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Biocompatible Transition Metal Nanoparticles for Antibacterial Apllication

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ABSTRACT

Nanoparticles exhibit size-dependent physical and chemical properties. These properties of nanoparticles make them very special, as they are. Hence, many researchers are doing their research in the field of nanotechnology. This review focuses on the antibacterial activity of transition metal nanoparticles. During this review, it is found that the biocompatible transition metal nanoparticles exhibit the photo-oxidizing and photocatalysis impacts on chemical and biological systems/species. This photo-oxidizing and photocatalytic impact are beneficial for killing bacteria or inhibiting their growth. The metal nanoparticles such as TiO2, Fe2O3, Silver nanoparticles, Gold nanoparticles, etc. have good antibacterial activity. This study can open new doors to fight and control future health hazards.
Keywords: Nanoparticles; transition metals; biocompatible

I. INTRODUCTION

'There's plenty of room at the bottom'. With this lecture, Dr. Richard Feynman presented a vision about controlling things at nanoscale [1]. Nanotechnology deals with the particles having size in the range of 1 nm to 100 nm [1-3]. The small size of nanomaterials (or the nanoparticles) leads to an increase in surface area to volume ratio. If something has more surface area, then there are more places for other chemicals to bind or react with it. When the size of materials is reduced to nanoscale, their properties are observed to change drastically. Research have shown that there are vast applications of Nanotechnology in Technology, Optics, Computer chips, pollutant elimination, targeted drug delivery [4], therapeutic inventions [4], advances in cancer therapies, biology and medicine [5], sensors, cosmetics, engineering, etc.

Among all the fields of Nanotechnology, 'Nanobiotechnology' is one of the most promising fields. Nanobiotechnology is considered as a fusion of Nanotechnology with Biotechnology [3]. The field has tremendous biomedical applications, antibacterial and antimicrobial applications; this field extends a helping hand into contemporary biological issues [3].

Biocompatibility is a word that is used broadly within biomaterial sciences. Biocompatibility simply means the ability of a material to perform with an appropriate host without causing harmful effects to its surrounding tissues. The term antibacterial activity refers to an activity of nanoparticles by virtue of which, the bacteria are killed or their growth is slowed down, without showing any harmful effects to the surrounding bodies.

Generally, the materials showing the antibacterial activity are referred as antibacterial agents. The antibacterial agents can be either 'Bactericidal' or 'Bacteriostatic'. Bactericidal antibacterial agents kill the bacteria; while bacteriostatic antibacterial agents slow down the bacterial growth. Many bacteria show some extent of resistance against antibiotics and other antibacterial agents and they continue to be a major health hazard. Hence many researchers are trying to overcome this problem with the help of nanoparticles.

Inspite of all the research that has been done until now, there is still an argument about positive and negative effects of nanoparticles on human health and environment. Some researchers are suggesting not using the nanomaterials in human medicine and in environment. On the other hand, some researchers have shown exemplary effects of nanoparticles on bacteria, viruses and they are suggesting the use of nanoparticles in environment. Some scientists believe that their side effects are acceptable [5]. Some researchers have shown that mostly toxic effects are shown to biological systems by non-biodegradable and non-biocompatible nanoparticles and they can also influence cells in bodies. But, there are ways to reduce the toxicity of nanoparticles. Therefore, suggestions are given to use biocompatible and biodegradable nanoparticles, which have been observed to show the reduction in toxicity and reduction in negative effects on biological systems; on which they are tested.

Despite of much research that has been conducted, the mechanism of antibacterial activity of nanoparticles is still not satisfactorily explained. Also the antibacterial activity can be proved beneficial in order to get control on bacterial infectious diseases. Its study can open new doors to fight and control future health hazards. Therefore, the presented review deals with the investigation of biocompatible transition metal nanoparticles for their antibacterial applications.

In future, this study could open up new strategies for the bacterial infection treatments, cancer treatments and for designing delivery vehicles for targeted drug delivery techniques. Nanoparticles showing antibacterial properties can be a good substitute to antibiotics. This study can be beneficial to employ in medicinal research and nano-biotechnology research.

II. SYNTHESIS METHODS

There are mainly two approaches for the synthesis of nanoparticles. One is 'Top-Down approach' and other is 'Bottom-Up approach'.

The top-down method involves breakup of bulk materials into a fine powder and then into nanoparticles. The bottom-up approach involoves the build-up of a material from the bottom: atom by atom, molecule by molecule or cluster by cluster. The main advantage of bottom-up method is that it involves wide range of preparation methods which allow good control over size of the particles and these methods are not as costly as the top-down methods.

A. Sol-gel method:

Sol-gel process is a bottom-up approach for preparation of nanoparticles.

Sol-gel method is based on the conversion of a system from a liquid phase (sol) into a gelatinous phase (gel). 'Sol' means a colloidal suspension of particles. Sol-gel method can be carried out either in aqueous or in non-aqueous medium. The starting materials i.e. precursors used in sol-gel method for the preparation of sol are usually inorganic metal salts or metal organic compounds. Sol is prepared by mixing liquid alkoxide precursor with an acid or base catalyst at room temperature. During this, alkoxide groups are removed by hydrolysis reactions and a network linkage is formed by condensation reaction. When the sol is formed, it is then cast into a mould and wet gel is formed. After this step, the treatment of sol is varied depending on the desired product.

This is a cost efficient process. It does not require high temperature maintenance. This process can be used to produce thin films of metal oxides, metal oxide nanoparticles and oxide nanocomposites, ceramic and glass nanomaterials.

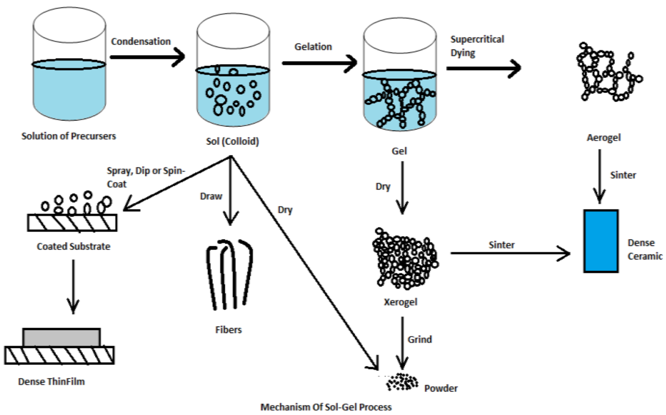

Figure 1. Diagramatic representation of sol-gel method

B. Electrochemical synthesis:

Electrochemical synthesis of nanoparticles technique consists of mainly six steps:-

1. Oxidative dissolution of anode
2. Migration of metal ions to the cathodes
3. Reduction of ions to zero-valent state
4. Formation of particles by nucleation and growth

5. Arrest of growth by capping agents
6. Precipitation of particles.

This method has been used to synthesize Ni, Co, Fe, Ti, Ag, and Au nanoparticles. Bimetallic colloids such as Pd–Ni, Fe–Co, and Fe–Ni have been prepared using two anodes consisting of metals. The size of the nanocrystals could be controlled by changing the current density, the distance between the electrodes, the reaction time, the temperature, and the polarity of the solvent.

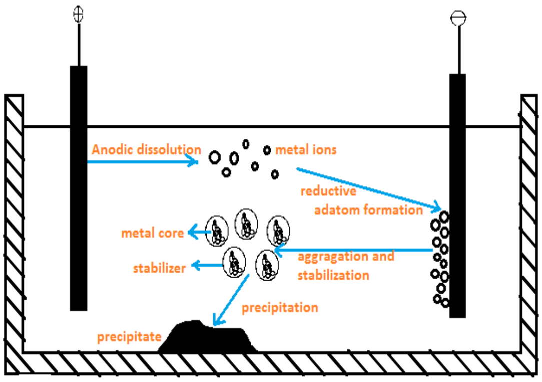

Figure 2. Schematic representation of electrochemical reduction of metal NPs by Reetz method

C. Biological method:

Nanoparticles can be produced using the intracellular and an extracellular extract of organisms [6], the extract is simply mixed with a solution of the metal salt at room temperature. The reaction is complete within minutes. The nature of the living extract, its concentration, the concentration of the metal salt, the pH, temperature and contact time are known to affect the rate of production, the quantity and other characteristics of the nanoparticles. Velusamy *et al* [7] have prepared nanoparticles by this process.

D. Thermal decomposition method:

Thermal decomposition technique is used to synthesize inorganic metal nanoparticles. Metal NPs are synthesized by the thermal decomposition of molecules containing zerovalent metals. In this method organometallic precursor compounds and surfactant are heated up to the combustion temperature of the metallic salt. Furthermore, metal oxides such as iron oxide, copper oxide and metal phosphors nanoparticles have also been synthesized by this method.

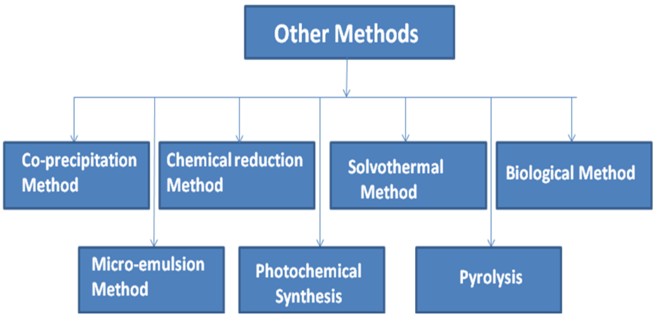

Figure 3. Tree diagram of synthesis methods of nanoparticles

III. APPLICATIONS

Nanoparticles have applications in optics, electronics, computing, biology and medicine, technology, engineering, etc.

1. Applications in Optics:

Photocurrent generation, electroluminescence, light emitting diode formation has been done on nano level. Lasers have also been fabricated by using the nanomaterials. The wavelength of the stimulated emission is varied by changing nanoparticles size.

2. Applications in Electronics:

Nanoelectronics can be used to build memory devices, to store bits of information, to manufacture nanotube transistors, nanotube flat-panel displays, nanotube integrated circuits, fast logic gates, switches [1]. Single electron transistors have been fabricated by using nanocrystals. The Single electron transistors (SET) are energy efficient transistors. Such transistors have been fabricated based on lithographically defined quantum dots. Another application of nanocrystals is their use as vapour sensors. Many researchers are taking interest in examining nanomaterial based electronic devices. Another application of nanoparticles is Supercapacitors. The electrode of supercapacitors are generally consists of transition metal oxides & high surface carbons. Supercpacitors have beneficial capacitive energy density and low material cost [8].

3. Applications in Biology and Medicine:

Magnetic oxide nanoparticles such as Iron oxide, ZnO, TiO_2, nanoparticles are considered to be biocompatible. By employing red blood cells labelled with iron oxide nanoparticles, malaria parasite can be detected.

Nanoparticles can be used for nano based wound dressing for infections [2]. Nanotechnology and nanomaterials find a wide application in cardiology and vascular therapy in the treatment of patients with venous and arterial thrombosis, the manufacture of intravascular and intra-cardiac implants. Nanotechnology is applicable in cancer therapy and diagnosis. Nanomedicines that have been manufactured have shown high sensitivity and precision for cancerous cells.

4. Antibacterial Applications:

Nanoparticles have shown excellent antibacterial activity against many bacterial strains viz. E. coli, Pseudomonas aeruginosa, Pseudomonas stutzeri, Bacillus subtilis, etc. [7]. ZnO nanoparticles have been investigated by various researchers and these nanoparticles have shown excellent antibacterial activity against bacterial strains [9]. Antibacterial, antimicrobial and antifungal activity of nanoparticles can be very useful in treating burn wounds [2]. Antibacterial activity of nanoparticles is also applicable for food packaging [9].

Metal Nanoparticles have been investigated for transport of drugs and genes. Food-borne illnesses are an increasing major health problem in many countries. Hence, another expected implication is in food industries i.e. using nanoparticles as an antibacterial agent in food packaging and towards food-borne pathogens [9]. Addition of nanoparticles on food surfaces to inhibit bacterial growth could be a leading tool for using nanoparticles as good packaging materials.

5. Applications in Technology:

Nanotechnology provides Cost-effective water decontamination, desalination and air purification techniques. Nanocrysatals such as ZnSe, ZnS, CdS are being used for improving the resolution of monitors, nanophosphors and HD televisions. Cutting tools made of nanocrystalline materials are found to be tougher, harder and wear resistant. Smoke detectors and ice detectors used on aircraft wings is one of the application of nanotechnology. Nanoscale bio sensors, electromagnetic sensors are applicable in the fields of electronics and medical fields.

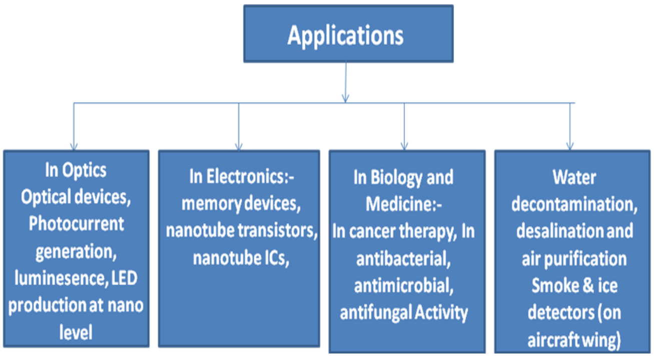

Figure 4. Applications of Nanoparticles

IV. CONCLUSION

From the literature survey, it is found that the transition metal oxide nanoparticles are biocompatible and they exhibits photo-oxidizing and photocatalysis impacts on chemical and biological systems/species. The photocatalytic activity is described as a photo-induced oxidation process that can damage and inactivate organisms. Hence, this photo-oxidizing and photocatalytic impact can be beneficial for killing bacteria or inhibiting their growth. Hence, transition metal oxide nanoparticles could be excellent antibacterial agents.

Also, from the literature survey, it is concluded that metal nanoparticles such as TiO_2, Fe_2O_3, Zn, Ag, Au etc. show good antibacterial activities.

Hence, it is concluded that biocompatible transition metal nanoparticles could be proved as excellent antibacterial agents and they could be applicable in various biological fields and in future, they can be used as an alternative for antibiotics and can further contribute for the betterment of the society.

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