

Available online on 15.05.2019 at <http://jddtonline.info>

# Journal of Drug Delivery and Therapeutics

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Review Article

## Role of Metals in Preparation of Nanofluids

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### ABSTRACT

Nanofluids are dispersion of nanoparticles in base fluids, it's a new challenge for thermal sciences given by nanotechnology. Due to their excellent features, nanofluids find wide applications in enhancing heat transfer. These show large increase of thermal conductivity in comparison with their base fluids. The particles used are generally metal or metal oxide which increases thermal conductivity & convection coefficient. Metallic nanofluids are prepared by dispersing nanoparticles made from metals such as aluminum, silicon, iron, silver, gold, titanium, copper, nickel etc. and nonmetallic nanofluids are prepared by dispersing nanoparticles of nonmetals i.e. metal oxides, various allotropes of carbon for example; Graphene, CNT etc. Synthesis and stability of nanofluids are the two very primary parameters to study nanofluids.

**Keywords-** Nanofluids, metal oxide & metal oxide ( $\text{Al}_2\text{O}_3$ ,  $\text{Fe}_3\text{O}_4$ ,  $\text{TiO}_2$ ,  $\text{SiO}_2$ ,  $\text{Cu}_2\text{O}$ ,  $\text{ZnO}$ ,  $\text{Ag}$ ,  $\text{Au}$  etc.), Nanoparticles.

**Article Info:** Received 26 March 2019; Review Completed 22 April 2019; Accepted 28 April 2019; Available online 15 May 2019



India

### Cite this article as:

Chaudhari PM, Nagare AS, Role of Metals in Preparation of Nanofluids, Journal of Drug Delivery and Therapeutics. 2019; 9(3):554-562 <http://dx.doi.org/10.22270/jddt.v9i3.2834>

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### INTRODUCTION-

The term 'nanofluid' was firstly proposed by Choi and Eastman in 1995 while presenting the new way to enhance the thermal conductivity of heat transfer fluid (HTF). In the past, the effort to increase the thermal conductivity of fluid has been done by dispersing the solid particles in millimeter or micrometer-sizes into conventional HTF (water, ethylene glycol, oil, etc.) as base fluids.<sup>1</sup>

The kinds of nanoparticles used are usually metals (Cu, Au), metal oxide ( $\text{Al}_2\text{O}_3$ ,  $\text{TiO}_2$ ,  $\text{Cu}_2\text{O}$ ,  $\text{Fe}_3\text{O}_4$ ), and nonmetallic element (carbon). In the past few decades, rapid advances in nanotechnology have led to introduction of new generation of coolants called "nanofluids".<sup>2</sup>

Metal nanofluid shows enhanced different thermophysical properties like thermal conductivity, heat transfer coefficient, viscosity and thermal diffusivity compared to those of base fluids like oil or water.<sup>3</sup>

**Thermal conductivity of metals:-** The thermal conductivity is the reciprocal of *thermal resistivity*, usually measured in kelvin-meters per watt ( $\text{K}\cdot\text{m}\cdot\text{W}^{-1}$ ). When dealing with a known amount of material.

The thermal energy  $\delta Q$ , transmitted during an infinitesimal time interval  $dt$  through a thickness  $dx$ , in a direction normal to a surface of area ( $A$ ), due to a temperature difference ( $dT$ ):

$$\frac{\delta Q}{dt} = q(x,t) = -KA \frac{\delta T(x,t)}{\delta x}$$

Where  $q$  is called heat current. This equation is suitable to describe the heat transport along a specified direction (here denoted by  $x$ ).

**Heat Transfer Coefficient:-** The heat transfer coefficient  $h$  is defined as the ratio of heat flux  $q$  (heat flow per unit area) to the difference between the temperature ( $T_s$ ) of the surface and that of the cooling medium, ( $T_a$ ).

$$h = \frac{q}{T_s - T_a}$$

It is observed that heat transfer enhances by increasing nanoparticles fraction up to 1% volume concentration. At higher concentrations, heat transfer coefficient growth stops and starts to decrease.<sup>4</sup>

Nanofluid is a composition of solid-liquid material which consists of nanoparticles of size 1-100nm which will be added to the base fluid in order to obtain the thermal conductivity. There were two types of solid material that can be used to prepare the nanofluid which are: (1) metallic solid and (2) nonmetallic solid.

All solid nanoparticles with high thermal conductivity can be used as additives of nanofluids. Metallic solid or metallic particles include- Aluminum oxide, Iron oxide, Copperoxide, Titanium oxide, Silicon dioxide, silver oxide, gold, nickel etc.

### Different fluids used for nanofluid preparation

**Water**-Tap water, distilled water, de-ionized water.

**Mineral oils e.g;** Paraffinic oils, Naphthenic oils, Aromatic oils.

**Thermal Conductivity of additives and base fluids used in nanofluids are as follows:-**<sup>4</sup>

Al-237W/m.K, Fe-83.5W/m.K, Cu-401W/m.K, Ag-428W/m.K, Au-318W/m.K, Al<sub>2</sub>O<sub>3</sub>-40W/m.K, CuO-76.5W/m.K, SiO<sub>2</sub>-148W/m.K etc.

## 1. ALUMINUM OXIDE:

**Synonyms:-** Alumina

### PROPERTIES:-

- It appear as a white powdery substance that has no odor.
- Is a compound made up of two component- aluminum and oxygen
- Though Al<sub>2</sub>O<sub>3</sub> is an electrical insulator it has a relatively high thermal conductivity (30 Wm<sup>-1</sup>K<sup>-1</sup>)<sup>3</sup>for a ceramic material.
- Is insoluble in water

### ADVANTAGES<sup>5-8</sup>

- Are readily available through established synthesis methods.
- Their vast surface area allows for readily conjugation with other molecules of various origins such as chemical and biological molecules.
- Can easily interact with the biological interfaces that allow for biological purposes.
- Are stable enough to be used in the various conditions, especially in the non-biological environments.

### DISADVANTAGE<sup>8,9</sup>

- Shows environmental biotoxicity.
- Can decrease the growth rate of Ceriodaphniadubia through induction of oxidative stress.

### APPLICATIONS OF ALUMINIUM OXIDE NANOFLUIDS<sup>10-14</sup>

- Drug delivery:- have been used in the form of ordered mesoporous for improved oral delivery of anti-blood pressure drug Telmisartan as a poor-water soluble compound.
- Cancer therapy:- induce cell death in human prostate cancer cells, changing the zeta potential of cell surface boosting the efficacy of cancer vaccines
- Anti-microbial effects: strong anti-microbial activities against E. coli and S. epidermis
- Immunotherapy: leishmania vaccine to induce autophagy in macrophages, as potent vaccination adjuvant
- Biosensing: have been considered as novel platforms for detection of different molecules, used to sense bovine serum albumin.
- The streptokinase- have a sustained release action and it has thrombolytic activity.

### TOXICITY<sup>15,16</sup>

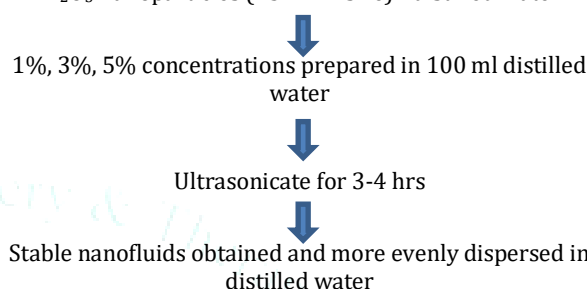
- It's free metal cation, Alaq<sup>3+</sup>, highly biologically reactive and causes toxicity.
- Biologically reactive aluminum is present throughout the human body and it can be acutely toxic.
- Direct exposure to Al<sub>2</sub>O<sub>3</sub> NPs leads to phytotoxicity mostly in wheat roots culminating in morphological, cellular, and molecular alterations.

### HOW TO OVERCOME TOXICITY:

- By using insoluble form of aluminum oxide as soluble form causes more toxicity
- By reduction in dose

### ➤ PREPARATION OF ALUMINIUM OXIDE-NANOFLUIDS<sup>17,18</sup>

Al<sub>2</sub>O<sub>3</sub> Nanoparticles (45nm in size)+ distilled water



## 2. FERROUS OXIDE:

**Synonym:** Hematite,

### PROPERTIS:

- Have diameters between 1 and 100 nanometers.
- Has main two forms are magnetite (Fe<sub>3</sub>O<sub>4</sub>) and its oxidized form magnetite (γ-Fe<sub>2</sub>O<sub>3</sub>).
- Has superparamagnetic properties <sup>19</sup>

### ADVANTAGES:-

- Used in cellular therapy such as cell labelling, targeting and as a tool for cell-biology research to separate and purify cell populations;
- Tissue repair, drug delivery, hyperthermia, magnetic resonance imaging(MRI)
- The particles in this size range (6-15nm) are rapidly removed through renal clearance.

### DISADVANTAGES<sup>19,20</sup>

- Decreases the coherence needed to form an MRI image (T2 relaxation agent), results in iron serves to darken the regions of the image where it is present (the bone marrow in the image below).
- Susceptible to Oxidation

### APPLICATIONS OF IRON OXIDE<sup>21</sup>

- Used in the magnetic nanotherapy which is controlled by external electromagnetic field, ROS mediated local toxicity in the tumor during chemotherapy with antitumor magnetic complex and lesser side effects in normal tissues.
- Contrast agents for Magnetic Resonance Imaging (MRI)
- Drug carriers for target specific drug delivery

- As gene carriers for gene therapy
- As therapeutic agents for hyperthermia based cancer treatments
- Also used as magnetic sensing probes for in-vitro diagnostics (IVD)
- Nano-adjuvant for vaccine and antibody production.

#### TOXICITY OF IRON OXIDE<sup>22,23</sup>

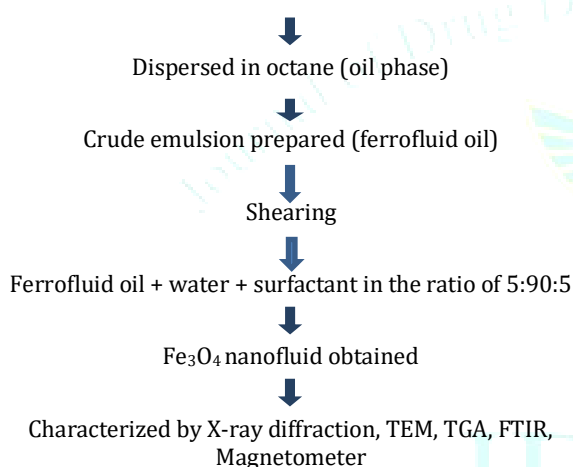
- Cytotoxicity induced by production of free radical
- Increase in expression of genes involved in cell signaling, including integrin subunits, tyrosine kinases and several members of the protein kinase C family.
- Caused severe damage in liver and lung tissues.
- Pulmonary fibrosis.

#### HOW TO OVERCOME TOXICITY:-

- The toxicity can be reduced by substitution with surface-saturated uncoated SPION.

#### PREPARATION OF FERROUS OXIDE NANOFLUID<sup>24,25</sup>

Fe<sub>3</sub>O<sub>4</sub> nanoparticle (size ~10 nm) sterically stabilized with oleic acid



### 3. TITANIUM DIOXIDE:-

**Synonym:-**Titania

#### PROPERTIES:-

- Has a good thermal stability
- Is soluble in hot concentrated sulfuric acid, hydrochloric acid, nitric acid, but it is insoluble in dilute alkali, dilute acid.
- Is a semiconductor, its conductivity increased rapidly with increasing temperature, but it is very sensitive to hypoxia.

- Is hygroscopic, but not too strong.

#### ADVANTAGES OF TiO<sub>2</sub> NANOFLUIDS<sup>26,27</sup>

- Widely used in the printing, cosmetics, air purification, etc., and it is recognized safe material without any toxicity for human beings.
- Has good chemical stability, resistance to acid, alkali, and most organic solution erosion.
- Are produced on larger industrial grade which makes them relatively economical.
- Have good dispersability in the polar and nonpolar base fluids when we add proper dispersant.

#### DISADVANTAGES OF TITANIUM DIOXIDE:-

- A whitish unsightly tint formed when it comes to Ultra-Violet Rays.
- It also leads to the generation of harmful radicals which in most times appear free in their forms via a mechanism known as photocatalytic as they are exposed to direct light.

#### APPLICATIONS OF TITANIUM DIOXIDE<sup>28,29</sup>

- Possess good photo catalytic properties, used as antiseptic and antibacterial compositions
- Degrading organic contaminants and germs
- As a UV-resistant material
- Used in cosmetic products such as sunscreen creams, whitening creams, skin milks, etc

#### TOXICITY:-

- TiO<sub>2</sub> NPs induce phototoxicity upon UV irradiations.
- **Neurotoxicity:-**Brain tissues are more susceptible to oxidative stress-induced damage
- **Respiratory Toxicity:-**The exposures of NMs via inhalation may affect the respiratory tract, resulting in an increased risk of lung cancer, fibrosis, blockage of interalveolar areas, and presence of inflammatory cells
- The changes of serum biochemical parameters (ALT/AST, LDH) and pathology (hydropic degeneration around the central vein and the spotty necrosis of hepatocytes) of liver indicated that the hepatic injury induced due to exposure to mass different-sized TiO<sub>2</sub> particles.

#### HOW TO OVERCOME TOXICITY:-

- Use of silica-coated rutile TiO<sub>2</sub> NPs inhibit the most soluble and cellular mediators of allergic asthma.
- Reduction in particle size and dose reduces toxicity.

**PREPARATION OF TITANIUM DIOXIDE NANOFLUIDS<sup>30</sup>****1) Vapor deposition:-**

Bulk solid material for nanoparticles (in low pressure container filled with inert gas) Heated and evaporated

Vapor of raw material cooled and settled in base fluids (base fluid- ethylene glycol)

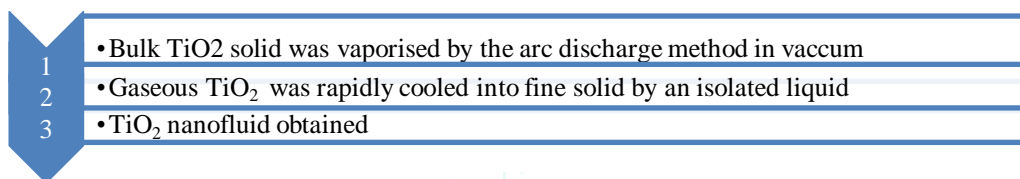
Pulsed wire evaporation technique is used (25 KV voltage applied for few milliseconds)

Plasma was interacted by argon oxygen to condensed into nanoparticles

TiO<sub>2</sub> Nanofluids obtained

**2) Submerged arc method**

The submerged arc method provide higher temperature for the preparation of TiO<sub>2</sub> nanofluids.

**4. COPPER OXIDE:**

**Synonyms:-** Cuprous Oxide,

**PROPERTIES<sup>31</sup>**

- Is introduced as working fluid of direct absorption solar collector.
- Absorbed energy fraction of Cu<sub>2</sub>O nanofluid is 4 times more than that of base fluid.
- Thermal conductivity increased with the increase of volume fraction.
- Thermal conductivity improvement of 13.7% is obtained by 100 ppm Cu<sub>2</sub>O nanofluid.
- Copper forms two oxides: tenorite (CuO) and cuprite (Cu<sub>2</sub>O).

**ADVANTAGES**

- Copper (I) oxide (Cu<sub>2</sub>O) is a less expensive material for the fabrication
- It is also Non-toxic
- Enhance mass transport and catalysis
- Enhance solubility

**DISADVANTAGES:**

- Exposure to higher doses can be harmful; can irritate your nose, mouth, and eyes, and cause headaches, dizziness, nausea, and diarrhoea.
- Increase in copper concentration in blood and urine increased the ceruloplasmin levels may be leads with conditions such as chronic liver disease

**APPLICATIONS OF COPPER OXIDE:-**

- It is effective against both, susceptible and antibiotic resistant microorganisms

- Has wide range of antifungal and antibacterial properties.
- Inhibits biofilm and the development of microorganisms on the surface of materials coated with Cu<sub>2</sub>O NPs.
- Labeling of antibodies, enzymatic chromogenic approach by ELISA (Enzyme Linked Immunosorbent Assay).

**TOXICITY:-**

- Small sized nanoparticles are much toxic than larger ones.
- The toxicity of nanoparticles is increase by a positive charge which facilitates interactions between cells and nanoparticles<sup>32</sup>.

**HOW TO OVERCOME TOXICITY:-**

- By use of coating agents.
- EDTMP coating could effectively reduce the ion shedding and oxidative stress on the surface of toxic metal oxide.

**PREPARATION OF COPPER OXIDE NANOFLUID<sup>33,34</sup>**

- 25 ml of ethylene glycol solution (0.1 M) of copper sulfate pentahydrate (CuSO<sub>4</sub>·5H<sub>2</sub>O) was mixed with 5 ml of ethylene glycol solution (0.01 M) of polyvinyl pyrrolidone (PVP-K30) in a 100-ml beaker, followed by magnetic stirring for 30 min.
- 25 ml of ethylene glycol solution (0.25 M) of sodium hypophosphite (NaH<sub>2</sub>PO<sub>2</sub>·H<sub>2</sub>O) was added and stirred for 15 min.
- The mixture is put into a microwave oven to react for 5 min under medium power.
- The color of the mixture converted from blue to dark red after the reaction. After cooling to room temperature, Cu nanofluid was obtained.

## 5. SILICON DIOXIDE:-

**SYNONYM:-**Silica, Vitreous Silica,

### PROPERTIES<sup>35</sup>

- Are divided into two types of particles P-type and S-type according to their structure. The P-type particles are characterized by numerous nanopores having a pore rate of 0.61 ml/g.
- The S-type particles have a smaller surface area than the p-type. The P-typenano-silica particles have great ultraviolet reflectivity when compared to the S-type.
- Have good Stability, lower toxicity.

### ADVANTAGES:-

- Has highest efficiency.
- It is thermally stable upto 1100°C.

### DISADVANTAGES:-

- It needs thick layer (crystalline).
- Brittle Limited substrates
- Production of silicon nanoparticles is expensive
- Some processing wasteful because has short life cycles.
- Toxic substances are produced and are used in manufacturing.

### APPLICATIONS OF SILICON DIOXIDE NANOFLUIDS<sup>36</sup>

- Used as a solid medium for protein immobilization, protein binding and separation. The iron oxide acts as magnetic core can respond to external magnetic field, and used for fast particle separation, while the silica shell gives biocompatibility, stability, and a platform for protein entrapment.
- **Nucleic acid detection and purification:-**Silica nanoparticles used for DNA detection, separation and purification, DNA biosensors by hybridization with target complementary DNA or RNA probes to obtain variable fluorescent intensity.
- **Drug and gene delivery:-**Mesoporous nanoparticles used as a carrier for drugs and genes delivery. The pores holds the drug molecules and addition agents like gold nanoparticles, are required as caps to close the pores. To release the drugs, some molecules that can break the covalent bond so that pores get open.
- **Imaging contrast agents construction:-**play an important role in medical imaging, used to encapsulate contrast agents particles, such as organic dyes, quantum dots, gold nanoparticles, iron oxide, also incorporated as contrast agents, and drug/gene/protein delivery.

### TOXICITY:-

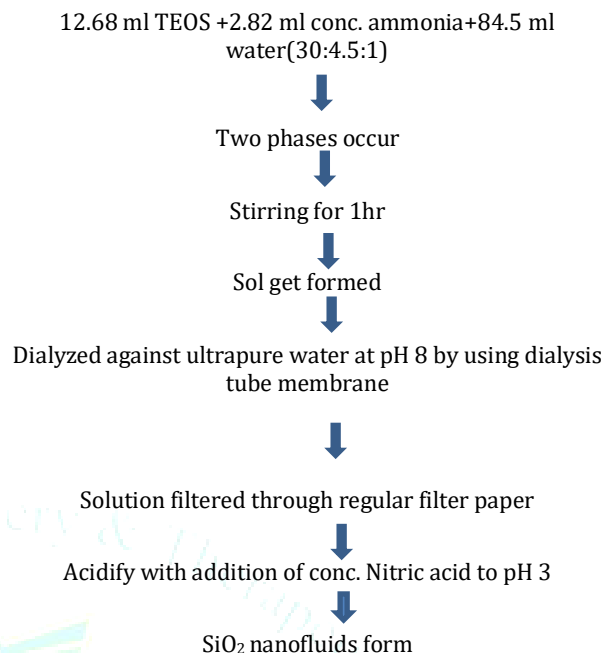
- Affect pregnancy and breastfeeding
- Small vessel vasculitis, autoimmune diseases, kidney damage, and rheumatoid arthritis.
- DNA damage associated with oxidative stress.
- Direct interaction with DNA, oxidative DNA damage, depletion of anti-oxidants, cell cycle arrest, and abnormal expression of genes.

### HOW TO OVERCOME TOXICITY:-

- Genotoxicity of SNP can be overcome by reduction in nanoparticles size range. SiNPs in the size range of 25–80 nm exert no or little genotoxicity

### PREPARATION OF SiO<sub>2</sub> NANOFLUIDS<sup>37</sup>

#### The Sol-gel Method:-



## 6. ZINC OXIDE:-

**SYNONYM:-**Zinc White

### PROPERTIES<sup>38</sup>

- Occur as a white powder that is insoluble in water.
- Has an antibacterial as well as deodorizing property.

### ADVANTAGES:-

- Helps in lowering skin inflammation associated with rashes, allergies or irritation
- Provides broad-spectrum sun protection which prevents burns, protection from skin cancer/neoplasias
- Improving wound healing and preventing bacterial infections
- As aid in recovery of burns and damaged tissue, treat acne, prevent bacterial infections.

### DISADVANTAGES<sup>39, 40</sup>

- Cause irritation, swelling, itching, or tingling.
- Cause allergic reactions
- Leads to genotoxicity and cytotoxicity, ROS generation immunomodulatory, apoptotic responses.

### APPLICATIONS OF ZINC OXIDE<sup>41,42</sup>

- Nanorod sensors, spintronics.
- Used in sun blocks and can often be seen on the nose and lips of lifeguards at the beach.
- Found in medical ointments to treat skin irritations.
- Great antimicrobial effect against multiple foodborne pathogens and food contaminants, for example enterobacteria.



toxigenic *E. coli*, *Botrytis Cinerea*, and *Penicillium expansum*.

- Have been valued in various applications, such as sunscreens, toothpastes, and cosmetics especially because of their ability to absorb ultraviolet radiation.

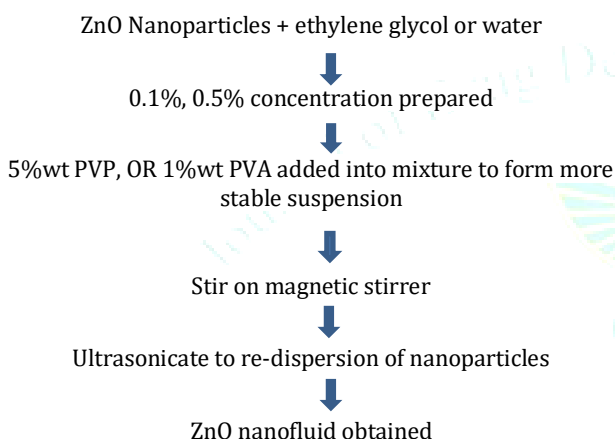
#### TOXICITY<sup>43</sup>

- Cytotoxicity, genotoxicity
- Increasing concentration greatly affect liver enzyme
- Increasing zinc oxide nanoparticles concentration affects sperm quality and quantity
- Affect the histopathology of liver and kidney
- Increasing concentration affect oxidant and antioxidant parameters.

#### HOW TO OVERCOME TOXICITY<sup>43,44</sup>

- The presence of silica coating effectively reduces the toxicity of ZnO NPs and maintains the antimicrobial properties of ZnO NPs.

#### PREPARATION OF ZNO NANOFLUIDS<sup>44,45</sup>



#### 7. SILVER OXIDE:-

**SYNONYM:-Ag**

**PROPERTIES<sup>46</sup>**

- Have particles size between 1 nm and 100 nm in size.
- Their extremely large surface area permits the coordination of a vast number of ligands.

**ADVANTAGES:-**

- Ecofriendly
- Involving living organism
- Less energy is used to synthesis nanoparticles

**DISADVANTAGES<sup>47</sup>**

- Short life up to (20 min)
- Release of sweet smelling amines
- Formation of by-items
- High cost of power
- Require long maintenance time

**APPLICATIONS OF SILVER OXIDE<sup>47,48</sup>**

- **Diagnostic Applications:** used as biosensors and in quantitative detection.

- **Antibacterial Applications:** incorporated in various cosmetic preparation for their antibacterial properties.
- **Conductive Applications:** as conductive inks and integrated into composites which enhance thermal and electrical conductivity.
- **Optical Applications:** to harvest light for enhanced optical spectroscopies including metal-enhanced fluorescence (MEF) and surface-enhanced Raman scattering (SERS).

**TOXICITY:-**

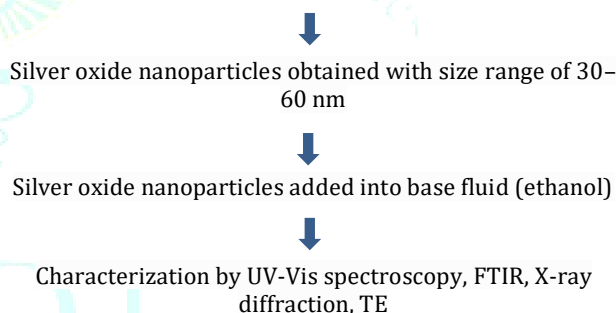
- Due to release of silver ions in cells as both silver nanoparticles and silver ions have been reported to have similar cytotoxicity
- Exposure to silver nanoparticles leads to inflammation, genotoxicity and cytotoxicity, allergic reactions.

**HOW TO OVERCOME TOXICITY:-**

- Can be reduced by surface aggregation on the plasma membrane of the cells without changing the specific surface functionalization.
- If coated with citrate particles of the same diameter reduce the toxicity induces by silver oxide nanoparticles.

#### PREPARATION OF SILVER OXIDE NANOFLUIDS<sup>49,50</sup>

Reduction of AgNO<sub>3</sub> done by polyvinyl pyrrolidone (PVP), used as stabilizing agent, having Ag concentrations of 1% by volume.



#### 8. GOLD NANOFLUID:-

**SYNONYM:-Au**

**PROPERTIES<sup>51</sup>**

- Possess number of surface ligands which allowing flexible design and multi-functionality by incorporating mixed ligands for optimal properties.
- Is inert and is also biocompatible.
- High chemical stability so potential applications in optics, catalysts, sensors, and biology

**ADVANTAGES:-**

- Has higher absorption with less bone and tissue interference achieving better contrast with lower X-ray dose.
- Clear the blood more slowly permitting longer imaging times. Gold nanoparticles of size 1.9 nm in diameter, were injected intravenously into mice and images recorded over time with a standard mammography unit.
- Used as X-ray contrast agents which overcome some significant limitations of iodine-based agents.

**DISADVANTAGES<sup>51</sup>**

- The high cost of gold.
- Clear the body more slowly than some small molecules which leading to longer-term whole-body retention in some cases.

**APPLICATIONS OF GOLD NANOFLUIDS<sup>51,52</sup>**

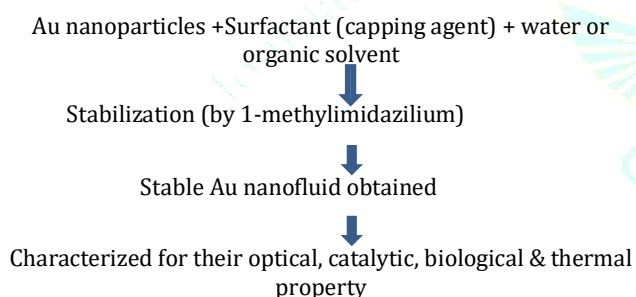
- **Nano-drug delivery**:-provide nontoxic carrier for gene and drug delivery
- Heat transfer application, energy storage
- In optical filter

**TOXICITY<sup>53,54</sup>**

- Shows genotoxicity and cell toxicity.
- Hepatotoxicity in mice with healthy or damaged livers was examined in mice.

**HOW TO OVERCOME TOXICITY:-**

- Modified thiol-PEG (SH-PEG) is an excellent candidate for stabilizing gold NPs in physiological condition and long lasting circulation in the blood
- Replacing cetyltrimethyl ammonium bromide (CTAB) by PEG on the surface of nanoparticles reduced the toxicity of nanoparticles (6.5 nm×11 nm).

**PREPARATION OF GOLD NANOFLUIDS<sup>55</sup>****9. NICKEL OXIDE NANOFLUIDS:-****SYNONYM:-Ni****PROPERTIES<sup>56-57</sup>**

- Can be easily altered by changing their shape, size and chemical properties.
- Have unexpected optical properties, and produce quantum effects.
- Is electrically conductive.
- Are available as nanofluid and in passivated, ultra high purity, high purity, coated and dispersed forms.

**ADVANTAGES<sup>58</sup>**

- Possess high specific surface area and therefore more heat transfer surface between particles and fluids.

- Are highly stable with predominant Brownian motion of particles.
- Due to reduction in particle clogging as compared to conventional slurries it promotes system miniaturization.
- Possess adjustable properties, including thermal conductivity and surface wettability, by varying particle concentrations.

**DISADVANTAGES:-**

- Due to limited service life deep discharge reduces service life.
- Requires complex charge algorithm
- It is unable to absorb overcharge well; trickle charge must be kept low
- Generates heat during fast-charge and high-load discharge

**APPLICATIONS OF NICKEL OXIDE NANOFLUIDS<sup>59</sup>**

- Nano drug delivery:-helps in increasing residence time of drug by controlled release of drug over extended period of time.
- Cancer therapeutics:-efficiently used in cancer imaging and drug delivery.
- Smart fluids:-used as energy resource for heat valve to control the flow of heat.
- Used for their thermal properties as coolants in heat transfer equipment such as heat exchangers, electronic cooling system and radiators
- Propellant and sintering additive, bio detection of pathogen
- Drug and gene delivery, protein detection
- Probing of DNA structure, tissue engineering
- Tumor destruction via heating (hyperthermia)

**TOXICITY:-**

- ROS production can cause serious and heritable damages to DNA, chemical changes in histones or other proteins, which plays important role in the formation of DNA, unwind the helical structure of DNA and exposed DNA to any change.
- Nickel nanoparticle-induced cell death.

**HOW TO OVERCOME TOXICITY<sup>60</sup>:-**

- Modifying bioavailability –by changing solubility
- By changing the surface contact charge
- Modification in particle size.

## PREPARATION OF NICKEL NANOFLUIDS<sup>61</sup>

- Nickel oxide nanoparticles are prepared using the ultrasonic irradiation technique

NaOH solution (0.1M, 100ml) +nickel chloride (0.1M, 50ml) aqueous solution +PEG (0.5ml)

↓  
Mixture exposed to ultrasonic irradiation (20 KHz, 200 W) for 3 hrs

↓  
Precipitate formed

↓  
Precipitate was washed with ethanol and water to separate the impurities

↓  
Annealed it in 4000 C for one hour.

↓  
Morphological and structural characterizations of annealed powder.

↓  
Ultrasonic irradiation

NiO nanoparticles suspended in ethylene glycol (uniform suspension obtained)

## CONCLUSION

The different metals and metal oxide plays an important role in preparation of nanofluids. Nanofluids have various applications - as coolant, heat transfer fluid, drug delivery, cancer treatment, antibacterial, antiviral activity, gene therapy, diagnostic application etc. Nanoparticles exert some toxic effect which can be overcome by various treatments.

## REFERENCES

- Jahanshah M, Hosseinizadeh SF, Alipanah M, Dehghani A, Vakilinejad GR, Numerical simulation of free convection based on experimental measured conductivity in a square cavity using Water/SiO<sub>2</sub>nanofluid, International Communications in Heat and Mass Transfer, 2010; 37:687-694.
- Manna I, Synthesis, Characterization and Application of Nanofluid-An Overview, Journal of the Indian Institute of Science, 2009; 89:21-33.
- Uddin MS, Rahman MM, Alam MS, Fundamentals of Nnanofluids, Evaluation, Applications and new theory, Biomathematics and systems Biology, 2016; 2:1-24.
- Sarviya RM, Fuskale V, Review on Thermal Conductivity of nanofluid, Materials Today:Proceedings, 2017; 4:4022-4031.
- Mukherjee A, Mohammed Sadiq I, Prathna TC, Antimicrobial activity of aluminium oxide nanoparticles for potential clinical applications, Science against microbial pathogens: Communicating current research and technical advances, 2011; 245-251.
- Sadiq IM, Chowdhury B, Chandrasekaran N, Antimicrobial sensitivity of Escherichia coli to alumina nanoparticles, Nanomedicine: Nanotechnology, Biology, and Medicine, 2009; 5:282-286.
- Vinardell MP, Sordé A, Díaz J, Comparative effects of macro-sized aluminum oxide and aluminum oxide nanoparticles on erythrocyte hemolysis: influence of cell source, temperature, and size, Journal of Nanoparticle Research, 2015; 17:80-90.
- Huang N, Yan Y, Xu Y, Alumina nanoparticles alter rhythmic activities of local interneurons in the antennal lobe of Drosophila, Nanotoxicology, 2013; 7 (2):212-220.
- Tarlani A, Isari M, Khazraei A, New sol-gel derived aluminum oxide-ibuprofen nanocomposite as a controlled releasing medication, Nanomedicine research journal, 2017; 2 (1) 28-35.
- Moslana MS, Sulaiman RW, Ismaila AR, Jaafara MZ, Applications of Aluminium Oxide and Zirconium Oxide Nanoparticles in Altering Dolomite Rock Wettability using Different Dispersing Medium, Chemical engineering transactions, 2017; 56:1339-1344.
- Tran PA, Aramesh M, Conformal nanocarbon coating of alumina nanocrystals for biosensing and bioimaging, Carbon, 2017; 122:422-427.
- Liu X., Luo L., Xu Y, Amperometric biosensors based on alumina nanoparticles-chitosan- horseradish peroxidase nanobiocomposites for the determination of phenolic compounds, Royal Society Chemistry, 2011; 136(4):696-701.
- Evdokiu A, Wang Y, Kaur G, Bio-inert anodic alumina nanotubes for targeting of endoplasmic reticulum stress and autophagic signaling: a combinatorial nanotube-based drug delivery system for enhancing cancer therapy, American chemical society, 2015; 7(49):27140-27151.
- Suresh S, Selvakumar P, Chandrasekar M, Srinivasa Raman V, Experimental studies on heat transfer and friction factor characteristics of Al<sub>2</sub>O<sub>3</sub>/water nanofluid under turbulent flow with spiraled rod inserts Chem. Eng. Process, International journal of nanoparticles, 2012; 53:24-30.
- Krewski D, Yokel RA, Niebar E, Borchett D, Human Health risk assessment of aluminium, aluminium oxide and aluminium hydroxide, Journal of Toxicology and Environmental Health Part B, 2011; 10:1-269.
- Beck MP, Sun T, Teja AS, The thermal conductivity of alumina nanoparticles dispersed in ethylene glycol, Fluid Phase Equilibria, 2007; 260 (2):275-278.
- Meenakshi SK, Sudhan J, Development and characterization of nanofluids as coolants for heat transfer applications, ChemXpress, 2016; 9(3):266-272.
- Mukharjee S, Paria S, Preparation and stability of nanofluids – A review, Journal of Mechanical and Civil Engineering, 2013; 9:63-69.
- Cornell, Rochelle M., and Schwertmann U. The iron oxides: structure, properties, reactions, occurrences and uses. John Wiley & Sons, 2003; 1-2.630.
- Lauret S, Forge D, Port M, Roch A, Magnetic iron oxide nanoparticles:synthesis, stabilization, vectorization, physicochemical characterization, American chemical society, 2009; 110(4):2574.
- Orel V, Shevchenko A, Romanov A, Shchepotin I, Magnetic properties and antitumor effect of nanocomplexes of iron oxide and doxorubicin”. J. Nanomedicine Nanotechnology Biology and medicine, 2015; 11(1):4755.
- Chen YC, Hsiao JK, Liu HM, Lai IY, Yao M, Hsu SC, Ko BS, Chen YC, Yang CS, Huang DM., The inhibitory effect of superparamagnetic iron oxide nanoparticle (Ferucarbotran) on osteogenic differentiation and its signaling mechanism in human mesenchymal stem cells, Toxicology and Applied Pharmacology, 2010; 245:272-279.
- Wu S, Sun A, Zhai F, Fe<sub>3</sub>O<sub>4</sub> magnetic nanoparticles synthesis from tailings by ultrasonic chemical co-precipitation, Journal of Material Letter, 2011; 65(12):1882-1884.



24. Narayanan KB, Sakthivel N, Biological synthesis of metal nanoparticles by microbes, *Advances in Colloid Interface Science*, 2010; 156:1-13.
25. Maity D, Agrawal D, Synthesis of iron oxide nanoparticles under oxidizing environment and their stabilization in aqueous and non-aqueous media, *Journal of Magnetism Magnetic Materials*, 2007; 308(1):46-55.
26. Taghizadeh-Tabari Z, Heris SZ, Moradi M, Kahani M, The study on application of TiO<sub>2</sub>/water nanofluid in plate heat exchanger of milk pasteurization industries, *Renewable and Sustainable Energy Reviews*, 2016; 58:1318-1326.
27. Chen H, Ding Y, He Y, Tan C (2007) Rheological behavior of ethylene glycol based titania nanofluids, *Chemical Physics Letter*, 2007; 444:333-337.
28. Lee GJ, Kim JK, Lee MK, Rhee CK, Characterization of ethylene glycol based TiO<sub>2</sub> nanofluid prepared by pulsed wire evaporation (PWE) method, *Reviews on Advanced Materials Science*, 2011; 28:126-129.
29. Chang H, Liu MK, Fabrication and process analysis of anatase type TiO<sub>2</sub> nanofluid by an arc spray nanofluid synthesis system, *Journal of crystal Growth*, 2017, 304:244-252.
30. Ahamed M, Alhadlaq H.A, Khan M., Karupiah P, Al-Dhabi N.A, Synthesis, characterization, and antimicrobial activity of copper oxide nanoparticles, *Journal of Nanomaterials*, 2014; 5:519-524.
31. Chang YN, Zhang M., Xia L, Zhang J, Xing G, The toxic effects and mechanisms of Cu<sub>2</sub>O and ZnO nanoparticles, *Materials*, 2012; 5: 2850-2871.
32. Manimaran R, Palaniradjak, Alagumurthi N, Sendhilnathan S, Hussian J, Preparation and characterization of copper oxide nanofluids for heat transfer application, *Applied Nanoscience*, 2014; 4:163-167.
33. Zhu HT, Lin YS, Yin YS, A novel one step chemical method for preparation of copper nanofluids, *Journal of Colloid and Interface Science*, 2004; 277:100-103.
34. Changwei Pang, Jung-Yeul Jung, Jae Won Lee, Yong Tae Kang, Thermal conductivity measurement of methanol-based nanofluids with Al<sub>2</sub>O<sub>3</sub> and SiO<sub>2</sub> nanoparticles, *International Journal of Heat Mass Transfer*, 2012; 55:5597-5602.
35. Guichard Y, Fontana C, Chavinier E, Cytotoxic and genotoxic evaluation of different synthetic amorphous silica nanomaterials in the V79 cell line, *Toxicology and Industrial Health*, 2016; 32(9):1639-50.
36. Yamaki K, Yoshino S, Comparison of inhibitory activities of zinc oxide ultrafine and fine particulates on IgE-induced mast cell activation, *BioMetals*, 2009; 22:1031-1040.
37. Augustine R, Dominic EA, Reju I, Kaimal B, Kalarikkal N, Thomas S, Investigation of angiogenesis and its mechanism using zinc oxide nanoparticle-loaded electrospun tissue engineering, *RSC Advances*, 2014; 4:51528-51536.
38. Jiang J, Oberdörster G, Biswas P, Characterization of size, surface charge, and agglomeration state of nanoparticle dispersions for toxicological studies, *Journal of Nanoparticle Research*, 2009; 11:77-89.
39. Navale G, Thirupuranthaka M, Late D, Shinde S, Antimicrobial activity of ZnO nanoparticles against pathogenic bacteria and fungi, *JSM Nanotechnology Nanomedicine*, 2015; 3:1033.
40. Rashmirekha P, Kumar MR, Soumitra M, Topical application of zinc oxide nanoparticles reduces bacterial skin infection in mice and exhibits antibacterial activity by inducing oxidative stress response and cell membrane disintegration in macrophages, *Nanomedicine: Nanotechnology, Biology and Medicine*, 2014; 6:101195-1208.
41. Mishra YK, Adelung R, Röhl C, Shukla D, Spors F, Tiwari V, Virostatic potential of micro-nanofilopodia-like ZnO structures against herpes simplex virus-1, *Antiviral Research*, 2011; 92:305-312.
42. Antoine TE, Mishra YK, Trigilio J, Tiwari V, Adelung R, Shukla D. Prophylactic, therapeutic and neutralizing effects of zinc oxide tetrapod structures against herpes simplex virus type-2 infection, *Antiviral Research*, 2012; 96:363-375.
43. Narayanan PM, Wilson WS, Abraham AT, Sevanan M. Synthesis, characterization, and antimicrobial activity of zinc oxide nanoparticles against human pathogens, *BioNano-Science*, 2012; 2:329-335.
44. Asfina B, Parvathy P, Jose J, Environmental fate of zinc oxide nanoparticles: Risks and Benefits, *Toxicology- New Aspects to this Scientific Conundrum*, 2016; 5:82-103.
45. Pati R, Das I, Mehta RK, Sahu R, Sonawane A, Zinc Oxide Nanoparticles Exhibit Genotoxic, Clastogenic, Cytotoxic and Actin Depolymerization effects by inducing oxidative stress Responses in Macrophages and Adult Mice, *Society of Toxicology*, 2016; 150(2):454-472.
46. Sun YG, Xia YN, Shape-controlled synthesis of gold and silver nanoparticles, *Science* 2002, 298: 2176.
47. Johnston HJ, Hutchison G, Christensen FM, Peters S, Hankin, S, Stone V, A review of the in vivo and in vitro toxicity of silver and gold particulates: particle attributes and biological mechanisms responsible for the observed toxicity, *Critical Reviews on toxicology*, 2010; 40(4):32846.
48. Yong NL, Ahmad A, Mohammad AW, Synthesis and Characterization of silver oxide nanoparticles by a novel method, *International Journal of Scientific Engineering Research*, 2013; 4:153-158.
49. Thiago VB, Rona MG, Adelina RW, Jonathan RB, Erdmann H, Insights into the Cellular Response Triggered by Silver Nanoparticles Using Quantitative Proteomics, *American Chemical Society Nano*, 2014; 8(3):2161-75.
50. Guo SJ, Wang EK, Synthesis and electrochemical applications of gold nanoparticles, *Analytica Chimica Acta*, 2007; 598:181.
51. Daniel MC, Astruc D, Gold nanoparticles: assembly, supramolecular chemistry, quantum-size-related properties, and applications toward biology, catalysis, and nanotechnology, *Chemical Review*, 2004; 104:293.
52. Itoh H, Naka K, Chujo Y, Synthesis of gold nanoparticles modified with ionic liquid based on the imidazolium cation, *Journal of the American Chemical Society*, 2004; 126:3026.
53. Chen SM, Liu YD, Wu GZ, Stabilized and size-tunable gold nanoparticles formed in a quaternary ammonium-based room-temperature ionic liquid under gamma-irradiation, *Nanotechnology*, 2005; 16:2360.
54. Jin Y, Wang PJ, Yin DH, Liu JH, Qin LS, Yu NY, Xie GY, Li BM, Gold nanoparticles prepared by sonochemical method in thiol-functionalized ionic liquid, *Colloids Surface A* 2007, 302:366.
55. Kema ME, Nagy N, Mehassab IE, Nickel oxide nanoparticles: synthesis and spectral studies of interactions with glucose, *Material Science in semiconductor processing*, 2013; 16:1747-1752.
56. Pietruska JR, Liu X, Smith A, McNeil K, Weston P, Zhitkovich A, Bioavailability, intracellular mobilization of nickel, and HIF-1 alpha activation in human lung epithelial cells exposed to metallic nickel and nickel oxide nanoparticles, *Toxicological Science*, 2011; 124:138-148.
57. Kakaç S, Pramuanjaroenkij A, Review of convective heat transfer enhancement with nanofluids, *International Journal of Heat and Mass Transfer*, 2009; 52 (13-14):3187-3196.
58. Witharana S, Chen H, Ding Y, Stability of nanofluids in quiescent and shear flow fields, *Nanoscale Research Letters*, 2011; 6: 231.
59. Sreelakshmy KR, Nair AS, Nair SC, An overview of recent nanofluid research, *International Research Journal of Pharmacy*, 2014; 5(4):239-243.
60. Oukarroum A, Barhoumi L, Samadani M, Dewoz D, Toxic Effect of Nickel Oxide Bulk and Nanoparticles on the Aquatic Plant *Lemna gibba* L, *Biomed Research International*, 2015; 1-7.
61. Wan M, Verma SK, Pandey DK, Yadhav RR, Synthesis and Frequency dependent ultrasonic characterization of NiO-EG nanofluids, 2013; 19:1-4.