Biological Synthesis of Nano catalysts and its applications in the treatment of industrial effluent/waste water

Dr. Rajeev Pradhan
Assistant Professor,
Department of Chemistry, P.K Roy Memorial College Dhanbad
rajivvbu@gmail.com

Abstract

Several well-established techniques are utilised for the manufacture of nano catalysts. The shortcomings of the most of conventional chemical and physical methods, such as toxicity of precursors, the requirement for higher precision, as well as the high cost of synthesis, impede their practical application in a variety of industries. The creation, execution, and development of chemical processes and products that minimize or remove waste and hazardous and toxic substances. Nano catalysts are distinguished by their nanoparticle size and high surface-to-volume ratio. The treatment and purifying of wastewater is an important use of nano catalysts. This article investigates nano catalysts based on noble and magnetically nano catalysts, as well as metallic catalyst accompanied by organic polymers, and their effluent treatment methods in an industrial context. This paper focuses on the biogenic production of nano catalysts.

Keywords: Nano catalyst , applications, synthesis, magnetic catalyst, wastewater treatment, nanomaterial

1. INTRODUCTION

The rapid expansion of different manufacturing sectors has detrimental effects on the environment, primarily the aquatic environment, as even the majority of businesses generate wastewater with substantial amounts of organic and inorganic toxins. Numerous sectors, including textiles, paints, medicines, print, leather, papers, and carpet, produce a significant amount of aroma pollutants, such as various compounds and dyes, every day. Even following regular cleaning methods, these industries would still emit a large amount of residual pollutants. [1-5]. Nano catalysts are often characterized by their size, content, morphology, material origin, aggregation, and homogeneity [6]. Nano catalysts can be produced by both chemical and physical techniques. Microemulsion, microwaves, pulsed laser deposition, lithography, photo - chemical reduction, ion sputtering, sol–gel, biological, ultra - sonic sparks discharging, and templates synthesis encompass aerosol technologies [7- 9] Nano catalysts combine both homogeneous and heterogeneous catalytic properties. This method permits the extraction and recovery of catalysis, as well as selective, rapid chemical reactions with such a quality products yield. Recovery is one of the most essential catalyst qualities. [10, 11]. Due to the nanoscale size and huge surface region of the catalyst particles, the interaction between both the catalysts and reactants is considerably increased during homogeneous catalysis. Due to the catalyst's insolubility in the solvent, heterogeneity is one of the characteristics of heterogeneous catalysis [12], is quickly removed from the solution. However, the majority of techniques have considerable drawbacks, because they require the use of expensive and dangerous chemicals as well as a substantial quantity of energy. It is demonstrated that the synthesis process is effective and can be used for an extended amount of time, but it has a number of drawbacks, such as particle aggregation when accepted to react for an extended amount of time, unpredictable nature of a final result, and insufficient control over crystal formation. In addition, this method is not environmentally beneficial because it produces a significant amount of harmful wastes and poison as by products. Physical and chemical processes generate hazardous pollutants such as organic solvents, capping agents, and reductants. Thus, it is crucial to restrict the use of hazardous solvents and compounds in nanomaterial production[13]. Hence, both conventional procedures for producing nanoparticles, i.e. chemical and physical processes, have become environmentally unfriendly and expensive. The shortcomings of existing processes need the development of novel nanomaterial production techniques [14] that are ecologically benign, inexpensive, non-hazardous, clean, and energy-efficient.

2. Nano catalysts

One of the initial applications of nanoparticles is catalysis. As nanoscale catalysts, numerous metals and chemicals, include silica, clays, titanium dioxide, iron, and aluminium, have been utilised [15-19]. Nanoparticles' extraordinary catalytic behaviour is, however, unexplained, and its specific source is unknown. Nanoparticles' enormous surface area has a significant impact on their reaction rate and it may contribute to their catalytic activity [20]. One of the early applications of nanoparticles is catalysis. In recent decades, numerous nanoscale metals and compounds, including as aluminium, iron, titanium dioxide, and silica, have been exploited as catalysts[21, 22]. Increasing nanoparticles surface has an undeniable favourable impact on the reaction rate and may provide a rationale for its own reactive transport. Every material's nanoscale structure and shape-dependent characteristics can affect the reactant mobility of a substance. The manufacture, shape, and size of nano catalysts have been modified to increase their selectivity. Any substance's catalytic activity is affected by its structure, shape, and nanoscale size. With the addition of supports, a core-shell structure, and bimetal shapes and sizes, the composition of nano catalysts was modified to increase their selectivity. By demonstrating how the physical qualities and preparations of nanoparticles affect their catalytic capabilities, it is possible to design nano catalysts with excellent activity, selectivity, and durability. These benefits allowed industry chemical reactions to produce less waste, utilize limited resources, and grow more asset [23-25], hence minimizing the environmental impact of chemical operations. Nanomaterials are crucial industrial catalysts, with applications in synthetic chemistry, storage solutions, and conversion. [26, 27].It was the heterogeneous and shape and size variations of nanoparticles that contributed to their extraordinary catalytic performance. Therefore, the emphasis of this study is the process through which the physical characteristics of nanoparticles influence their reactive characteristics, along with the effects of manufacture boundary on these physical characteristics [28, 32]. A researcher is able to build and create nano catalysts that are exceedingly dynamic, incredibly specialised, and tremendously robust by obtaining a deeper understanding of them. All of these advantages will allow present synthetic processes to become more resource-efficient, use fewer resources, and generate less waste, hence minimizing the environmental impact of our reliance on synthesis techniques. Nanomaterials are regarded as the most significant catalysis of the twenty-first century and have a wide range of uses, include chemical processing, energy storage, and transformation.

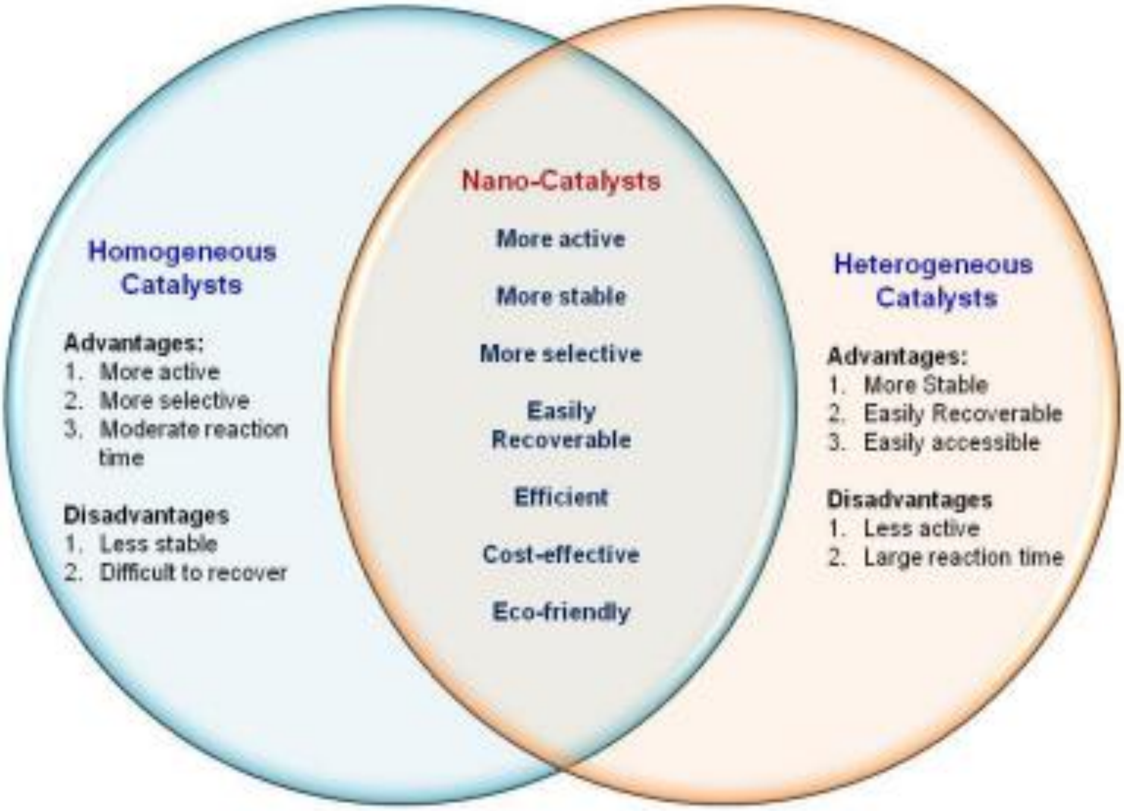

Fig. 1 Difference between homogeneous, heterogeneous and nano-catalysts

2.1 Different Methods of Nano catalyst Synthesis

In general, there seem to be two approaches for producing nano catalysts: bottom-up and top-down. In the initial step, the substance is broken down into nanoparticles [33,34]. Many nanoparticles of metal are generated using top-down techniques. The bottom-up process, on the other hand, involves the successive building of molecules, atoms, and clusters. This approach investigates the development of single-molecule nanoscale structures [35]. Bottom-up techniques include synthesis and characterization, supercritical synthesis, plasma or flaming spatter synthesis, laser pyrolysis, molecules condensation, the sol–gel method, and chemical reduction(Figure 2). Physicochemical interactions can affect the properties of nanomaterials during this procedure, while smaller units are utilised to form particles. Thus, the structure and dimension of nanoparticles are regulated by kinetics processes that influence methodologies.

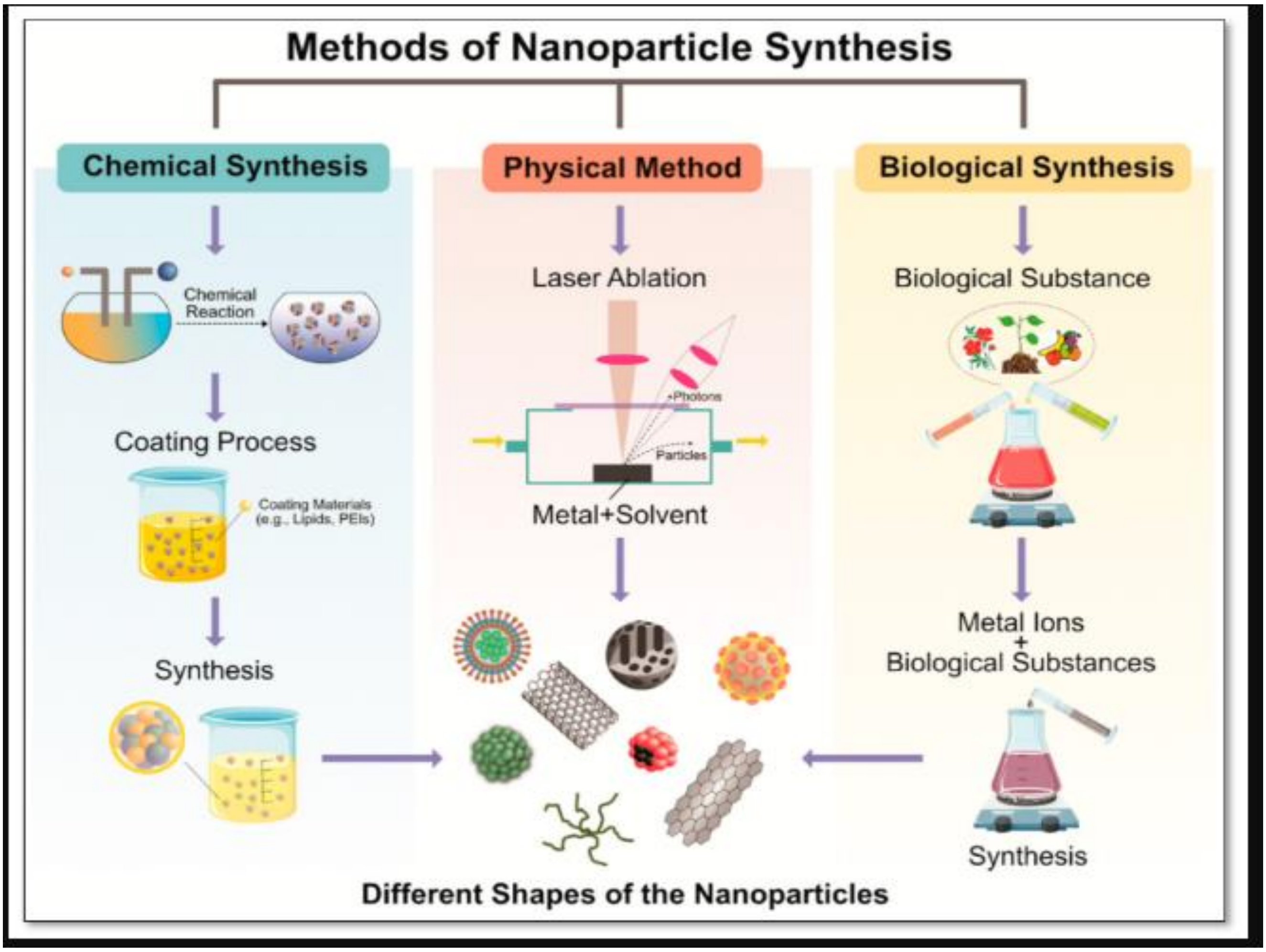

Figure 2. Method of Nanoparticle synthesis

2.2 Biological Approach for Nano catalyst

Due to it's own eco-friendliness, efficacy, and ecological value, the biology method is favoured over the other two prominent procedures [36]. The biological process generates nanoparticles with an increased surface area, a higher catalytic rate, metal salt, and enhanced enzymes [37]. Thus, the primary purpose of the biological particles synthesis technique is to make use of minimal resources and promote the continuous production of nanoparticles. Using renewable resources for synthesizing nanoparticles offers a straightforward procedure, a simple rise in biomass, and homogeneous particle size and multiplication. Employing microorganisms to produce nanoparticles is among the most frequent biological approaches. Due to their ability to live and multiply under extreme climatic circumstances, bacterial cells are the species best suitable for nanoparticle manufacturing. Even with the presence of elevated metal concentrations, they are able to reproduce and multiply, which could be the result of specific resistance mechanisms.

Furthermore, bacterial strains that aren't resistant to high concentrations of metals may be used as suitable microorganisms. Significant biological applications, such as bioleaching, biocorrosion, biomineralization, and bioremediation, are produced by nanoparticles produced by microorganisms. It is straightforward to mass-produce nanoparticles with tunable size and shape [38]. Similarly, algae may create a wide range of bioactive compounds, pigments, and protein that aid in salt reductions and serve as a stabilizing factor in the production mechanism. [39]. Besides bacteria, fungus and algae are also capable of producing nanoparticles from green sources.

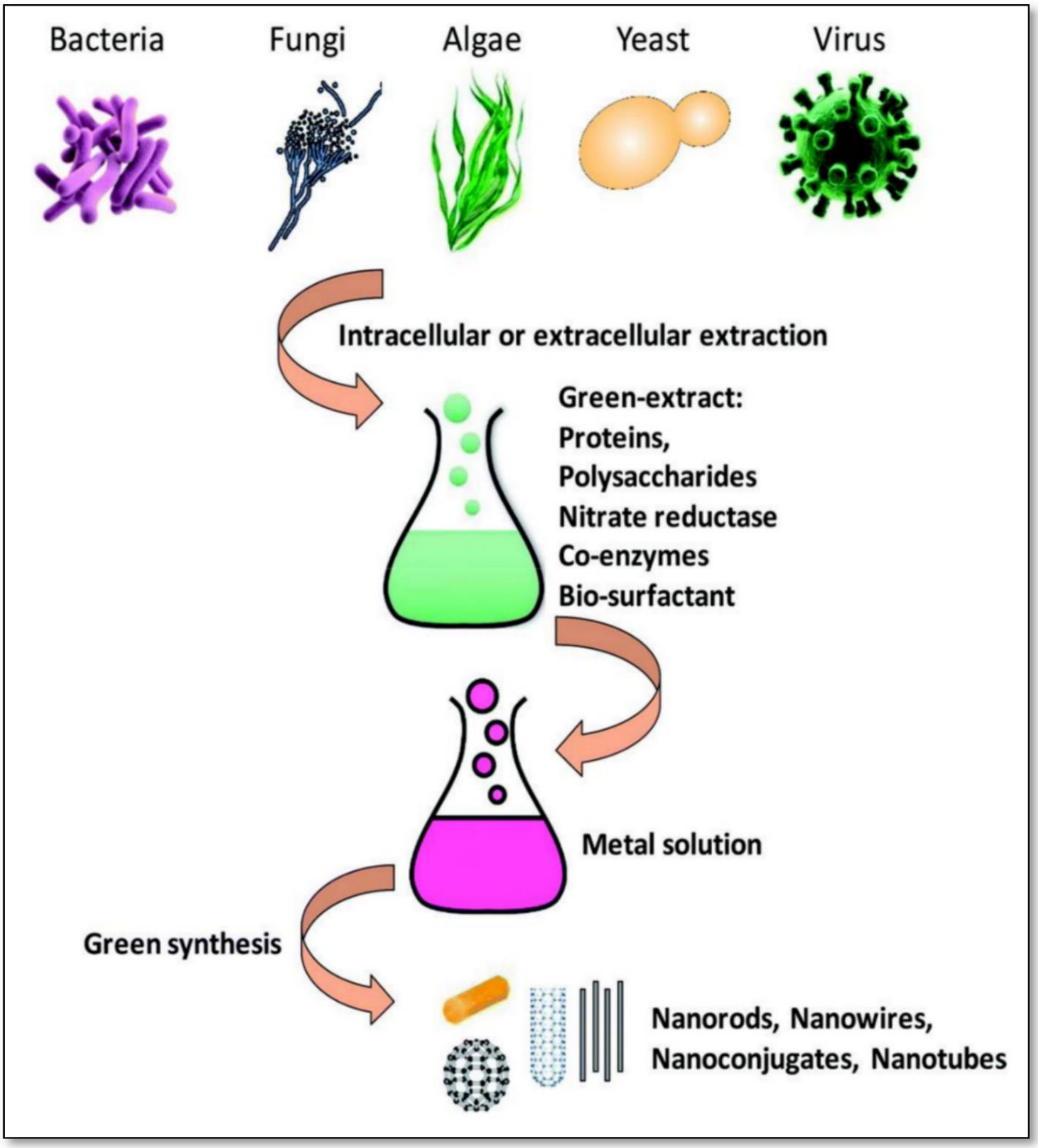

Figure 3. Biological approach to nanoparticle synthesis

3. Applications of Nano catalysts

There are a range of applications for biosynthesized nanoparticles. Also identified was the utilisation of nanoparticles of gold and silver as antibacterial drugs against a variety of ailments. In addition, they are anticancer, antiviral, antimalarial, and antifungal [40,42]. In addition to the electrical, optical, cosmetic, coating, sensing device, pharmaceutical, environmental health, and chemical sectors, these materials are also utilized in the optical, cosmetic, medical, and environmental health industries. [43]. They have developed a revolutionary approach of giving medications and DNA through a drug delivery system. Acc. to another study [44], nano particles with different surface and active faces can demonstrate a range of antibacterial effects as a result of their unique form. Mishra et al. [45] found that Penicillium brevi compactum manufactures gold nanoparticles and evaluated their potential efficacy against lateral blast cancer cells. The analyses Chauhan et al. [46] disclosed the manufacture of nano particles and evaluated their anticancer efficacy against liver cancer cells. In a second investigation, the antibacterial efficacy of silver nanoparticles derived from Stoechospermum marginatum was investigated against Enterobacter faecalis. It is more antibacterially effective than tetracycline, though E. coli was resistant to it [47]. Soni and Prakash [48] utilized Aspergillus niger to generate gold nanoparticles and assessed their effectiveness against the larvae of Anopheles stephensi, Aedes aegypti, and Culex quinquefasciatus. It was discovered that nanoparticles are more effective against C. quinquefasciatus. Sunkar and Nachiyar [49] found the synthesis of silver nanoparticles by Bacillus cereus. [50] Antibacterial activity against S. aureus, K. pneumonia, E. coli, S. typhi, and P. aeruginosa has been identified. Abdeen et al. study reported the production of particles from Ulva lactuca and discovered that at low concentrations, these particles hindered the growth of Plasmodium falciparum[52]. Streptomyces bikiniensis was used in a different study to produce selenium nanorods, and its potential anticancer impact on human cancer cells was evaluated [53]. Borse et al. [54] evaluated the antitumor efficacy of nanomaterials against Saccharomyces boulardii-derived MCF-7 and A431 cell lines. Mohamed et al. It has been demonstrated that nanostructured materials limit B. subtilis viability. Streptomyces cyaneus was employed in a different study to manufacture gold nanoparticles and analyze their anticancer activity on liver and breast cells. Researchers found that gold nanoparticles exacerbate mitochondrial apoptosis, DNA damage, and cytokinesis cessation [56]. Salmonella infantis, Salmonella typhimurium, and Salmonella typhimurium [57]. aureus, Bacillus subtilis, Proteus mirabilis, Klebsiella pneumoniae, Pseudomonas aeruginosa, and E. coli. According to Arya et al., E. coli, K. pneumoniae, P. aeruginosa, and S. aureus are potentially hazardous. According to Husain et al. [59], cyanobacteria-produced silver nanoparticles exhibited photocatalytic capabilities against dye. Nanoparticles, according to Dananjaya et al., are effective antifungal agents and, as a result, are non-cytotoxic to all cell types. Escherichia sp. was used in this work to produce copper nanoparticles, degrade azo dye, and purify textile effluent. Electrical conductivity, pH, turbidity, total dissolved solids, total suspended solids, harshness, chlorides, and sulphates of textile effluent were dramatically reduced in comparisonto untreated samples[61].

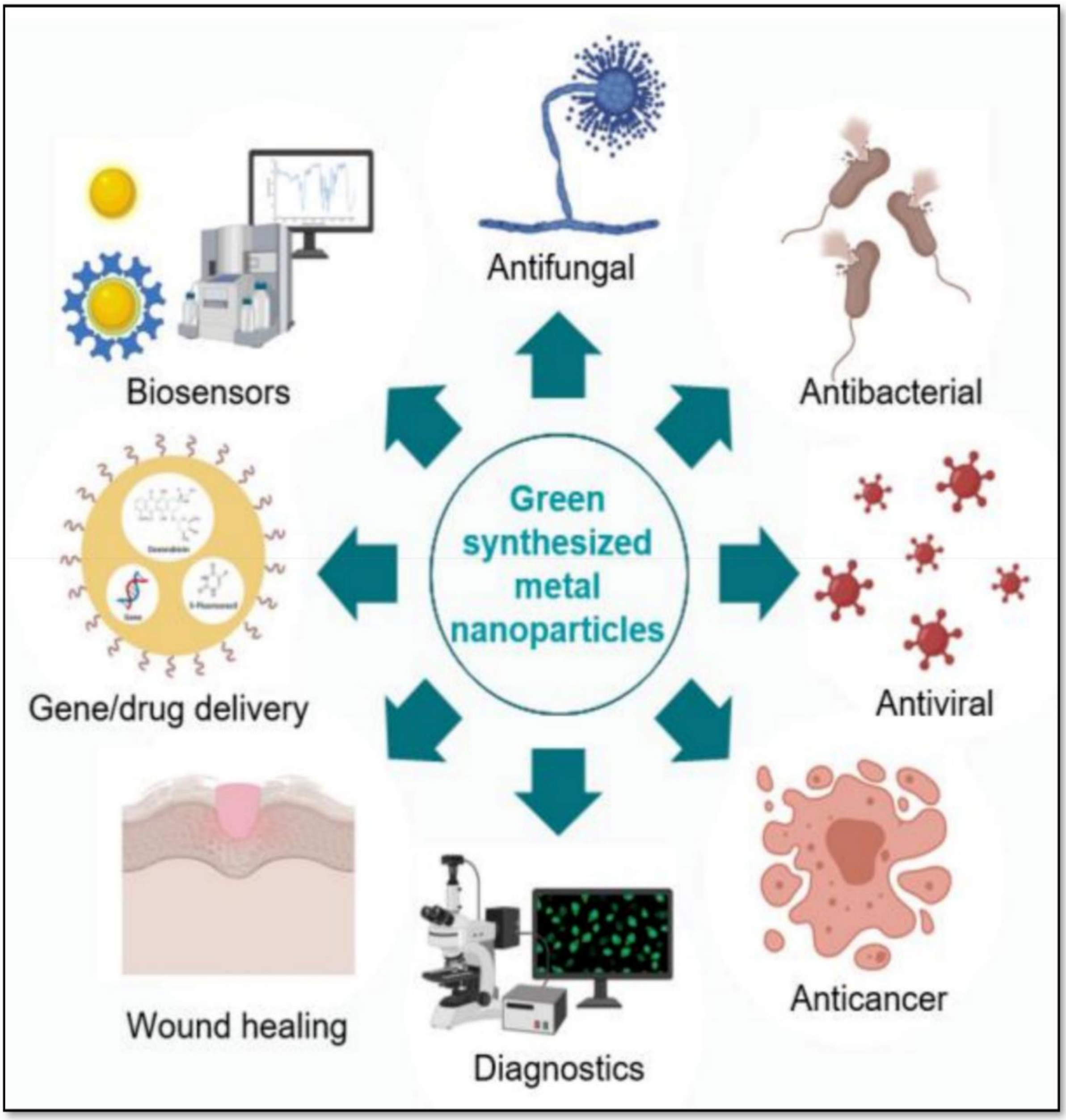

Figure 4. Biological applications of nano catalyst

3.1 Application of nano catalyst in the treatment of industrial effluent /waste water

Gawande, et al. [14] Nano magnetite-coated nanoparticles were investigated for their potential utility in critical medicinal, green chemical, and catalytic reactions. Several major reactions have been catalysed by metal nano catalysts supported on magnetite [62] that have been successfully exploited in organic synthesis. Nanoparticles can purify wastewater by eliminating a variety of contaminants. Nanoparticles are manufactured for a specific purpose, and there is no chance that pollutants will remain following nano treatment. TiO2, ZnO, ceramic membranes, nano-structured membrane proteins, polymer membranes, nanotubes, submicron nano powder, metal (oxides), nanocrystals, etc. are cost-effective nanoparticles for wastewater treatments, and their large surface area, rapid dissolution, high sensitivity, and high adsorption contribute to efficient purification. Making use of particle in treating wastewater typically involves the five methods outlined below:

3.1.1 Absorption

Absorption, the first step in the treatment of wastewater, eliminates both organic and inorganic pollutants. The absorption kinetic capabilities, the lack of selectivity, and the active site all have an impact on how effective absorbents are.Ca-based adsorbents have desired nanomaterial features, including a large specific area, easily reliable adsorption sites, a variety of contaminant-CNT interactions, flexible surface chemistry, and easy reusability. Using carbon nanotubes, pollutants are preconcentrated, identified, and adsorbed.

3.1.2 Membranes and membrane processes

The membrane's size-dependent barrier effectively separates solutes from solvents. Membrane technologies also provide more effective water filtration with less area and chemicals, a greater level of adequate automation, and the highest level of adaptability since water flowing solids of varying sizes. In contrast, the most challenging aspect of this situation is the economic progress among membranes selectivity and permeability.

3.1.3 Photocatalysis

We eradicate dangerous trace contaminants and pathogenic bacteria using photocatalysis. It is a technique for the photocatalytic oxidation of low-intensity light using a slow-kinetic catalyst. TiO2 is used in nano-photocatalytic optimisation, a photocatalysis technique, because of its photocatalytic properties in the UV and perhaps visible spectrum, low cost, high stability, and low toxicity to humans. TiO2 photocatalysts can enhance the kinetic and photoactivity range of photocatalysts.

3.1.4 Disinfection and microbial control

Due to the harmful by-products that chlorine and ozone disinfectants produce, including such halogenated disinfectant by-products, carcinogenic nitrosamines, bromate, etc., they can be detrimental to organisms and their environment. UV-disinfection also requires a high viral concentration. In the absence of considerable oxidation, nano-Ag, nano-ZnO, nano-TiO2, nano-Ce2O4, CNTs, and fullerenes demonstrate antibacterial characteristics and a limited capacity to generate DBPs. These can enhance the water's quality by disinfection, fouling controls on membranes, and biofilm access on other appropriate surfaces

3.1.5 Sensing and Monitoring

These nano sensors are highly effective at detecting any remaining compounds and pathogenic organisms in water. After eradicating all pollutants and pathogens, there is still a possibility that they exist, and even minor negligence can rapidly spread fatal diseases. The broad absorption spectrum of these particles is accompanied by a narrow, brilliant, and continuous emission that is proportionate to their size and chemical make-up. High conductivity, sensitivity, and consistency, superparamagnetism, enhanced regionally based resonance, abundant silica chemistry for simple conjugation, a vast surface area, superior mechanical force and chemical stability, exceptional electrical structures, and tunability surface composition are all characteristics of this material.

CONCLUSION

The development of ecologically friendly and economically advantageous nano - materials processing and application technologies is in high demand. Although several chemical and physical processes have been developed for the synthesis of nanomaterials, the creation of dangerous and nonbiodegradable by products continues to be a serious problem. In this perspective, the biogenic production of nanomaterials provides an alternate technique for resolving the limitations of chemical and physical processes. The biological process provides precise control over the particle size and form, while maintaining the same physical properties as the physical and chemical procedures. Due to their decreased toxicity, biologically produced nanomaterials are better suited for biomedical applications. This paper focuses on organic polymer-supported metal catalysts, noble metal nano catalysts, and magnetic nano catalysts, and then outlines their mechanism in industrial effluent treatment. For the elimination of industrial effluents, these nano catalysts have been shown to be effective and have interesting applications, according to studies. Since that low-cost preparation is essential for their use in wastewater treatment, future study might concentrate on measuring the interaction processes of these nanomaterials in the water treatment system and enhancing their economic feasibility. In addition, the environmental toxicity of these nanomaterials must be considered.

REFERENCES

1 Roy, A.; Bharadvaja, N. Silver nanoparticle synthesis from *Plumbago zeylanica* and its dye degradation activity. *Bioinspired Biomim. Nanobiomaterials* 2019, *8*, 130–140

2 H. Hu, J.H. Xin, H. Hu, X. Wang, D. Miao, Y. Liu, Synthesis and stabilization of metal nanocatalysts for reduction reactions–a review, Journal of materials chemistry A 3(21) (2015) 11157-11182.

3 Ahmed, H.M.; Roy, A.; Wahab, M.; Ahmed, M.; Othman-Qadir, G.; Elesawy, B.H.; Khandaker, M.U.; Islam, M.N.; Emran, T.B. Applications of Nanomaterials in Agrifood and Pharmaceutical Industry. *J. Nanomater.* 2021, *2021*, 1472096.

4 A. Tkaczyk, K. Mitrowska, A. Posyniak, Synthetic organic dyes as contaminants of the aquatic environment and their implications for ecosystems: a review, Science of The Total Environment 717 (2020)

5 Jeevanandam, J.; Barhoum, A.; Chan, Y.S.; Dufresne, A.; Danquah, M.K. Review on nanoparticles and nanostructured materials: History, sources, toxicity and regulations. *Beilstein J. Nanotechnol.* 2018, *9*, 1050–1074.

6 Remya, V.R.; Abitha, V.K.; Rajput, P.S.; Rane, A.V.; Dutta, A. Silver nanoparticles green synthesis: A mini review. Chem. Int. 2017, 3, 165–171.

7 S.B. Singh, P.K. Tandon, Catalysis: a brief review on nano-catalyst, J Energy Chem Eng 2(3) (2014)

8 Iravani, S.; Korbekandi, H.; Mirmohammadi, S.V.; Zolfaghari, B. Synthesis of silver nanoparticles: Chemical, physical and biological methods. Res. Pharm. Sci. 2014, 9, 385.

9 Raina, S.; Roy, A.; Bharadvaja, N. Degradation of dyes using biologically synthesized silver and copper nanoparticles. *Environ. Nanotechnol. Monit. Manag.* 2020, *13*, 100278.

10 Nagore, P.; Ghotekar, S.; Mane, K.; Ghoti, A.; Bilal, M.; Roy, A. Structural Properties and Antimicrobial Activities of *Polyalthia longifolia* Leaf Extract-Mediated CuO Nanoparticles. *BioNanoScience* 2021, *11*, 579–589.

11 Khan, I.; Saeed, K.; Khan, I. Nanoparticles: Properties, applications and toxicities. Arab. J. Chem. 2019, 12, 908–931.

12 Roy, A.; Bharadvaja, N. Qualitative analysis of phytocompounds and synthesis of silver nanoparticles from Centella asiatica. Innov. Tech. Agric. 2017

13 Nath, D.; Banerjee, P. Green nanotechnology—A new hope for medical biology. Environ. Toxicol. Pharmacol. 2013, 36, 997–1014.

14Jeyaraj, M.; Gurunathan, S.; Qasim, M.; Kang, M.H.; Kim, J.H. A comprehensive review on the synthesis, characterization, and biomedical application of platinum nanoparticles. Nanomaterials 2019, 9, 1719.

15 Q. Sun, X. Fu, R. Si, C.H. Wang, N. Yan, Mesoporous silica-encaged ultrafine bimetallic nanocatalysts for CO2 hydrogenation to formates, ChemCatChem 11(20) (2019)

16 P.C.L. Muraro, S.R. Mortari, B.S. Vizzotto, G. Chuy, C. Dos Santos, L.F.W. Brum, W.L. da Silva, Iron oxide nanocatalyst with titanium and silver nanoparticles: Synthesis, characterization and photocatalytic activity on the degradation of Rhodamine B dye, Scientific reports 10(1) (2020)

17 G. Jaiswal, V.G. Landge, D. Jagadeesan, E. Balaraman, Iron-based nanocatalyst for the acceptorless dehydrogenation reactions, Nature communications 8(1) (2017)

18 H. Suo, L. Xu, Y. Xue, X. Qiu, H. Huang, Y. Hu, Ionic liquids-modified cellulose coated magnetic nanoparticles for enzyme immobilization: improvement of catalytic performance, Carbohydrate polymers 234 (2020)

19 S.L. Candelaria, Y. Shao, W. Zhou, X. Li, J. Xiao, J.-G. Zhang, Y. Wang, J. Liu, J. Li, G. Cao, Nanostructured carbon for energy storage and conversion, Nano energy, 1 (2012)

20 K. Yan, A. Chen, Efficient hydrogenation of biomass-derived furfural and levulinic acid on the facilely synthesized noble-metal-free Cu–Cr catalyst, Energy, 58 (2013)

21 K. Yan, C. Jarvis, T. Lafleur, Y. Qiao, X. Xie, Novel synthesis of Pd nanoparticles for hydrogenation of biomass-derived platform chemicals showing enhanced catalytic performance, RSC advances 3(48) (2013) 25865-25871.

22 S. Luo, Z. Zeng, G. Zeng, Z. Liu, R. Xiao, M. Chen, L. Tang, W. Tang, C. Lai, M. Cheng, Metal organic frameworks as robust host of palladium nanoparticles in heterogeneous catalysis: Synthesis, application, and prospect, ACS applied materials & interfaces 11(36) (2019)

23 M.J. Ndolomingo, N. Bingwa, R. Meijboom, Review of supported metal nanoparticles: synthesis methodologies, advantages and application as catalysts, Journal of Materials Science 55(15) (2020)

24 Roy, A.; Bharadvaja, N. Silver nanoparticles synthesis from a pharmaceutically important medicinal plant *Plumbago zeylanica*. *MOJ Bioequivalence Bioavailab*. 2017, *3*, 00046.

25 Liang, X.J.; Kumar, A.; Shi, D.; Cui, D. Nanostructures for medicine and pharmaceuticals. *J. Nanomater*. 2012, *2012*, 921897

26 Guilger-Casagrande, M.; de Lima, R. Synthesis of Silver Nanoparticles Mediated by Fungi: A Review. *Front. Bioeng. Biotechnol.* 2019, *7*, 287.

27 Huynh, K.H.; Pham, X.H.; Kim, J.; Lee, S.H.; Chang, H.; Rho, W.Y.; Jun, B.H. Synthesis, properties, and biological applications of metallic alloy nanoparticles. *Int. J. Mol. Sci.* 2020, *21*, 5174.

28 Roy, A.; Bharadvaja, N. Silver nanoparticle synthesis from *Plumbago zeylanica* and its dye degradation activity. *Bioinspired Biomim. Nanobiomaterials* 2019,8,130-140

29 Roy, A. Plant Derived Silver Nanoparticles and their Therapeutic Applications. *Curr. Pharm. Biotechnol.* 2021, *22*, 1834–1847.

30 Rajathi, F.A.A.; Parthiban, C.; Kumar, V.G.; Anantharaman, P. Biosynthesis of antibacterial gold nanoparticles using brown alga, *Stoechospermum marginatum* (kützing). *Spectrochim. Acta Part A Mol. Biomol. Spectrosc.* 2012, *99*, 166–173.

31 Soni, N.; Prakash, S. Synthesis of gold nanoparticles by the fungus *Aspergillus niger* and its efficacy against mosquito larvae. *Rep. Parasitol.* 2012, *2*, 1–7.

32 Sunkar, S.; Nachiyar, C.V. Biogenesis of antibacterial silver nanoparticles using the endophytic bacterium *Bacillus cereus* isolated from *Garcinia xanthochymus*. *Asian Pac. J. Trop. Biomed.* 2012, *2*, 953–959

33 Ahmad, M.S.; Yasser, M.M.; Sholkamy, E.N.; Ali, A.M.; Mehanni, M.M. Anticancer activity of biostabilized selenium nanorods synthesized by *Streptomyces bikiniensis* strain Ess_amA-1. *Int. J. Nanomed*. 2015, *10*, 3389.

34 Borse, V.; Kaler, A.; Banerjee, U.C. Microbial synthesis of platinum nanoparticles and evaluation of their anticancer activity. *Int. Conf. Recent Trends Eng. Technol.* 2015, *11*, 26–31.

35 Mohamed, Y.M.; Azzam, A.M.; Amin, B.H.; Safwat, N.A. Mycosynthesis of iron nanoparticles by *Alternaria alternata* and its antibacterial activity. *Afr. J. Biotechnol.* 2015, *14*, 1234–1241.

36 El-Batal, A.I.; Mona, S.; Al-Tamie, M. Biosynthesis of gold nanoparticles using marine *Streptomyces cyaneus* and their antimicrobial, antioxidant and antitumor (in vitro) activities. *J. Chem. Pharm. Res.* 2015, *7*, 1020–1036.

37 Składanowski, M.; Wypij, M.; Laskowski, D.; Golińska, P.; Dahm, H.; Rai, M. Silver and gold nanoparticles synthesized from *Streptomyces* sp. isolated from acid forest soil with special reference to its antibacterial activity against pathogens. *J. Clust. Sci.* 2017, *28*, 59–79.

38 Husain, S.; Afreen, S.; Yasin, D.; Afzal, B.; Fatma, T. Cyanobacteria as a bioreactor for synthesis of silver nanoparticles—An effect of different reaction conditions on the size of nanoparticles and their dye decolorization ability. *J. Ofmmicrobiological Methods* 2019, *162*, 77–82.

39 Dananjaya, S.H.S.; Thao, N.T.; Wijerathna, H.M.S.M.; Lee, J.; Edussuriya, M.; Choi, D.; Kumar, R.S. In vitro and in vivo anticandidal efficacy of green synthesized gold nanoparticles using *Spirulina maxima* polysaccharide. *Process Biochem*. 2020, *92*, 138–148.

40 Noman, M.; Shahid, M.; Ahmed, T.; Niazi, M.B.K.; Hussain, S.; Song, F.; Manzoor, I. Use of biogenic copper nanoparticles synthesized from a native *Escherichia* sp. as photocatalysts for azo dye degradation and treatment of textile effluents. *Environ. Pollut.* 2020, *257*, 113514.

41 A. Marjani, M.H. Zare, M.H. Sadeghi, S. Shirazian, M. Ghadiri, Synthesis of alginate-coated magnetic nanocatalyst containing high-performance integrated enzyme for phenol removal, Journal of Environmental Chemical Engineering (2020)

42 Rónavári, A.; Igaz, N.; Adamecz, D.I.; Szerencsés, B.; Molnar, C.; Kónya, Z.; Pfeiffer, I.; Kiricsi, M. Green silver and gold nanoparticles: Biological synthesis approaches and potentials for biomedical applications. *Molecules* 2021, *26*, 844.

43 Batool, S.; Akib, S.; Ahmad, M.; Balkhair, K.S.; Ashraf, M.A. Study of modern nano enhanced techniques for removal of dyes and metals. *J. Nanomater.* 2014, *2014*, 1–20.

44 Srivastava, N.; Mukhopadhyay, M. Biosynthesis of SnO_2 nanoparticles using bacterium *Erwinia herbicola* and their photocatalytic activity for degradation of dyes. *Ind. Eng. Chem. Res.* 2014, *53*, 13971–13979.

45 Kalpana, V.N.; Kataru, B.A.S.; Sravani, N.; Vigneshwari, T.; Panneerselvam, A.; Rajeswari, V.D. Biosynthesis of zinc oxide nanoparticles using culture filtrates of *Aspergillus niger*: Antimicrobial textiles and dye degradation studies. *OpenNano* 2018

46 M.J. Ndolomingo, N. Bingwa, R. Meijboom, Review of supported metal nanoparticles: synthesis methodologies, advantages and application as catalysts, Journal of Materials Science 55(15) (2020)

47 Roy, A.; Bharadvaja, N. Silver nanoparticle synthesis from *Plumbago zeylanica* and its dye degradation activity. *Bioinspired Biomim. Nanobiomaterials* 2019, *8*, 130–140.

48 Ahmed, H.M.; Roy, A.; Wahab, M.; Ahmed, M.; Othman-Qadir, G.; Elesawy, B.H.; Khandaker, M.U.; Islam, M.N.; Emran, T.B. Applications of Nanomaterials in Agrifood and Pharmaceutical Industry. *J. Nanomater.* 2021, *2021*, 1472096.

49 Raina, S.; Roy, A.; Bharadvaja, N. Degradation of dyes using biologically synthesized silver and copper nanoparticles. *Environ. Nanotechnol. Monit. Manag.* 2020, *13*, 100278.

50 Nagore, P.; Ghotekar, S.; Mane, K.; Ghoti, A.; Bilal, M.; Roy, A. Structural Properties and Antimicrobial Activities of *Polyalthia longifolia* Leaf Extract-Mediated CuO Nanoparticles. *BioNanoScience* 2021, *11*, 579–589.

51 "Kunduru, Konda Reddy & Nazarkovsky, Michael & Farah, Shady & Pawar, Rajendra & Basu, Arijit & Domb, Abraham. (2017). Nanotechnology for water purification: Applications of nanotechnology methods in wastewater treatment. 10.1016/B978-0-12-804300-4.00002-2."