and energy-efficient alternative [2]. Moreover, the use of nano microbial conjugates, such as phage-conjugated  $\text{Fe}_3\text{O}_4$  nanoparticles, has demonstrated significant antibacterial activity against resistant strains in wastewater, highlighting a novel approach in water management systems [3]. Lastly, the application of titanium oxide nanoparticles in a lab-scale wastewater treatment plant

has proven effective in enhancing water quality by reducing turbidity, total solids, suspended solids, and biological and chemical oxygen demands, as well as removing heavy metals and decreasing microbial counts [4].

Microorganisms play a vital role in augmenting water treatment efficacy. Their metabolic processes break down contaminants in wastewater, including organic matter, nitrogen, phosphorus, and other pollutants, into environmentally benign substances. Biological wastewater treatment processes [5] exploit diverse microbial communities to achieve this, leading to reductions in biological oxygen demand (BOD) and chemical oxygen demand (COD). This results in the generation of treated water suitable for reuse in various applications. Specific microbial species, such as *Candidatus accumulibacter phosphatis*, *Spirogyra*, *Aspergillus luchuensis*, and *Candida*, are instrumental in contaminant removal from wastewater sources [6]. Notably, the type of treatment technology employed influences the composition of microbial communities within wastewater treatment plants. Additionally, environmental factors such as dissolved oxygen concentration and pH significantly impact nitrogen metabolism and microbial interactions [7]. By leveraging microbial biotechnology, we can not only decrease the concentration of diverse water contaminants but also generate valuable energy products like biohydrogen, bioethanol, biogas, and bioelectricity [8].

Nano-conjugates offer distinct advantages in water purification. By combining the unique properties of various materials, they can enhance membrane performance. For instance, the functionalization of carbon nanotubes with diferuloylmethane creates a novel carbon conjugate for membrane reinforcement [1]. Additionally, nanomaterials like zeolites, chitosan, and various nano-composites and oxides showcase promise in pollutant removal [9]. Notably, nano-conjugates can simplify and increase purification efficiency, enabling large-scale production as demonstrated in the method for purifying water-soluble iron oxide nanoparticle-antibody conjugates [10]. Overall, nano-conjugates present a versatile and effective approach for improving water purification processes.

Newly designed prototypes play a crucial role in advancing water purification by incorporating innovative and cost-effective methods. For instance, a prototype for aid workers integrates activated carbon, ceramic candle filtration, and UV irradiation to effectively remove bacteria, turbidity, and viruses from water sources in underdeveloped regions. Similarly, a recently developed system in Pakistan utilizes gravity flow to address

arsenic contamination in groundwater, significantly reducing heavy metal levels post-treatment [11]. Furthermore, a domestic wastewater treatment prototype employs a two-filter system for efficient wastewater treatment, producing clean water for reuse [12–15]. These prototypes showcase advancements in water purification technology, addressing various contaminants and improving water quality for diverse applications.

Keeping the above discussion in mind, this chapter will discuss the basics of nanobioremediation along with the fabrication and scale-up techniques for microbes and nano-conjugate based prototypes of wastewater treatment via emphasizing the different matrix for the microbes and nano-conjugate fabrication factors of scale-up of water treatment plant (size, capacity, aeration, filtration).

## 1.2 Basics of Nanobioremediation

Nanobioremediation is one such method that has gained popularity in recent years.

Bioremediation entails the use of plants, enzymes, and microbes, or a combination of these, for biosorption, bioaccumulation, biotransformation, and biological stabilization. It functions as a remediation approach for removing inorganic, organic, and emergent pollutants from agricultural soil [3]. In the case of nanobioremediation, by combining the concepts of bioremediation with nanotechnology, nanobioremediation may remove pollutants from soil, water, and air more precisely and efficiently. The fundamental idea is to use manufactured nanomaterials, such as nanoparticles, to enhance the natural processes that microbes do to break down pollutants and detoxify the environment. Combining the natural processes of bioremediation with the power of nanotechnology is a revolutionary technique known as nanobioremediation [2].

## 1.3 Basics of Wastewater Treatment Plant

Water is an invaluable resource, and understanding its treatment is essential before the construction of any wastewater treatment facility. Wastewater, in its simplest terms, is water that has been contaminated through residential, commercial, and industrial activities [21]. The heterogeneous and dynamic chemical composition of wastewater presents challenges in its precise definition. Wastewater treatment encompasses a series of processes designed to meet specific standards or discharge quality, as mandated by regional

or federal regulatory authorities. These processes are crucial in mitigating the environmental impact of wastewater and ensuring the sustainability of water resources. Wastewater is typically classified into two categories based on its source: domestic wastewater and industrial wastewater [22].

Domestic wastewater, also known as municipal wastewater or simply sewage, is produced by a community of people. This type of wastewater is discharged from residences and collected from nearby commercial, institutional, and public institutions. Sewage is a combination of water, human waste, leftover bathroom water, food preparation residue, laundry detergent, and other waste materials from daily life. In general, it contains organic and inorganic solids and microorganisms, mainly bacteria. The composition depends on its source and the generation of waste [23]. In industrial treatment plants, water is used for manufacturing processes including fabrication, processing, washing, diluting, cooling, or transporting products, as well as for facility cleanliness, in large and medium-scale industries. Water quality and quantity vary depending on the industry and its process methods. Pollutants including heavy metals (Cd, Ni, Pb, Hg, As, Cu, and Cr), a high amount of organic matter, dyes and chemicals, suspended particles, and pathogenic microbes are what define industrial wastewaters [24].

### 1.3.1 Treatment Methods

A centralized facility can treat wastewater using a variety of methods. These methods are developed to meet effluent regulations, and technologies and processes are often chosen depending on their ability to effectively treat specific wastewater produced by a community or company [25]. Three types of treatments are usually applied for wastewater treatments which are physical, chemical, and biological treatment. Screening, primary treatment, secondary or biological treatment, polishing (disinfection and filtration), and sludge treatment are among the treatment procedures used in many conventional wastewater treatment facilities [25]. For the **physical methods**, aeration, sedimentation, or thermal effect are used in mechanical preparation. In this method, screens, filters, and sieves are used for the separation of liquid and major solid substances. The purpose of separating certain particles from wastewater is to prevent blockages in pumps and pipes, as well as reduce equipment wear [26]. After the physical treatment, **biological procedures** are applied for sludge digestion, biochemical oxidation, and anaerobic digestion. After the biological treatment, the **chemical treatment** is used for precipitation, flocculation, disinfection, and

neutralization of the process [27]. For the membrane-based procedures, osmosis, nanofiltration, and filtration are used [28].

### *1.3.1.1 Primary Treatment*

Primary treatment is based on the concepts of sedimentation, gravity, and filtering. In a traditional wastewater treatment facility, the suspended particles are eliminated via sedimentation and gravity [29]. The basic principle of this treatment is to remove large floating objects such as rags and sticks that might clog pipes or damage equipment. Primary clarifiers, sedimentation basins, settling basins, or primary settling tanks are examples of traditional methods or equipment used to carry out conventional primary treatment. Examples of more recent technologies include the lamella separator or clarifier, which also uses sedimentation; rotating belt filters (RBF), which similarly use filtration; and nano or micro-bubbles, which help simpler flotation of suspended solids in situations such as dissolved air flotation or induced gas flotation [30].

### *1.3.1.2 Secondary Treatment*

Secondary treatment involves biological processes. Carbon, nitrogen, and phosphorus that are present in wastewater in either a dissolved or particulate form are removed by secondary or biological treatment [31]. Secondary treatments are designed to reduce the amount of organic materials in the wastewater. Typically, secondary sedimentation or a clarifying stage comes after the aeration process that grows the microorganisms in the wastewater in a conventional biological treatment. This process was also referred to as the activated sludge technique when it was initially created more than a century ago [32]. Activated sludge operations currently include most biological wastewater treatment methods that use air or oxygen to create a more easily separated mass of bacteria and other wastewater particles [33].

### *1.3.1.3 Disinfection-Filtration Treatment*

The effluent of secondary treatment is usually free from dense solids or sludge as it goes onto the disinfection and filtration steps, sometimes referred to as polishing or tertiary treatment [34]. The goals of disinfection and filtration are to guarantee that the wastewater is free of hazardous levels of substances that cause illness or hazardous microorganisms before it is discharged back into the environment or utilized again by a municipality for purposes like cooling, toilet flushing, farming, etc. [35]. The treated

effluent has to be sampled to see if it satisfies the discharge requirements specified by regional or national regulations before it may be released into the environment or used again as clean water [36]. Samples are taken from the different treatment tanks for analyzing the water quality. The most common measures of water quality are phosphorus, nitrogen, fecal coliform or bacteria, chemical oxygen demand (COD), biochemical oxygen demand (BOD), and nitrogen [37].

#### 1.3.1.4 *Sludge Treatment*

Although sludge is abundant in minerals and nutrients, it includes hazardous microbes and other particles that can disturb natural habitats, just like wastewater does before it is filtered and disinfected [38]. Before being kept or utilized again, it is generally treated to lessen such pathogens and chemicals. A modern sludge treatment procedure is used on the sludge from primary and secondary treatment to recover nutrients and biogas, lessen pathogens, and decrease quantities of biosolids [39]. Sludge is frequently just dewatered and sometimes even limed before being disposed of or applied to land. Sludge may be used by certain wastewater treatment facilities to create premium soil products and fertilizers.

## 1.4 Secondary Treatment Systems

The wastewater treatment process removes and separates contaminants from wastewater [40]. There are two different types of wastewater treatment: domestic wastewater treatment and industrial wastewater treatment [22]. The treatment facility for household wastewater is referred to as a sewage treatment plant. Domestic wastewater is sometimes known as sewage or municipal wastewater [41]. The primary and secondary stages of waste treatment are the two fundamental phases. In the primary stage, solids are extracted from wastewater and allowed to settle. Further, wastewater is purified by biological processes in the secondary stage [42]. In some cases, these phases are integrated into a single procedure. Before the wastewater is released into a disposal field for ultimate treatment and soil dispersal, secondary wastewater treatment uses a biological treatment method to lessen the amount of organic components in the wastewater [43]. Compared to a septic tank, secondary treatment generates substantially higher-quality wastewater [44].

The secondary treatment based on activated sludge has the following functions: The naturally occurring bacteria in the wastewater are exposed

to ambient air or are pumped with air or oxygen [45]. Usually, an aeration tank or basin is used for this. Certain organic compounds in wastewater, such as lipids, sugars, and other biodegradable substances found in food and human waste, are consumed and reproduced more easily by these microbes when there is oxygen present [46]. The microbes and other organic substances multiply, becoming denser and forming a biological floc. In the secondary sedimentation or clarity process, it separates as secondary or waste activated sludge (WAS) because it can then settle out or float more readily [47]. The effluent continues on to polishing or disinfection, while WAS, or secondary sludge, undergoes sludge treatment. Aeration tanks, basins, membrane bio-reactors (MBR), trickling filter bed filters, moving bed biofilm reactors (MBBR), integrated fixed film reactors, biological aerated filters (BAF), and sequencing batch reactors (SBR) are among the technologies used for biological treatment [48]. Rotating belt filters, dissolved air flotation tanks, and secondary clarifiers can all be used for the secondary sedimentation or clarity process, and the sequencing batch reactors cover all steps in the same unit [49].

### 1.4.1 Types of Secondary Treatment

Microorganisms are added to wastewater as a secondary wastewater treatment step, and these microorganisms use metabolic processes to extract waste from the water. Anaerobic, anoxic, and aerobic treatment are the three categories of secondary treatment. Although the biological mechanism behind each technique varies, they all successfully purge water of contaminants.

#### 1.4.1.1 *Aerobic and Activated Sludge Treatment*

Aerobic treatment systems convert organic contaminants into water, carbon dioxide, and more as by-products. Microorganisms that need oxygen for their metabolic functions are used in this treatment approach. In aerobic treatment systems, oxygen is added to wastewater through aeration, which in turn feeds microorganisms that eat the wastewater's waste [31]. Activated sludge treatment is a common aerobic process. This process uses a sludge layer made of clumped biosolids called flocs, together with flocculation and aeration [50]. These flocs develop during the aeration process and settle to the bottom of the water tank. During the activated sludge treatment process, water treatment plants use secondary clarifiers to mix settled sewage with raw or primary sludge [51]. Then, to give the microorganisms in the return sludge more time to break down waste, they rely on

air compressors to add compressed air to the mixture and push the flocs back into the water within the aeration tank. Treatment centers provide a variety of techniques and resources for this type of treatment.

#### 1.4.1.1.1 Surface Aerators or Diffusers

To introduce air into the water, some treatment facilities utilize surface aerators in lagoons. Other plants employ ceramic diffusers or rubber membranes in their aeration tanks [52]. An aeration tank pumps air through a tube or disc-shaped diffusers that have several microscopic holes in them. Through the holes, little air bubbles are let into the aeration tank [53]. These bubbles rise through the water tank to aid in oxygen transfer and aerobic digestion.

#### 1.4.1.1.2 Media Filters

Certain treatment facilities use media filters to encourage aerobic digestion. A typical media filter system is the moving bed biofilm reactor (MBBR) technology [54]. Thousands of tiny plastic media fragments are used in a basin by this kind of device. Bacteria attach to the media pieces and create a biofilm on them. The media particles cover between 50% and 70% of the basin's capacity and provide surface areas for bacterial growth. Because of their density, the pieces make the most of the available area by floating throughout the water [55]. With several tiny spokes like a wheel, each complex media component maximizes the surface area available for bacterial growth. The optimal shape and density of media pieces allow them to reach as much waste as possible and efficiently digest it to reduce hydraulic retention time [56].

#### 1.4.1.2 Anaerobic Treatment

Anaerobic techniques produce biofuel gas from organic pollutants without the need for oxygen [57]. This procedure, which frequently takes place in enclosed digestive lagoons, operates without the need for oxygen. Anaerobic microorganisms in the lagoons decompose organic waste [58]. Since anaerobic digestion does not require a pump to introduce oxygen into wastewater, it consumes less energy than aerobic digestion. Methane, carbon dioxide, and water vapor are common biogas by-products of anaerobic water treatment [59]. The resulting methane is frequently used by wastewater treatment facilities as plant fuel. Anaerobic treatment is the ideal choice for facilities that handle wastewater containing large amounts

of biodegradable materials, such as food waste, animal dung, or municipal trash [60].

#### 1.4.1.3 *Anoxic Treatment*

Anoxic treatment uses microbes with no oxygen metabolic pathway to purify the water. This activity can take place in the presence of some oxygen in the form of sulfates, nitrates, or nitrites, but it does not require free molecular oxygen to proceed [61]. This procedure is frequently used by plants to denitrify wastewater with a high nitrogen concentration. Nitrogen is converted to nitrate by anoxic denitrification using a trickling filter or a suspended growth system [62]. After that, certain bacteria are added by the wastewater treatment plant to break down the nitrogen in the nitrate, leaving behind just oxygen molecules. Treatment facilities usually completely surround their reactors to mitigate the effect of radicals of oxygen [63].

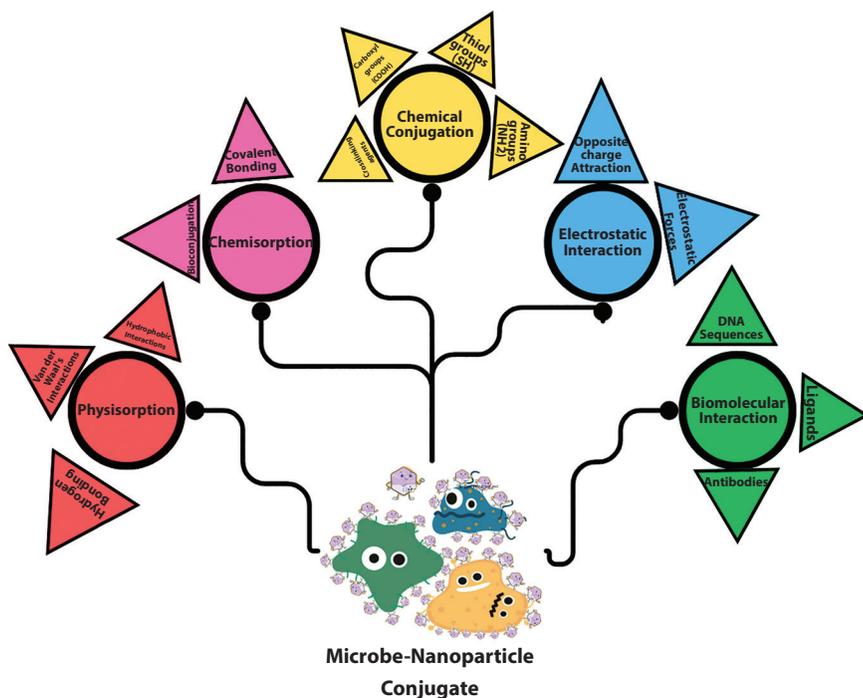
## 1.5 **Different Matrix for the Microbes and Nano-Conjugate Fabrication**

In the dynamic realm of science and technology, the fusion of seemingly unrelated elements often leads to groundbreaking innovations. A notable example of this is the collaboration between microbes, the smallest forms of life on Earth, and nanoparticles, the marvels of the material world. This interaction, termed “microbe and nanoparticle conjugation,” has emerged as a significant area of research and discovery, offering a wide range of applications across biotechnology, medicine, environmental science, and beyond. The combination of these two distinct entities in modern science frequently results in unique properties and potential applications, driving forward transformative advancements [64].

Nanoparticles (NPs) are ultra-small particles with unique properties due to their size, typically ranging from 1 to 100 nanometers. They exhibit high surface area, enhanced reactivity, and distinct optical, electrical, and magnetic characteristics [65]. These properties make them valuable in various fields, from medicine to materials science and electronics. Immobilized microbial cells have superior operational stability, are easier to separate from products for potential reuse, and have sufficient catalytic efficiency as compared to loose cells, they are widely utilized in bioconversion, bio-transformation, and biosynthetic processes. Because of their high surface energy and large specific surface area, the NPs’ nano-size effect causes

them to be heavily adsorbed on the surfaces of microbial cells. The interaction force between cells and NPs also heavily relies on electrostatic interactions. The primary mechanism of NP-coated bacterial cells was thought to be an electrostatic interaction between the positive and negative charges of magnetite NPs and the surface of the bacteria [66]. NPs have the ability to create hydrogen bonds with the extracellular matrix. Extracellular polymeric substances (EPSs), which are also rich in functional groups including carboxyl, hydroxyl, and phosphate groups, frequently coat the surfaces of cells [67].

Conjugation of microbes and nanoparticles is a technique that involves attaching or linking nanoparticles to the surface of microorganisms, such as bacteria or yeast cells. The result is a hybrid entity that amalgamates the biological functionalities of microbes with the exceptional properties of nanoparticles. These hybrid entities, or conjugates, hold immense promise across an array of applications, opening up new horizons for science and technology Figure 1.1 [68].



**Figure 1.1** Different possible mechanisms for microbe-nanoparticle conjugation.

The significance of this conjugation lies in the extraordinary combination of features it provides. Microbes are inherently gifted with a wide spectrum of biochemical processes, encompassing the ability to metabolize various compounds, produce enzymes, and even carry out specialized functions, such as bioremediation or drug synthesis. Nanoparticles, on the other hand, exhibit unique physical and chemical properties that can be finely tuned and harnessed for specific applications. The choice of nanoparticles is a pivotal decision in microbe and nanoparticle conjugation, as it profoundly influences the resulting hybrid material's properties and applications [69].

### 1.5.1 Conjugation Criteria for Nanoparticles

The most important criterion for conjugation in regards to nanoparticles is the selection of stable and economical nanoparticle that has biocompatibility and is non-toxic. In [70–74] nanoparticles were utilized like iron oxide,  $\alpha$ - $\text{Fe}_2\text{O}_3$ ,  $\text{Fe}_3\text{O}_4$ , and  $\gamma$ - $\text{Al}_2\text{O}_3$  for performance efficiency testing, respectively.

Sometimes, it is necessary to conduct surface oxidization of the nanoparticles to achieve improved efficiency in bioremediation. This is because work by Lu *et al.* [75] has shown that naked NPs oxidize easily and lose their magnetism and dispersibility. Polydopamine, oleic acid, ammonium oleate, and glycine are utilized for surface modification. This is because covalent bonds are formed between cells and carriers, which is a strong binding mode and enhances their stability for use in wastewater treatment.

Different nanoparticles also need varied times and temperatures for stable conjugation with host microbes. Feng *et al.* [76] tabulated essential combinations of temperature, time, and microbe-NP ratios essential for stable conjugations.

Poorly soluble NPs (e.g., gold, palladium, silver sulfide, and platinum) are less toxic to the host microbial cells compared to other metal or metal oxide NPs.

### 1.5.2 Conjugation Criteria for Microbes

The successful conjugation of microbes with nanoparticles requires specific criteria to be met. Microbes should have the capability to degrade or immobilize the target contaminants present in the wastewater or environmental system. The selection of microbial strain is one of the most essential criteria for remediation efficiency. El Bestawy *et al.* [77] created conjugates using microbial consortia while genetically engineered bacteria