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Nanoparticles in Environmental Remediation with special reference to Polyethylene biodegradation-A review

Sharique Ali , Ayesha Ali & Shazia Khan
Department of Biotechnology and Bioscience, Saifia Science College, Bhopal, MP- India
Corresponding Author: Ms. Shazia Khan, Research Scholar, Department of Biotechnology and Bioscience, Saifia Science College, Bhopal, Madhya Pradesh, India,
E-mail - shaziakhan.i2013@yahoo.in

ABSTRACT
Polyethylene has become integral part of modern life and is used in different sectors of applications like packaging, building materials, cosmetics, consumer products, medicine etc. The world wide use of polyethylene is expanding and global demand is increasing day by day. The polyethylene being an unavoidable necessity has spanned high level of environmental pollution due to its poor waste disposal and therefore requires sophisticated methods for its degradation management. The conventional methods have shown inadequate degradation. Nanotechnology has vast applications in various fields and researchers are discovering its horizon in the field of Environmental Remediation. Nano materials may serve as a plausible weapon for the reduction and management of solid wastes accumulating in the environment. Nano materials may be applied for bioremediation, which will not only have less toxic effect on microorganisms, but will also improve the microbial activity of the specific waste and toxic material reducing the overall time consumption and cost. In this review paper we have briefly summarized the major types of nanoparticles that have been used so far in bioremediation of polyethylene waste and we have found that these nanoparticles are effective in polyethylene degradation. The mechanism is by enhancing the bio film formation rate on polyethylene by altering the metabolism of microorganisms and their multiplication rate. Alternatively nanoparticles may enhance the rate of photo oxidation of polyethylene.
Keywords: nanoparticles, polyethylene, biodegradation, microorganisms, environment, remediation

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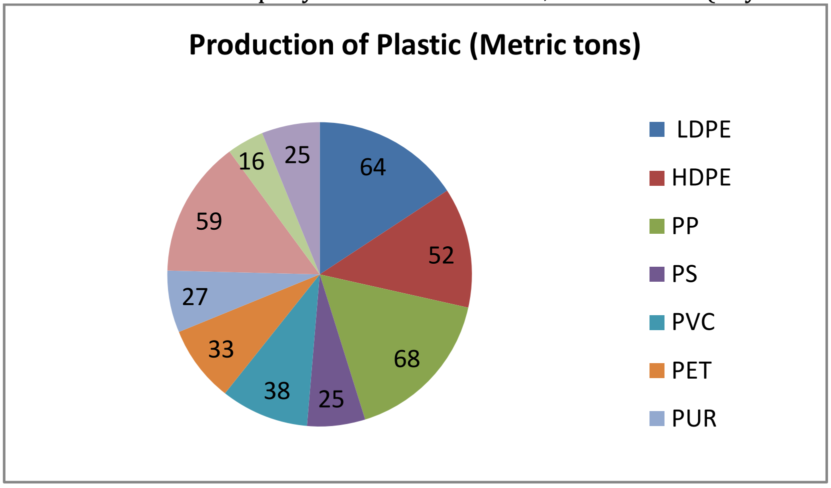
INTRODUCTION

The contamination of soil and water bodies due to dispersal of industrial wastes and urban waste generated by human activities is of great environmental concern (1). One of the major threats to environment is the slow degradation or non degradation of plastic under natural conditions. Plastics like polyethylene-terephthalate (PET), nylon, polycarbonate, high density polyethylene (HDPE), low density polyethylene (LDPE), polyvinyl chloride (PVC), polypropylene (PP), polystyrene (PS), polyurethane, and styrene are continuously used in our day to day life. Among these polyethylene is the most commonly used plastic which is a linear hydrocarbon polymer consisting of long chains of ethylene monomers and shares 64% of the synthetic plastic waste [2].

Polyethylene is extensively used in packaging of products like food, pharmaceuticals, cosmetics, detergents and chemicals. The disposal methods of polyethylene involve incineration, recycling and land filling [3]. Recycling is costly, land filling and Incineration causes pollution. Polyethylene contributes as a major pollutant due to its vast usage, durability and non-degradability. It accumulates at the rate of 25 million tons per year [4]. Polyethylene waste is a widespread and persistent global challenge with negative impacts on the environment, economy, human health and aesthetics [5].

Figure 1.Production of Plastic per year in metric tonnes, Data Source: (Geyer et al. 2017)



Incineration of polyethylene causes heavy toxic smoke generation releasing hazardous gases such as methane, ethane, aldehydes, ketones and acrolein [6; 7]. Chemicals like vinyl chloride (in PVC), dioxins (in PVC), benzene (in polystyrene), phthalates (in PVC), formaldehyde, and bisphenol-A, or BPA (in polycarbonate) used during plastic synthesis are responsible for diseases like cancers, birth defects, impaired immunity, endocrine disruption and other ailments in humans [8]. Toxic chemicals from plastics drain out and seep into groundwater, flowing downstream into lakes and rivers [9]. Plastic has entered the food chain of Wildlife they eat it or mistake it for food; marine animals are losing their lives entangled in plastic [10]. Plankton, the tiniest creatures in our oceans, are eating micro plastics and absorbing their hazardous chemicals. The plastic debris is displacing the algae needed to sustain larger sea life who feed on them in water bodies [11].

The scientist's fraternity is looking for the eco friendly alternatives to replace the plastic either with bio plastic which are designed to degrade under environmental conditions or in municipal and industrial biological waste treatment facilities [12; 13]. However, none of them is efficiently biodegradable in landfills. At present, biodegradable polyethylene represents just a tiny market as compared with the conventional petrochemical market. Hence, there is an urgent need to develop efficient microorganisms and their products to solve this global issue [14]. Biodegradation plays a key role in reducing the molecular weight of the polyethylene by naturally occurring microbes like bacteria, fungi and actinomycetes isolated from different environments [15; 16]. But this process is slow due to deliberate growth rate of micro-organisms which are involved in the procedure.

Nanoparticles have entered the scientific world with varied impending applications. Studies with nanoparticles have shown that they influence the growth profile of polyethylene degrading micro-organisms which in turn boost the polyethylene biodegradation rate. The present review focuses on the researches related to the degradation aspect where nanoparticles have acted as enhancers of biodegradation.

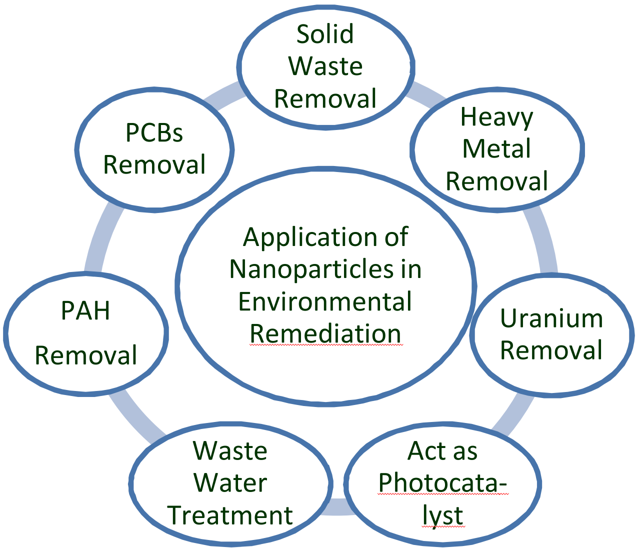
NANOPARTICLES OVERVIEW

Recent advancements in the field of nanotechnology and the unique properties of nanoparticles make them usable in various fields like medicine, diagnostics, Cell-signaling, drug-targeting, waste water treatment, food packaging, agriculture and other Industries [17-23]. The high surface to volume ratio of nanoscale materials is associated with a number of novel and desirable properties compared with the corresponding bulk materials. Nanoparticles, with a size range of about 1–100nm, are said to have a greater surface area per weight than larger particles, making them more reactive to other molecules [24]. Owing to the huge surface area to volume ratio, nanostructures display unique properties and extensively changing physical, chemical and biological properties by cause of their fine size, structure, and morphology. There are expanding achievements of nanotechnology to protect the environment from toxic waste, and remove the problems, which are present from the long-term use of hazardous waste materials. Nanoparticles are exploited for remediation for example, Zinc Oxide (ZnO), iron oxide (Fe_2O_3), cobalt oxide (Co_2O_3) and additional different nanoparticles can eliminate contaminants from topsoil and ground water and nanostructure sensors hold guarantee for improved detection and tracking of contaminants [25].

Nanoparticles with dimensions 1-100nm are far more advantageous than their majority phase counterparts in the field of remediation technology because of definite characteristics such as high surface-to-volume ratio, enhanced magnetic and special catalytic properties etc. [26]. The high surface area and surface reactivity of nanoparticle accelerates remediation of the contamination with lesser harmful by products [27]. Different type of nanomaterials like carbon nanotubes (CNTs), nanoscale zeolites, dendrimer enzymes, biometallic particles and metal oxides are used for decontamination processes (28).Multi-walled carbon nanotubes are used to remove organic contaminants like Poly Aromatic Hydrocarbons (PAH) and polychlorinated biphenyls (PCBs) [29].

Nanoparticles are incorporated with enzymes which are helpful for remediation, as nanoparticles provide biocompatible and inert microenvironment without interfering with the properties of enzyme and help them in their biological actions [30]. Nanoparticles are also used for immobilization of cells, enzymes and proteins from the reaction mixtures using magnetic properties of the nanoparticles escaping the need of centrifugation or purification [31]. In remediation procedure some selective nanoparticles are used which are non toxic for the microorganisms to be used for bioremediation [32].

Figure 2.Applications of Nanoparticles in Environmental Remediation



Synthesis of nanoparticles

Nanoparticles are prepared by various methods such as chemical, physical and biological methods. Various chemical methods are used for the fabrication of nanostructure materials such as controlled precipitation, sol–gel synthesis, hydrothermal reactions, sonochemical reactions, reverse micelles and micro-emulsion technology, hydrolysis and thermolysis of precursors. Physical method involves techniques like Pulse laser ablation, evaporation–condensation, ball milling, sputtering and pulse wire discharge method. The physical and chemical approach demands lot of energy, high temperature, pressure, uses harmful chemicals, time consuming, less productive and non eco-friendly process so scientists focused on Biological synthesis of nanoparticles which entail less energy, lesser time, cost effective and eco-friendly process [33].

Microorganism as nanofactories holds enormous potential as cost-effective, ecofriendly, non-toxic, chemical free and peripheral energy free method of nanoparticles synthesis giving rise to an era of "Green Nanotechnology" [34]. Microbes have the capability to accumulate and detoxify heavy metals with the help of diverse Reductase enzymes able to reduce metal salts to metal nanoparticles with narrow size distribution and less polydisperity. In last few years various bacteria, fungi, yeasts, and algae are exploited for the extra- and intracellular synthesis of silver nanoparticles [35].

The use of plants and plant extract in green synthesis of nanoparticles "Phytonanotechnology" has stimulated as it is locally available, eco-friendly, cost effective, easily accessible, non-pathogenic, single step and safe to handle method and have a large range of metabolites that can advance the reduction of metal salts [35]. It is studied that green synthesis using plant and plant extracts appears to be faster than other microorganisms, such as bacteria and fungi and synthesize nanoparticles using universal solvent, water, as reducing medium [36]. The plant parts like roots, latex, stem, seeds, fruits, leaves and their extracts are being used for nanoparticle synthesis [37].

Characterization of Nanoparticles

The prepared nanoparticles are examined by numerous characterization techniques such as X-ray diffraction (XRD), scanning electron microscopy (SEM), transmission electron microscopy (TEM), Brunauer– Emmett–Teller (BET), absorbance spectroscopy, and photoluminescence spectroscopy. XRD revealed the crystalline nature of the nanoparticles. SEM and TEM images provide information about the morphology and particle size distribution, and BET disclose the surface properties of the nanoparticles. Optical properties are studied by absorbance and photoluminescence spectroscopic techniques [25].

NANOPARTICLES IN POLYETHYLENE DEGRADATION: MAJOR FINDINGS

To enhance the efficiency of biodegradation, several researchers have explored the unique properties of nanoparticles (NPs), predominantly their size-activity relationships which influence the growth statics of microorganisms (38). Nanoparticles affect bacterial growth kinetics in both adverse and favourable ways, barium nanoparticles have been shown to inhibit the growth of bacteria, fungi, mosses, and algae (62). Gold nanoparticles, Titanium dioxide and silver are reported to have antimicrobial activities [39; 40], whereas cobalt-ferrite nanoparticles have been reported to increase the growth of *E. coli* and *C. xerosis* [41]. This positive impact of nanoparticles on the growth of certain bacteria in appropriate concentration has opened a way for plastic waste management, as they can enhance plastic biodegradation. Here are some reviews signifying the enhanced biodegradation rate of polyethylene using nanoparticles *in vitro*.

Flores *et al*. 2004 [41] investigated the effect of cobalt ferrite nanoparticles 15-40 nm in size on the growth of *E.coli* and *C. xerosis*. Cobalt ferrite reported to augment the growth of *Escherichia coli* and *Corynebacterium xerosis*. They took 4 sets of experiment; the one set is with medium (Nutrient Broth) containing test organism *E.coli*, LDPE and nanoparticles, the second set is with medium (Nutrient Broth) containing test organism *C.xerosis*, LDPE and nanoparticles, third with medium (Nutrient Broth), LDPE and *C.xerosis* and the last one with medium (Nutrient Broth), LDPE and *E.coli.* They kept them for incubation at 37^0C with homogeneous shaking. The growth was measured by Spectrophotometer at 640nm in the visible range of 30-min for 20hr. Initially there is difference in the growth rates of *E.coli* with nanoparticles and without nanoparticles, the growth rate of *E.coli* containing nanoparticles at the start was very high but after third hour of incubation both behave the same way possibly because of the presence of a critical population of bacteria. The *Corynebacterium xerosis* has shown more growth in the presence of nanoparticles in comparison with the one which grow in the absence of nanoparticles. Flores and his associates concluded that the enhanced growth of microorganisms in the presence of nanoparticles is due to Bacterial cell-interaction via the electric polarity of bacteria with magnetic property of the Cobalt Ferrite nanoparticles. Alternatively they have concluded that nanoparticles may act as Biosurfactants and helps in the attachment of microorganisms with the plastic surface by providing hydrophilic surface for microorganism to adhere and grow properly. Another possible cause of this action is the creation of cofactors produced in the medium in presence of the Nanoparticles. These cofactors are not yet determined.

Sah *et al.* [42] assessed the quality of Fullerene-60 nanoparticles for studying their effect on the low-density polyethylene (LDPE) biodegradation using two potential polymer-degrading consortia. Consortium 1 comprising *Microbacterium sp. strain MK3* (DQ318884), *Pseudomonas putida strain MK4* (DQ318885*), Bacterium Te68R strain PN12* (DQ423487) and consortium 2 comprising *P. aeruginosa strain PS1* (EU741797), *P. putida strain PW1* (EU741798), and *P. aeruginosa strain C1* (EU753182). They have selected these strains as they have showed pre-identified potential to degrade a variety of polymers like LDPE (43; 44; 45), HDPE (44), epoxy, and epoxy silicone blends [46]. Sah and his associates (42) used four concentrations 0.01%, 0.25%, 0.5%, and 1% (w/v) of fullerene-60 and found that the fullerene-60 is harmful for the growth of bacteria at higher concentrations (viz., 0.25%, 0.5%, and 1%). However, addition of 0.01% fullerene-60 into the biodegradation assays containing 5 mg/ml LDPE subside growth curves considerably, further analysis of the degraded products revealed an enhanced biodegradation. Fourier transform infrared spectroscopy (FTIR) analysis revealed breakage and formation of chemical bonds along with the introduction of ν C-O frequencies into the hydrocarbon backbone of LDPE. Thermogravimetric-differential thermogravimetry-differential thermal analysis (TG-DTGDTA) results revealed higher number of decomposition steps along with 1,000-fold decrease in the heat of reactions (ΔH) in fullerene-assisted biodegraded LDPE, indicating the probable formation of multiple macromolecular by products.

Kapri *et al.* [43] using the same consortium as mentioned above observed the effect of nanobarium titanate (NBT) nanoparticles on the efficiency of LDPE biodegradation and found that these nanoparticles shorten the lag phase and elongates the exponential as well as stationary growth phases increasing the biodegradation rate. *In-vitro* biodegradation studies unveil better dissolution of LDPE in

the presence of NBT as compared to control. Noteworthy shifting in λ-max values was observed in the treated samples through UV-Vis spectroscopy, while FTIR and simultaneous TG-DTG-DTA further confirmed the breakage and formation of bonds in the polymer backbone. They concluded that the implementation of NBT as nutritional additive for plastic waste management accelerates bacterial growth.
Pathak and Kumar; 2017 [47] demonstrated that the use of Silicon dioxide (SiO_2) at concentration of 0.01% w/v for low density polyethylene (LDPE) degradation *in vitro* using minimal salt medium, two strains *Bacillus sp. V8 and Pseudomonas sp. C 2 5* were found effective in biodegradation of LDPE. SiO_2 nanoparticles improved growth profiling by shifting in lag phase and increases the biodegradation efficiency of bacterial strains by means of k-max shifts, and FTIR analysis revealed the formation or alteration of the chemical structure (C–H stretching, O–H stretching, and C:H stretching) of the degraded polymer.
Recently Erika *et al.* [48] used Iron Nanoparticles for enhancing LDPE Biodegradation using a bacterial consortium composed of *Bacillus pseudofirmus* and *Bacillus agaradhaerens*. They found that the supplementation of iron oxide nanoparticles (IONPs) significantly increased the bacterial growth, along with shortened lag phase and longer stationary phase. After 60 days of Incubation the bacterial consortium, in the presence and absence of IONPs, was able to reduce the weight of the residual polymer up to 18.3 ± 0.3% and 13.7 ± 0.5%, respectively. Hydrocarbon test demonstrated higher hydrophobicity of the consortium with IONPs. FTIR and SEM analysis revealed chemical bond shifting and pronounced disruption of surface texture in the presence of IONPs confirming biodegradation. They also concluded that the formulation of alkaliphilic bacterial consortium grown in the presence of nanoparticles accelerates the rate of LDPE film degradation. Literature review shows that these particles could enhance biodegradation by increasing the growth rate of microorganisms, thereby amplifying the production of hydrolytic enzymes, acids, organic acids and exoenzymes [49].
Different classes of microorganisms show different susceptibilities to nanoparticles it is dose-size dependent process some nanoparticles are antimicrobial while some enhances microbial growth [40]. Furthermore different factors such as synthesis, shape, size, composition, agglomeration rate and addition of stabilizers can lead to different conclusions even for very closely related nano suspensions [38].There are various nano-particles that augment growth cycle, mechanical and physiochemical stability along with biodegradability (Listed in Table 1 near here).

Probable Mechanism of polyethylene degradation using Nanoparticles

Photo catalysis

Nanoparticles as Photocatalyst enhance the photooxidation process in polyethylene by intensifying the absorption of Ultra Violet (UV) radiation which represents only 5% of the solar spectrum [25; 50]. Nanoparticles facilitate the absorption of photons and generation of electrons which reacts with environmental oxygen to form reactive oxygen species (ROS) or free radicals like hydroperoxide. Free radicals formed will react with the oxy and peroxy radicals and they remove hydrogen from the polymer (polyethylene) chains making them easily available as source of carbohydrates for the micro-organisms. Oxidative degradation leads to chemical structure changes in polymers and reduction in polymer molecular weight due to the breakage of molecular chain. The other visible impact are loss in flexibility, scratches, fine cracks, discoloration and transparency change or reduced gloss on the polymer surface [51].

Genetic Alteration

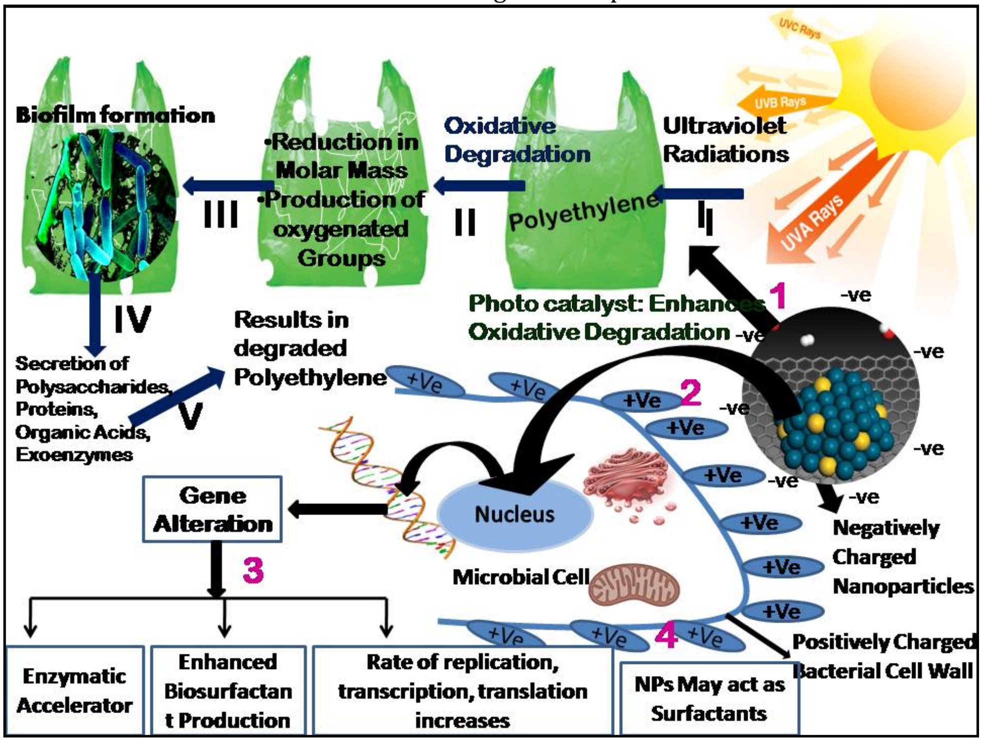
The toxicity of Nanoparticles towards microbial cells is a well researched fact. But how come some of the microbial cells are not affected by nanoparticles and grow well in their presence? As nanoparticles become more common and widely used in various fields, the chances of unplanned events leading to their dissemination and accumulation in the environment increase, and could lead to unforeseen changes to biological systems [52]. The interaction of the microbial cells and nanoparticles in the natural environment cannot be denied as a matter of fact some microbes become vulnerable while others mutated and become tolerant. Might be some have mutated in a positive way and started using these nanoparticles as growth supplement/co-factor or might be they accumulate them in their nucleus which leads to alteration in genes leading to enhance protein or enzyme production which ultimately enhanced replication, transcription and translation processes. Literature review showed that some of the microbes produce excessive Biosurfactants in the presence of nanoparticles that can inhibit the hydrophobicity of petroleum hydrocarbons by reducing the surface tension and appreciating the bioavailability of hydrophobic pollutants to microorganisms [53]. Same is the possibility with the bioremediation of polyethylene using nanoparticles of defined size and shape or may be nanoparticles themselves can act as Biosurfactants and enhances the biodegradation.

Table 1: List of Nanoparticles with their impact on the growth of micro-organisms

S.No.	Nanoparticle/ Nanocomposite	Size/ Concentration	Bacteria/ Consortium	Effect on growth	Reason	Reference
1.	Nanobarium titanate (NBT)	38 nm	**Consortium:** *Mycobacterium sp. Strain MK3, Pseudomonas putida strain MK4* and *bacterium Te68R strain PN12*	Decreases the duration of lag phase and increases the duration of log phase and stationary phase.	Nanoparticle act as a nutritional additive that accelerate the degradation	(43)
2.	Fullerene 60	0.01%	**Consortium 1:** *Mycobacterium sp. Strain MK3 (DQ318884), Pseudomonas putida strain MK4 (DQ318885)* and *bacterium Te68R strain PN12(DQ423487)* **Consortium 2:** *P. aeruginosa strain PS1 (EU741797), P. putida strain PW1 (EU741798),* and *P. aeruginosa strain C1 (EU753182)*	Consortium 2 had shown decrease in growth rate. Consortium 1 had shown increase growth rate except PN12. Also it entered in log phase faster in comparison to consortium 2. . Moreover the biomass of consortium 2 was found to be greater in the presence of LDPE and fullerene as compared with consortium 1.	0.01% fullerene-60 enhances the degradation of LDPE using both the consortium.	(42)
3.	Cobalt-ferrite	15-40 nm	*Escherichia coli* and *Cornybacterium xerosis*	Reduces the duration of lag phase and increases the duration of log phase and stationary phase.	Due to some unknown cellular level interaction that enhances the metabolism of the bacteria.	(41)
4.	Gold nanoparticles	5 nm	*Escherichia coli*	Increases the size of microbial cell abruptly.	Inactivation of certain gene expression required for cytokinesis during cell division	(58)
5.	Magnetic Iron oxide nanoparticles (Fe_3O_4)	8 nm	*Escherichia coli*	Micro biostatic effect	The reactive oxygen species (ROS) and formation of free radicals. ROS results in oxidative stress, inflammation and consequent damage to proteins, membranes and DNA which is one of the primary mechanisms of nanotoxicity	(58)

6.	Superparamagnetic iron oxide nano-particles (SPION)	10.6	*Microbacterium sp., Pseudomonas putida* and *Bacterium Te68R was*	Accelerates bacterial growth also Improves the exponential phase durability	Exhibit magnetic properties that might interact with the electric polarity of the bacteria and influences its growth.	(59); (60)
7.	Silver nanoparticles	Between 20- 80 µg /ml	*Cupriavidus necator*	Extended lag phases and partial growth inhibition.	Delayed release of silver from processed material which lead to the formation of cellular stress response against nanoparticle.	(61)

Figure 3. Biodegradation of Polyethylene, Step **I, II, III, IV** and **V** represent natural degradation which takes years to degrade polyethylene, whereas step 1, 2, 3 and 4 represents how nanoparticles work in the escalation of biodegradation process.



Analytical Techniques used to monitor degradation

Several techniques are used to monitor the extent and nature of degradation of polyethylene. The mechanical properties like tensile strength, elongation at fail and modulus of the polymer give an insight about the state of polymer before degradation and after degradation. The physical properties like micro cracks, embrittlement are studied using SEM and TEM. The products from polythene degradation are also characterized using various techniques such as Thin Layer Chromatography (TLC), High Performance Liquid Chromatography (HPLC), Gas Chromatography-Mass Spectrometry (GC-MS), X-ray diffraction, Small angle X- ray scattering (SAXS) and Wide angle X-Ray scattering (WAXS). The changes in the chemical properties that could be measured include formation or disappearance of functional groups is determined by FTIR. CO_2 evolution is measured by using Modified Sturm test, biofilm studies can be carried out using the acridine orange or BacLight bacterial viability kit or triphenyl tetrazolium chloride reduction test. The metabolic activity of the cells in the culture as well as in the biofilm can be done by ATP assays, protein analysis and FDA analysis [54].

Other Applications of Nanoparticles in Environmental Remediation

There are various reports on the use of variety of nanoparticles for treatment and remediation of pollutants in the environment. Nanoparticles as adsorbents, nanosized zero valent ions or as nanofiltration membrane has been used for the removal/separation of contaminants from water since past few years. Nanoscale, bimetallic particles, such as iron/palladium, iron/silver, or zinc/palladium, can serve as potent reductants and catalysts for a large variety of common environmental contaminants such as poly chlorinated biphenyls (PCBs,) organochlorine pesticides, and halogenated organic solvents (55). Iron based nanoparticles are used to reduce many stroppy contaminants, including anions (perchlorate, nitrate, and dichromate), heavy metals (nickel and mercury), and radionuclides (uranium dioxide). ZnO nanoparticles were shown to act both as sensor and photocatalyst for treatment of chlorinated phenols [56].

Researchers are also quite interested in manipulating the surface of nanoparticles with organic or inorganic dyes to extend their photoresponse from UV to visible light, making them even more efficient as photocatalysts for the transformation of environmental contaminants because UV light represents only 5% of the solar spectrum (50). Nanoparticles that are activated by light, such as the large band-gap semiconductors titanium dioxide (TiO_2) and zinc oxide (ZnO), continue to be studied for their ability to remove organic contaminants from various media. These particles are readily available, inexpensive, and have low toxicity [56; 57].

Nanoparticles are used as photocatalysts for chemical or photochemical oxidation for the destruction of contaminants. The toxic gases present in the air can be removed by nano-photocatalysts along with simple catalyst with an enhanced surface area for gaseous reactions. Catalyst usually enhances the chemical reactions that convert harmful gases that have evolved from automobiles and industrial plants into harmless gases [25].

Nanoscale zero-valent iron (NZVI) is used for the removal of As (III), which is a highly toxic, mobile, and predominant arsenic species in anoxic groundwater. They are also used in the remediation of Dichlorobenzens, Bromoform, TNT, Chlorobenzene Dibromochloromethane, Dichromate, DDT, Dibromochloromethane, Lindane Tetrachloroethene Perchlorate etc [32].

CONCLUSION

While reviewing the papers related to degradation of polythene in the presence of nanoparticles different and sometimes contradictory results have been mentioned concerning the effect of the nanoparticles in enhancing microbial growth and Oxidative degradation rate. There are various papers suggesting that nanoparticles have no obvious effect on the growth of micro-organisms, some of them suggested a small to substantial enhancement and some others suggested acceleration in growth of micro-organisms which in turn inflate the biodegradation. Critical understanding of influence of these nano particles on microbial cell growth and functions in polyethylene degradation is still need to be investigated. We need to find out the perfect combination of particular sized nanoparticle, their concentrations/ dose and micro-organism or group of microorganism which together as a combo completely degrade the polythene in no time.

Alternatively we can immobilize those extracellular enzymes which act as catalyst in biodegradation of polyethylene using magnetic properties of nano materials from the polyethylene degrading medium. It is an effective way which will increase the stability, longevity, and reusability of the biodegradable enzymes. Magnetic nanoparticles shield the enzymes protecting them from being oxidised. The ability of nanoparticles to impede environmental pollution is in progress and could potentially catalyze the most revolutionary changes in the environmental field in the coming decades.

The nanoparticles-microbial interaction can be utilized for beneficial biological application but significantly it also possesses potential to produce nano toxicity, challenging the eco friendly nature of nanoparticles. So the proper knowledge of these interactions can lead to a safe era of nanotechnology without threat of human health risk.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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