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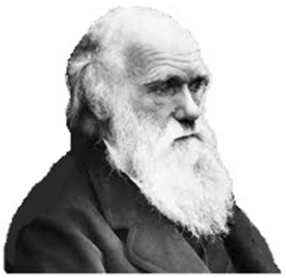

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Nanoparticles, Synthesis Methods and Applications - A Simple Review

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ABSTRACT

Nanotechnology has gained so much interest in today's world. It is known to be the science of nanoscales which is less than 100 nanometre in size. This technology has been employed for different applications due to its eco-friendly and sustainable ability in the various fields of applications. Recently, nanotechnology is used in bio sensing, drug delivery, nano devices, separation and purification purposes. These nanoparticles which are used in the building blocks of many materials, and the synthesis methods vary for all due to their physical and chemical properties. This study attempts to review the field of nanotechnology, synthesis of nanoparticles, the properties of nanoparticles, the advantages and disadvantages of different methods and their applications.

***Keywords*:** Nanoparticles, synthesis, eco-friendly, applications

1. INTRODUCTION

Nanotechnology which is the synthesis of nanoparticles is the assembling of precursor particles substances with at least one of the dimensions less than 100 nanometre (Laurent *et al*., 2010); Depending on the overall shape, these materials can be 1D, 2D, or 3D (Tiwari *et al*., 2012). This nanoparticles which have gain so much interest due to its modernised and advanced nanotechnology can be used as stabilisers, nano devices, computing and imaging, purification (Yunus *et al*., 2012). These nanoparticles are been classified into different types based on the basis of synthetic methods, shapes, and sizes. On the basis of synthetic methods, it is synthesised into two main classes which are bottom-up synthesis- formed from relatively

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simpler substances, also called building up approach and top-down synthesis- formed from larger molecule, which decompose into smaller units and then units are converted into suitable nanomaterials.

Nanomaterials are very small sized particles having nanoscale dimension with amplified catalytic reactivity, thermal conductivity, nonlinear optical performance and chemical steadiness owing to its large surface area to volume ratio (Khan *et al*., 2016). This work reviews the various methods of synthesising nanoparticles from the two approaches, characteristics, its advantages in various fields and the application of nanoparticles. Some of the important classes of nanoparticles are: Organic, Inorganic ,metal, Metal Oxide, Ceramic and biological nanoparticles

1. 1. Organic Nanoparticles

Organic nanoparticles are synthesised from organic materials. The main groups of organic nano carries are micelles, ferritin, dendrimers, and liposomes. Organic nanoparticles have a size range of 1-100 nm, and they are an ideal choice for drugs delivery due to their known shape of nanosphere or nano capsule (Patra *et al*., 2018).

1. 2. Inorganic Nanoparticles

Inorganic nanoparticles are non-toxic, biocompatible, and hydrophilic. They tend to be more stable than organic materials. They are classified into metal and metal oxide nanoparticles (Sun *et al*., 2018).

1. 2. 1. Metal Nanoparticles

Metal nanoparticles are synthesised from pure metal materials by using both destructive and constructive method. Examples of metal nanoparticles are gold, silver, titanium, cerium, platinum, zinc, iron, and thallium (Mody *et al*., 2010).

1. 2. 2. Metal oxide Nanoparticles

The synthesis of metal oxide nanoparticles modifies the property of their respective metal nanoparticles such as zinc oxide nanoparticles. They exhibit large surface area, thermal stability, and antimicrobial properties (Stankic *et al*., 2016). Some other metal oxide nanoparticles include silicon dioxide, titanium oxide, iron dioxide, aluminium oxide, cerium oxide, and magnetite known as ferric oxide (Siddiqi *et al*., 2018).

1. 3. Ceramic Nanoparticles

Ceramic nanoparticles are synthesised from ceramics, which are known as non-metallic solid. They are heat resistant, and are widely applicable in photodegradation of dye, photocatalysis, and imaging (Thomas *et al*., 2018).

1. 4. Biological Nanoparticles

Biological nanoparticles are an assembly of atoms or molecules. They show great diversity either intracellular structure (magnetosomes) or extracellular structure (lipoprotein/viruses), and have a dimension in the range of 1-100 nm.

2. NANOMATERIALS AND CLASSIFICATION ON BASIS OF DIMENSION

Nanomaterials are materials which possess a single unit small sized (in at least one dimension) measuring 1-100 nm which is the usual definition of nanoscale. They are classified into one-dimension (1D) nanomaterials, two-dimension (2D) nanomaterials, and three-dimension (3D) nanomaterials.

2. 1. One-dimension

The word nano means 10^{-9} which shows the one billionth of any unit in a nanoscale. The monolayer or thin film size ranges from 1-100 nm. These nanomaterials have much importance in research and used in the field of fabricating electronics, storage systems, LEDs with nanoscale dimension, optoelectronics, chemical and bio sensing, magneto optics, fibre optic system, and optical devices (Pospisilova *et al*., 2015).

2. 2. Two-dimension

They have a 2D nanostructure which is composed of thin layers. They can be used as key components for building nano devices (Zhang *et al*., 2016). The two-dimension nanomaterials have application in energy storage, sensors, optoelectronics, batteries.

2. 3. Three-dimension

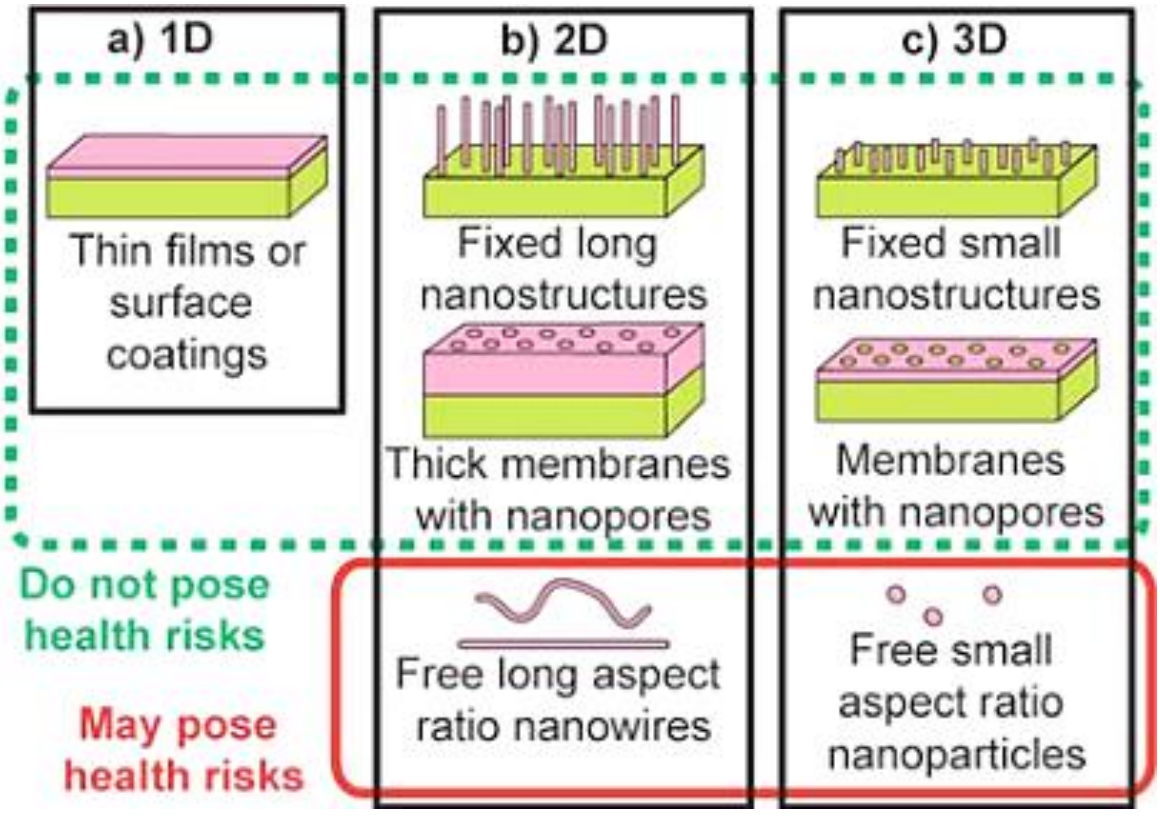

Figure 1. Various dimensions of Nanoparticle

These are nanomaterials that have a wide range of applications in the field of catalysis, magnetic materials, and lots more. Examples include fullerenes, dendrimers (Abbasi *et al*., 2014).

3. CLASSIFICATION ON THE BASIS OF SHAPES

Nanomaterials are divided into two main shapes known as high-aspect ratio and small-aspect ratio. The high-aspect ratio nanomaterials are: nanotubes, nanowires, helices, zigzags, belts whereas the small-aspect ratio ones are spherical, oval, cubic, prism, pillar nanomaterials.

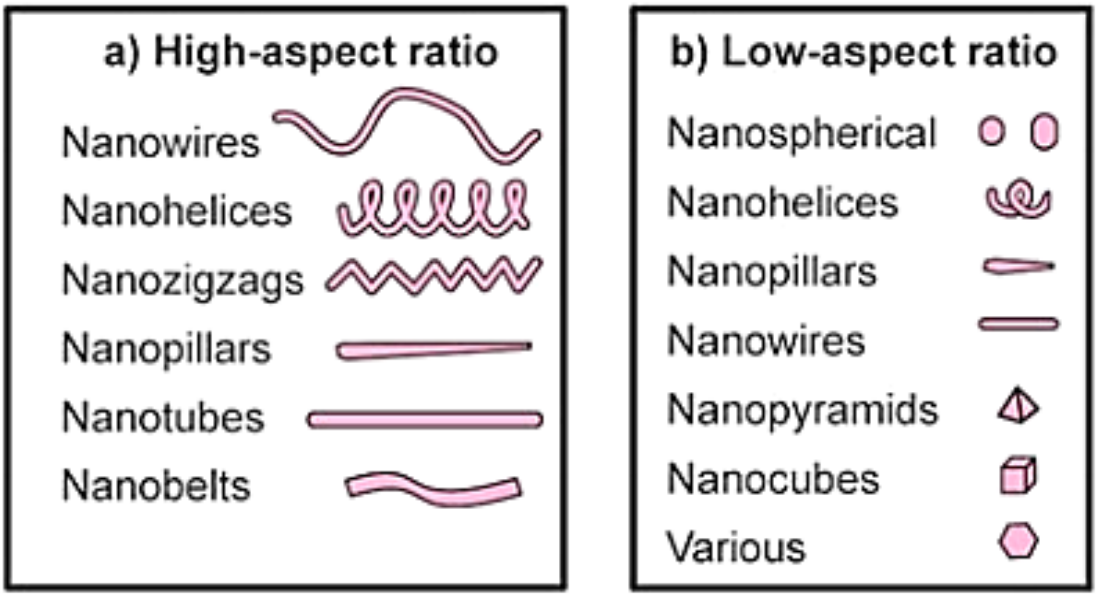

Figure 2. Shapes of Nanoparticles

4. SYNTHESIS OF NANOPARTICLES

The different classes of nanoparticles are synthesized using two methods which are top-down synthesis and bottom-up synthesis as shown in Fig. 3 (Khan *et al*., 2019).

4. 1. Top-down Synthesis of Nanoparticles

This method involves the breaking down of larger molecules into nano sized structures. Examples of top-down destructive methods are mechanical/ball milling, thermal decomposition, laser ablation, lithography, sputtering (Iravani *et al*., 2020) (Fig. 4).

4. 1. 1. Thermal decomposition

This is an innovative method that is an endothermic process in which chemical bonds are broken by heat. The deposition happens at a specific temperature at which element is chemically decomposed.

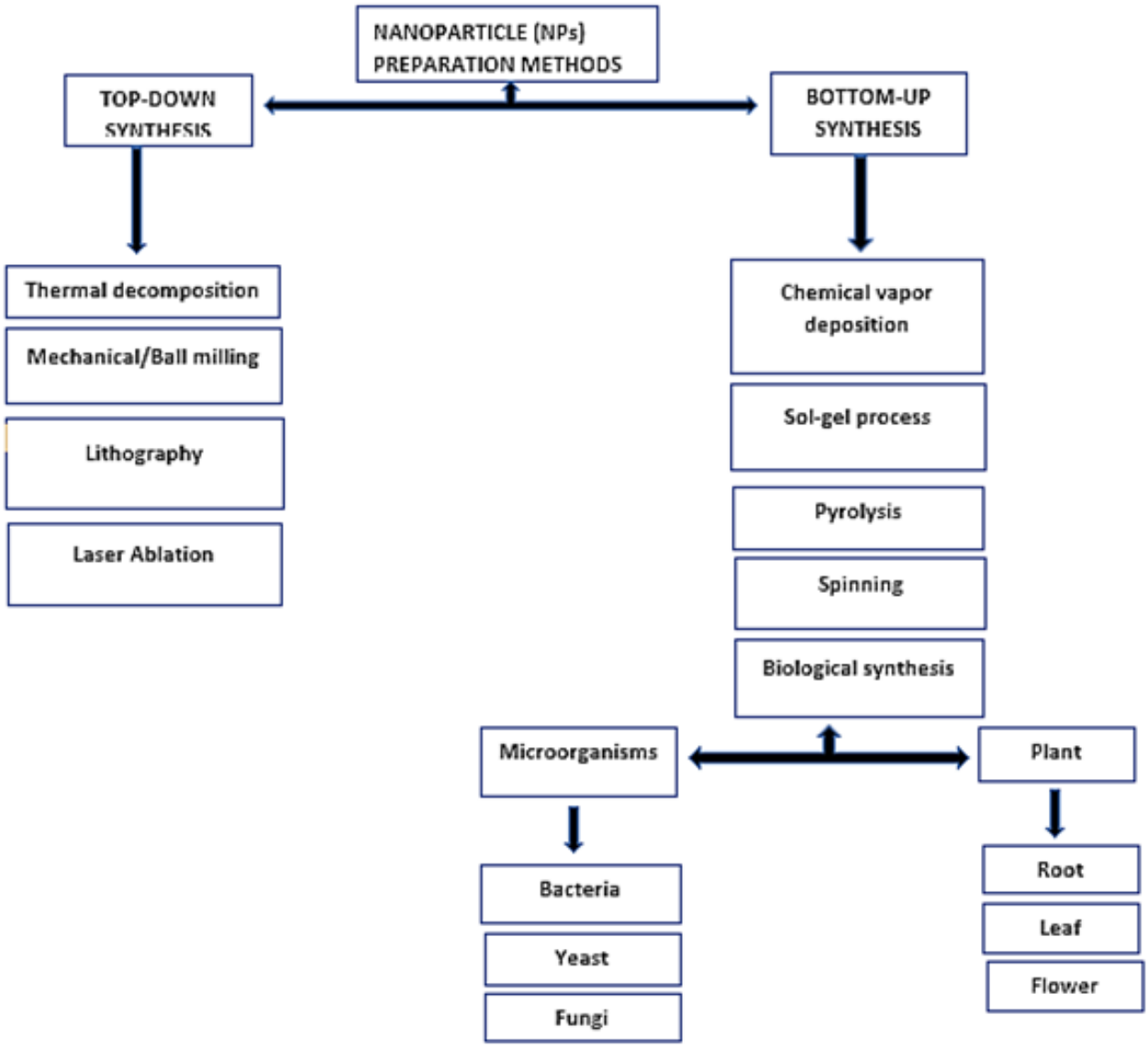

Figure 3. Synthesis methods of nanoparticles (Ijaz *et al.*, 2020)

4. 1. 2. Mechanical/ball milling

This is a process of grinding bulk materials into extremely fine powders (Yadav *et al.*, 2012). It is a medium that undergo reduction through kinetic energy. This process has the ability to reduce and blend particles into new phases.

Advantages of Mechanical/Ball milling

i. It can be scale up to produce large quantities
ii. Method of application is simple
iii. Cost of production is low

Disadvantages of Mechanical/Ball milling

i. It is difficult to get a uniform shape
ii. Takes longer time to produce an ultra-fine particles

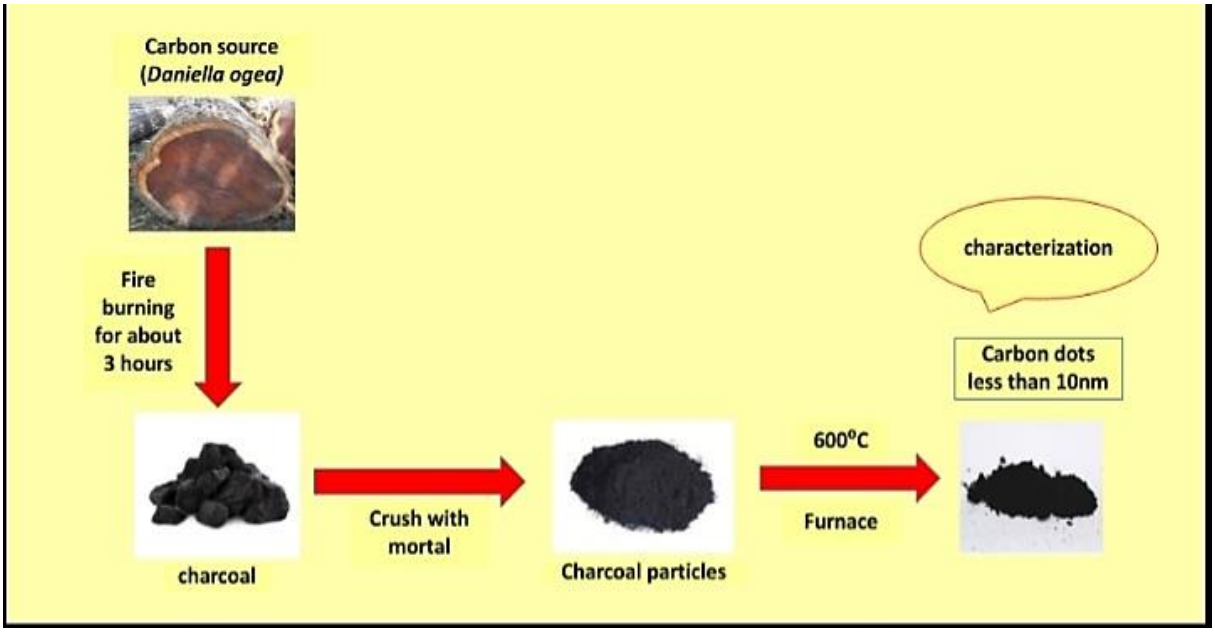

Figure 4. Carbon-dots nanoparticles

4. 1. 3. Lithographic method

This method requires a standard and complex machine to produce simple structures. They are very expensive and are used to make printed circuit and computer for several decade. There is different types of lithography which are nano-imprint, electron beam lithography, photo-lithography, focused ion lithography.

4. 1. 4. Laser ablation

This method can be used to produce carbon nanotubes, semiconductor quantum dots, nanowires, and core shell (Chernysheva *et al*., 2017). They are used to synthesis NPs from different solvent where irradiation of metals submerges in solution through laser beam to produce nanoparticles.

Advantages of Laser Ablation

i. Simplicity
ii. It works with a wide range of metals and ceramics
iii. It gives a high pure nanoparticles

Disadvantages of Laser Ablation

i. Requires high temperature

ii. Materials deposited is of low quality

4. 1. 5. Sputtering

This method occurs when ionized gas molecule is used to displace atoms of a specific material i.e., involving the deposition of NPs by means of ejection particles from it (Abdelrahman, 2015).

Advantages of Sputtering

i. It is non-thermal
ii. It is necessary to use a low vacuum

Disadvantages of Sputtering

i. High cost
ii. It is difficult to regulate the parameters of the deposition process

4. 2. Bottom-up Synthesis of Nanoparticles

This is a building up approach known as constructive method (Yan *et al.*, 2020). In this method, nanoparticles are formed from simpler substances. The below diagram is a zinc oxide nanoparticles synthesised through the building up approach. Using plant extract from *Moringa oleifera* which is mixed in a ratio with zinc acetate and sodium hydroxide to form a solution under temperature.

This solution is centrifuged and dried to form zinc oxide nanoparticles (Fig. 5).

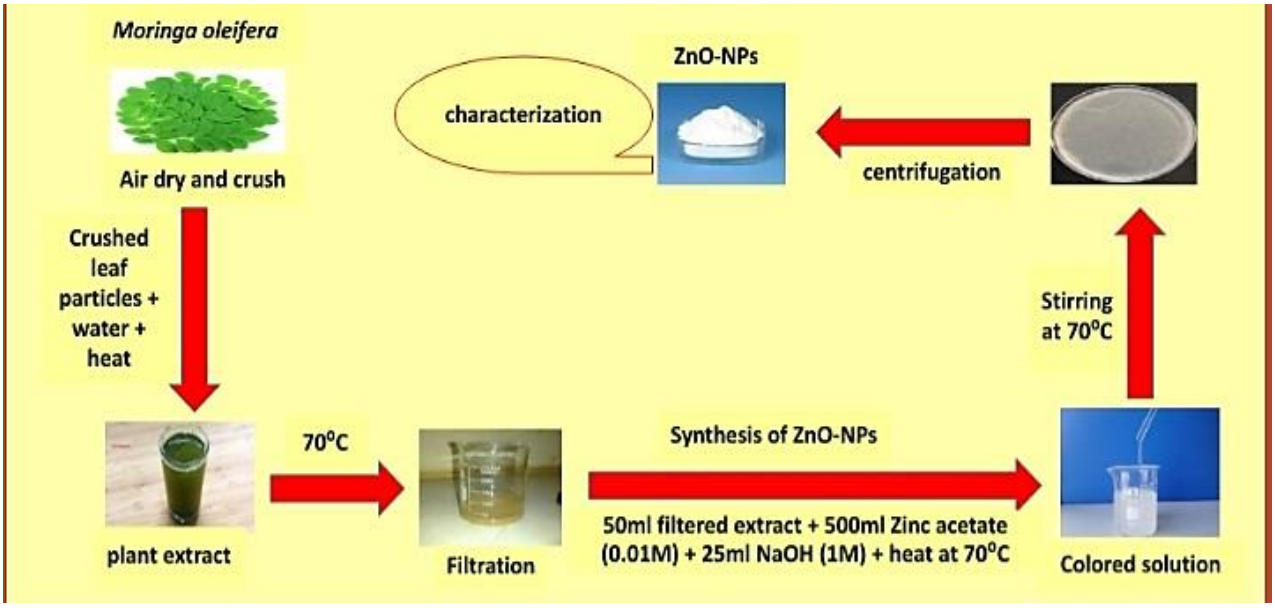

Figure 5. Zinc oxide nanoparticles

4. 2. 1. Chemical Vapour Deposition (CVD)

This is a process that forms solid powders in the gas phase or depositing films on substrates from precursors 'metal salt' in the gas phase (Beaudette et *al.*, 2020).

Chemical Vapour Deposition method involves three steps which are as follows:

i. Transportation of reactants on the growth surface by a boundary layer.
ii. Chemical reaction on the growth surface.
iii. Removal of by-products produced by the gas-phase reaction from the surface.

4. 2. 2. Sol-gel Process

This is the most preferred bottom-up method for synthesis of nanoparticles, because suitable chemical solution act as precursor (Kumar *et al.*, 2015). The suitable precursors are metal oxide, chlorides, nitrates, sulphates. This method involves stirring and shaking, the precursor 'metal salt' is dispersed as host liquid. The resultant solution consists of solid phase and liquid which is separated by filtration, sedimentation, and centrifugation to recover the nanoparticles.

Advantages of Sol-gel process

i. It uses low temperature procedure
ii. It is versatile
iii. It allows for facile shaping

Disadvantages of Sol-gel process

i. It requires long processing time
ii. Use of potentially toxic organic solutions
iii. Hydroxyl and/or carbon group that are still present

4. 2. 3. Pyrolysis

This process is mostly common as the precursor 'metal salt' which may be in state of liquid or vapor is transferred into furnace at high pressure and recovered as nanoparticles (Sakhiya *et al*., 2020). Spray pyrolysis involves the spraying of a solution of a precursor chemical as tiny droplets. When this aerosol droplet is heated and diluted, solvent evaporation occurs. Each of these droplets are generally transformed into a single product particle in spray pyrolysis microparticles.

4. 2. 4. Spinning

Nanoparticles are synthesized by spinning disc reactor (SDR). It consists of rotating disc where temperature can be controlled. It involves fusion of molecules or atom due spinning, precipitation, collection, and drying (Sana *et al*., 2020).

4. 2. 5. Biological Synthesis

This involves the synthesis of nanoparticles by using plant materials or microorganisms such as bacteria and fungi.

Advantages of Biological synthesis

i. Cost-effective
ii. Environmental friendly

Disadvantages of Biological synthesis

i. Many biological molecules in plants such as proteins, amino acids, polysaccharides, alcoholic compounds and vitamins could be produced a critical effect

4. 2. 6. Plant extract

Plant is used to reduce and stabilize nanoparticles. They are used to synthesize metal or metal oxide nanoparticles (Kulkarni *et al.*, 2014). Different nanoparticles are synthesized using different plant species that has some phytochemical components needed for antimicrobial activities.

Advantages of plant extract

i. Helps in developing large scale-up technology
ii. Acts as reducing and stabilizing agents

Disadvantages of plant extract

i. Plants cannot be manipulated
ii. Plant produce low yield of secreted proteins which decreases the synthesis rate

4. 2. 7. Microorganisms

Different microorganisms can be used to synthesize nanoparticles such as fungi and yeast. It is the transporting of ions into the microbial cell to form nanoparticles with the presence of enzymes known as yeast. It is also an efficient method with well-defined morphology (Khandel *et al.*, 2018).

5. GREEN SYNTHESIS

Green synthesis method involves economic and environmentally friendly benefits when applied or used. It is a nontoxic and eco-friendly method whether chemical and physical which is not harmful when used. The synthesis of nanoparticles using green method increase the phytochemical properties due to plant based materials which overcome the limitations of conventional physical and chemical methods of nanoparticles synthesis (Naseer *et al*., 2020).

5. 1. Advantages of Green Synthesis

i. Simplicity
ii. Non-toxic
iii. Cost effectiveness
iv. Greater stability
v. Good dimension

5. 2. Disadvantages of Green Synthesis

i. Plant may have low yield of needed phytochemicals which decreases the synthesis rate.
ii. Plant cannot be manipulated when choosing the kind of nanoparticles through optimal synthesis
NB: the advantages overweigh the disadvantages

6. CHARACTERISTICS OF NANOPARTICLES

They fall into two categories which are quantitative and qualitative analysis.

6. 1. Quantitative (direct) analysis

Transmission electron microscopy (TEM), scanning electron microscopy (SEM), atomic force microscopy (AFM). They can image nanoparticles, directly measure size, and infer shape information, but are limited to study only a few particles at a time (Eaton *et al*., 2017).

6. 2. Qualitative (indirect) analysis

X-Ray diffraction (XRD), UV-Vis spectrometry, Fourier transforms infrared spectroscopy (FT-IR). They simultaneously give information of large nanoparticles (Zhang *et al*., 2016).

7. APPLICATIONS OF NANOPARTICLES

7. 1. In Medicine

i. Cellular imaging
ii. In drugs and gene delivery
iii. In biological detection of pathogens
iv. In probing of the DNA structures
v. By using many kinds of biosensor that are based on NPs diagnosis of different disease
vi. Used for tumour destruction through heating (hyperthermia)

7. 2. In Food and Agriculture

i. For water filtration and desalination
ii. For food preservation
iii. Production of airtight plastic for packaging of foods
iv. Genetic modification of crop plant can be made

7. 3. In Energy Harvesting

i. Solar cells generation
ii. Water splitting
iii. Energy storage application
iv. Convert mechanical energy into electrical energy by using piezoelectric

8. CONCLUSIONS

Nanotechnology which is a synthetic method to produce nanoparticles has proven to become a good source of different applications today. These various applications of nanoparticles has different approaches how they are synthesised either by bottom-up or top-down synthesis, their dimensions because this has a lot on the kind of nanoparticles to be synthesised and used, and their characteristics. With this, a better understanding has been detailed on the kind of synthetic method to use, character, and application.

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