Available online at www.ijpsdronline.com

International Journal of Pharmaceutical Sciences and Drug Research 2014; 6(4): 263-270

Review Article

ISSN: 0975-248X
CODEN (USA): IJPSPP

High Performance Nanoparticle Fluid Suspensions (Nanofluids): A Future of Pharmaceutical Nanotechnology

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ABSTRACT

Pharmaceutical nanotechnology is evolved as a powerful tool for pharmaceutical chemist and formulation scientists. It has given a new direction to pharmaceutical and drug discovery research. Nanofluid technology which deals with nanofluids has provided an ultimate engineering solution for heat transfer application and automotive application in different industries. Nanofluids are engineered colloidal suspensions of nanoparticles in a base fluid. The nanoparticles used in nanofluids are typically made up of metals, oxides, carbides or carbon nanotubes. Common base fluids include water, ethylene glycol and oil. Preparation of nanofluids may be done by one step, two step method, chemical approach or laser ablation. The stability of nanofluids can be enhanced by different means such as addition surfactants, surface modification technique, pH control and ultrasonic agitation. Nanofluids are well known for their applications in engineering field, many researchers have also reported their use for different biological, medical and biomedical applications. Considering the tremendous growth of pharmaceutical nanotechnology with respect to drug discovery, formulation and development of nanoparticulate novel drug delivery systems, it is expected in coming years that high performance drug nanoparticle fluid suspensions (nanofluids) will begin a new era of formulation research. This review article summarises method of preparation, characterization, stability, recent research and applications of nanofluids. It also identifies future scope of nanofluid technology for applications in pharmaceutical field.

Keywords: Nanofluids, synthesis, characterization, stability, pharmaceutical applications.

INTRODUCTION

Nanotechnology can simply be defined as the technology at the scale of one-billionth of a meter. It is the design, characterization, synthesis and application of materials, structures, devices and systems by controlling shape and size at nanometre scale. Materials exhibit unique properties at nanoscale of 1 to 100 nanometre (nm). The changes in properties are due to increase in surface area and dominance of quantum effects which is associated with very small sizes and large surface area to volume ratio. [1] Nanofluid technology have wide applications like coolant in nuclear reactor, extraction of geothermal power and other energy sources, car radiator coolant, cooling of microchips etc. Different types of nanoparticulate drug system s nanoemulsions, nanosuspensions, nanoparticles, nanostructure lipid carrier and nanofluids. Nanofluid is a new class of heat transfer fluids containing nano-sized particles, fibers or tubes that are stably suspended in a carrier liquid. [2] These fluids are engineered colloidal suspensions of nanoparticles in a base fluid. Commonly used nano materials are oxide ceramics

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Received: 05 September, 2014; **Accepted:** 18 September, 2014

(Al_2O_3, CuO), nitride ceramics (AlN, SiN), carbide ceramics (SiC, TiC), metals (Cu, Ag, and Au), semiconductors (TiO_2, SiC), carbon nanotubes and composite materials such as alloyed nanoparticles Al70Cu30 or nanoparticle core–polymer shell composites. Water, ethylene glycol, and oil are generally used as base fluids. Instability is a common problem associated with nanofluids. Stability of nanofluids can be evaluated by using various advanced techniques like Zeta potential analysis, Spectral absorbency analysis etc. Stability of nanofluids can be improved by using various methods like addition of surfactants or controlling the pH of nanofluid. Stability of nanofluids can be achieved by two simple stabilization mechanism viz. electrostatic stabilization and steric stabilization. Current biomedical applications of nanofluids are cellular therapy involving cell labeling. Nanofluid technology is useful as a tool for cell-biology research to separate and purify cell populations; tissue repair and hyperthermia for cancer treatment. Few of the pharmaceutical applications include targeted nanodrug delivery system, antibacterial activity. Future scope is to develop high performance nanofluids by inventing non-toxic or biodegradable nanoparticles.

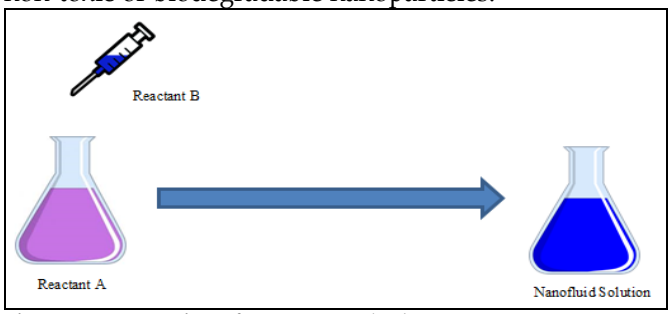

Fig. 1: Representation of one step method

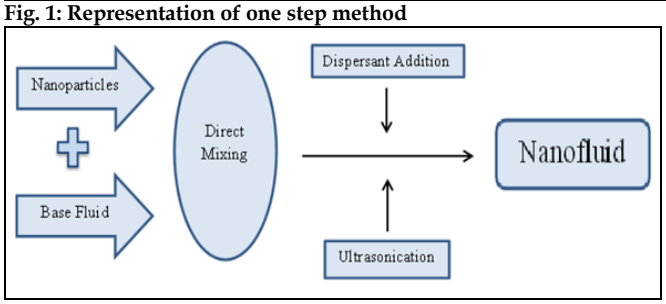

Fig. 2: Representation of two-step method

METHODS OF PREPARATION OF NANOFLUIDS

Various methods have been proposed to formulate nanofluids are as follows;

One Step method

One step method indicates the preparation of nanofluids in one single step. Process consists of simultaneously making and dispersing the particles in the base fluid. In this method the processes of drying, storage, transportation and dispersion of nanoparticles are avoided, so the agglomeration of nanoparticles is minimized and the stability of fluid is increased. Akoh *et al.* [4] reported single step direct evaporation method for preparation of nanofluids. This process is known as vacuum evaporation onto a running oil substrate (VEROS). Only limitation of this process is difficulty in separation of nanoparticles. Zhu *et al.* [5] presented a single-step chemical process for the preparation of Cu nanofluids by reducing $CuSO_4.5H_2O$ with $NaH_2PO_2.H_2O$ in ethylene glycol under microwave irradiation. This method also proved to be a good way to produce mineral oil based silver nanofluids. Lo *et al.* [6] developed vacuum based submerged arc nanoparticle synthesis to prepare CuO, Cu_2O and Cu based nanofluids with different dielectric liquids. A suitable power source is required to produce an electric arc between 6000-120000C which melts and vaporizes a metal rod in the region where arc is created. The vaporized metal is condensed and then dispersed by deionized water to produce nanofluids. The one-step process can prepare uniformly dispersed nanoparticles and the particles can be stably suspended in the base fluid. Some drawbacks of one step method are that, the method cannot prepare nanofluids in large quantities. Most important one is that the residual reactants are left in the nanofluids due to incomplete reaction or stabilization. It is difficult to elucidate the nanoparticle effect without eliminating this impurity effect. One step method is illustrated in Figure 1.

Two-step method

Two step method is one of the most widely used method to prepare nanofluids. Two step method consist of preparation of nanofluids by mixing base fluids with nanopowder obtained from different methods. Nanopowders are mixed with host fluids with the help of an ultrasonic vibrator or high shear device. To reduce particle agglomeration frequent use of ultrasonication or stirring is required. Eastman *et al.* [7], Lee *et al.* [8], Wang *et al.* [9] used two-step method to produce alumina nanofluids. Murshed *et al.* [10] prepared TiO_2-water nanosuspension by the same method. Xuan *et al.* used commercially available Cu nanoparticles to prepare nanofluids of both water and transformer oil. Kim *et al.* used two-step method to prepare CuO dispersed ethylene glycol nanofluids by sonication and without stabilizers. Two-step method can also be used for synthesis of carbon nanotube based nanofluids. Single -walled and multi-walled carbon nanotubes are first produced by pyrolysis method and then suspended in base fluids with or without the use of surfactants. [11-13] Some authors suggested that two-step process is very suitable to prepare nanofluids containing oxide nanoparticles than those containing metallic nanoparticles. Two-step method is the most economic method to produce nanofluids in large scale, because nanopowder synthesis techniques have already been scaled up to industrial production levels. But due to high surface area nanoparticles generally form aggregates. [14] So such problems can counteract by addition of surfactants. Two step method is illustrated in Figure 2.

Chemical approach

Chemical approach using wet technology is emerging as a powerful method for growing nanostructures of

different metals, semiconductors, non- metals and hybrid systems.

Laser ablation

Laser ablation is another much sought, single-step technique that simultaneously prepare and disperses nanoparticles directly in the base fluids.

A variety of nanofluids have been prepared by laser ablation method by ablating solid metals, semiconductors etc. which are submerged in the base fluid (water, lubrication oils etc.). By creating a nanofluid in this way, stable nanofluids resulted without using any property-changing dispersants. [15]

MATERIALS USED TO PREPARE NANOFLUIDS

Modern fabrication technology provides great opportunities to process materials actively at nanometer scales. Nanostructured or nanophase materials are made up of nanometer-sized substances engineered on the atomic or molecular scale to produce either new or enhanced physical properties not exhibited by conventional bulk solids. All physical mechanisms have a critical length scale below which the physical properties of materials are changed. Therefore, particles smaller than 100 nm exhibit properties different from those of conventional solids. The noble properties of nanophase materials come from the relatively high surface area/volume ratio, which is due to the high proportion of constituent atoms residing at the grain boundaries. The thermal, mechanical, optical, magnetic and electrical properties of nanophase materials are superior to those of conventional materials with coarse grain structures. [16]

Following are the various types of materials used.

Nano material

Nanoparticles used in nanofluids have been made of various materials, such as oxide ceramics (Al_2O_3, CuO), nitride ceramics (AlN, SiN), carbide ceramics (SiC, TiC), metals (Cu, Ag, and Au), semiconductors (TiO_2, SiC), carbon nanotubes, and composite materials such as alloyed nanoparticles Al70Cu30 or nanoparticle core–polymer shell composites. In addition to nonmetallic, metallic, and other materials for nanoparticles, completely new materials and structures, such as materials "doped" with molecules in their solid–liquid interface structure, may also have desirable characteristics. [16]

Host liquid types

Many types of liquids such as water, ethylene glycol and oil have been used as host liquids in nanofluids. [16]

STABILITY OF NANOFLUIDS

Investigation on stability is also a key issue that influences the properties of nanofluids and it is necessary to study and analyze the factors which influence the stability of nanofluids.

Nanofluids stability can be assessed by following methods;

- Zeta potential analysis
- Sedimentation method
- Centrifugation method
- Spectral absorbency analysis
- Three ω Method
- Electron microscopy and light scattering method

Zeta potential analysis

Zeta potential is electric potential in the interfacial double layer at the location of the slipping plane versus a point in the bulk fluid away from the interface, and it shows the potential difference between the dispersion medium and the stationary layer of fluid attached to the dispersed particle. Stability of colloidal dispersions is associated with its zeta potential value. In general, a value of 25 mV (positive or negative) can be taken as the arbitrary value that separates low-charged surfaces from highly-charged surfaces. The colloidal dispersion with zeta potential value 40–60 mV is considered as a stable dispersion. Those with more than 60 mV are considered as best stable. [17] Various instruments are used to measure zeta potential. Zeta potential of colloidal suspension is illustrated in Figure 3.

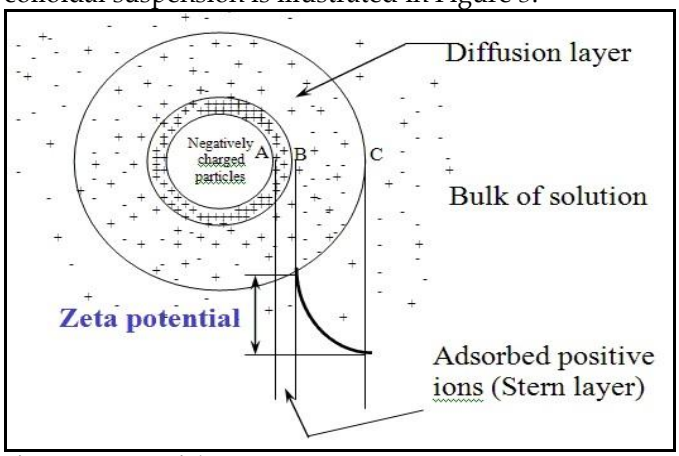

Fig. 3: Zeta Potential

Sedimentation method

Sedimentation method is the most elementary method for evaluation of nanofluids. An external force field is applied to start the sedimentation of nanoparticles in the nanofluids. The weight of sediment or the volume of sediment indicates the stability of nanofluids. Nanofluids are generally considered to be stable if the concentration of the supernatant particles remains constant with time. Sedimentation photograph of nanofluids in test tubes taken by a camera is also a usual method for observing the stability of nanofluids. [18]

Centrifugation method

Big drawback of sedimentation method is long period of observation. Therefore centrifugation method is developed to evaluate the stability of nanofluids. Singh et al. evaluated stability of silver nanofluids formulated by the microwave synthesis in ethanol by reduction of $AgNO_3$ with PVP as stabilizing agent. [19] It has been found that the obtained nanofluids found stable at 3000 rpm for 10 hours and stable for more than 1 month in the stationary state. The growth and agglomeration of

nanoparticles by steric effect was delayed due to protective action of PVP leads to excellent stability. Li et al. used the centrifugation method to evaluate the stability of aqueous polyaniline colloids. Electrostatic repulsive forces between nanofibers are responsible for the long-term stability of the colloids. [20]

Spectral absorbency analysis

Spectral absorbency is one of the common and effective technique to check stability of the nanofluids. There is a direct relationship between the intensity of absorbance and the concentration of nanofluids present in the fluid. The dispersion characteristics of alumina and copper suspensions were evaluated by Huang *et al.* [21] If the nanomaterials dispersed in fluids have characteristic absorption bands in the wavelength 190-1100 nm, it is an comfortable and dependable method to evaluate the stability of nanofluids using UV-Vis spectral analysis. The variation of supernatant particle concentration of nanofluids with sediment time can be obtained by the measurement of absorption of nanofluids, because there is a linear relation between the supernatant nanoparticle concentration and the absorbance of suspended particles. The outstanding advantage comparing to other methods is that UV-Vis spectral analysis can present the quantitative concentration of nanofluids.

Three ω Method

In this method, stability of suspensions can be evaluated considering thermal conductivity growth caused by the nanoparticle sedimentation in a wide nanoparticle volume fraction range. A new literature has found using this method to check the stability of nanofluids. [22-23]

Electron microscopy and light scattering method

Measurement of particle size distribution by microscopy and light scattering techniques are two general methods for observing particle aggregation. Very high resolution microscope such as TEM and SEM are applied to capture the digital image of nanoparticles, known as electron micrograph. [24] Cryogenic electron microscopy can be used for the same purpose if the microstructure of nanofluids is not changed during cryoation. Light scattering technique can also be used for the study of complex nanosuspensions.

Stability enhancement of nanofluids

Stability of nanofluids can be enhanced by different approaches as follows;

- Use of surfactants
- Surfactant free method i.e. Surface modification techniques.
- pH control of nanofluids
- Ultrasonic agitation

Use of surfactants

One of the easy and economic methods to enhance the stability of nanofluids is addition of surfactant. Surfactants are a unique class of chemical compounds which have ability to radically alter surface, interfacial properties, to self-associate and solubilize themselves in micelles. These properties provide the means to apply surfactants in wettability modification, detergency and the displacement of liquid phases through porous media on one hand and to stabilize dispersions (including foams, froths and emulsions). [25] Surfactants consists of a hydrophobic tail portion, usually a long-chain hydrocarbon and a hydrophilic polar head group. To increase the contact of two materials surfactants are used. This phenomenon sometimes called as wettability. In a two-phase system, a dispersant tends to locate at the interface of the two phases, where it introduces a degree of continuity between the nanoparticles and fluids. One of the key issues is to select suitable surfactant. When the base fluid of nanofluids is polar solvent, we should select water soluble surfactants and vice versa.

Surfactant free method i.e. Surface modification techniques

Although surfactant addition is an effective way to enhance the dispersibility of nanoparticles, but this method is not suitable every time. Because contamination, foaming like problems can be encountered due to addition of surfactants. Functionalized nanoparticle is a promising approach to achieve long-term stability of nanofluids. In Surface modification techniques the surface of silica nanoparticles are grafted by using silanes directly instead of adding any surface active agent. [26]

pH control of nanofluids

Stability of nanofluid is directly related to its electro-kinetic properties; therefore, pH control of them can increase stability due to strong repulsive forces. For example, Lee et al. investigated various pH values for Al_2O_3 nanofluid and observed decrease or increment of agglomeration by changing pH. [27] Aggregation of nanoparticles is due to the sum of attractive and repulsive forces between particles. If attractive forces prevail over repulsive one then particle aggregate in clusters. Therefore enhancement of repulsive forces over attractive forces can prevent particle aggregation and ensure stability.

Ultrasonic agitation

After preparation of nanofluids, agglomeration might occur over the time which results in fast sedimentation of nanoparticles due to enhancement of downward body force. Manson et al. investigated two different nanofluids; carbon black-water and silver-silicon oil and they utilized high energy of cavitation for breaking clusters among particles. [28]

Mechanism behind stabilization of nanofluids

Stabilization of nanofluids can be takes place via two mechanisms are as follows.

- Electrostatic stabilization
- Steric stabilization

Electrostatic stabilization

Existence of an electric charge on the surfaces of particles is a major source of kinetic stability.

Electrostatic stabilization occurs by adsorption of ions to the electrophilic metal surface. Adsorption creates an electrical double/multi-layer which results in columbic repulsion force between the nanoclusters. Electrostatic stabilization is a pH sensitive method and of limited use. [29]

Steric stabilization

Steric stabilization of nanoparticles is achieved by attaching (grafting or chemisorption) macromolecules such as polymers or surfactants to the surfaces of the particles. The stabilization is due to the large adsorbents which provide steric barrier to prevent particles coming close to each other. For example, stability of graphite nanofluids is due the protective role of PVP as it prevents the agglomeration of nanoparticles due to steric effect. [29]

BIOMEDICAL, BIOLOGICAL AND PHARMACEUTICAL APPLICATIONS OF NANOFLUIDS

Antibacterial activity of nanofluids

At high temperatures or pressures organic antibacterial materials are often less stable. But inorganic materials such as metal and metal oxides have lots of attention over the past decade due to their ability to withstand harsh process conditions. The antibacterial behaviour of zinc oxide (ZnO) nanofluids shows that the ZnO nanofluids have bacteriostatic activity against *Escherichia coli* (*E. coli*). Electrochemical measurements suggest some direct interaction between ZnO nanoparticles and the bacteria membrane at high ZnO concentrations. Reduction in growth of *E. coli* was observed by Jalal *et al*. in antibacterial activity of suspensions of ZnO nanoparticles. Survival ratio of bacteria decreases with increasing the concentrations of ZnO nanofluids and time. Further investigations have clearly proved that ZnO nanoparticles have a wide range of antibacterial effects on a number of other microorganisms. The antibacterial activity of ZnO may be dependent on the size and the presence of normal visible light. Recent research showed that inhibitory activity ZnO nanoparticles against an important foodborne pathogen, *E. coli* O157:H7 increases as the concentrations of ZnO nanoparticles increased. ZnO nanoparticles changed the cell membrane components including lipids and proteins. ZnO nanoparticles could deform bacterial cell membrane, leading to loss of intracellular components, and ultimately the death of cells, considered as an effective antibacterial agent for protecting agricultural and food safety. [30]

The antibacterial activity research of copper oxide (CuO) nanoparticles showed that they possessed antibacterial activity against four bacterial strains. The size of nanoparticles was less than that of the pore size of the bacteria and thus they had a unique property of crossing the cell membrane without any hindrance. It could be hypothesized that these nanoparticles formed stable complexes with vital enzymes inside cells which hampered cellular functioning resulting in their death. [31]

Nanomaterials have unique properties compared to their bulk counterparts. For this reason, nanotechnology has attracted a great deal of attention from the scientific community. Metal oxide nanomaterials like ZnO and CuO have been used industrially for several purposes, including cosmetics, paints, plastics and textiles. A common feature that these nanoparticles exhibit is their antimicrobial behaviour against pathogenic bacteria. ZnO, CuO and iron oxide (Fe_2O_3) nanoparticles have excellent antimicrobial activity against Gram-positive and Gram-negative bacteria. Among the three metal oxide nanomaterials, ZnO showed greatest antimicrobial activity against both Gram-positive and Gram-negative bacteria used in this study. It was observed that ZnO nanoparticles have excellent bactericidal potential, while Fe_2O_3 nanoparticles exhibited the least bactericidal activity. The order of antibacterial activity was demonstrated to be the following: ZnO, CuO, and Fe_2O_3. [32]

Biomedical applications

In biomedical applications, Polymerase chain reaction (PCR) is one of the most popular tools in molecular diagnosis. It can amplify DNA samples to a detectable signal level within a short period of time and amplify a single or few copies of a piece of DNA across several orders of magnitude, generating thousands to millions of copies of a particular DNA sequence. However, primer–dimer and GC-rich regions of the template and the PCR system's heating/cooling ratio may interfere with the efficiency of the PCR. To increase the efficiency and yield of the PCR, two key components of PCR should be considered; reagent and equipment. The reagents include the Taq DNA polymerase, primers and the template. The Taq DNA polymerase derived from the thermalphilic bacterium *Thermus aquaticus* has shown the best activity at 72°C. Primer design, buffer content and the occurrence of primer–dimer have also been reported to affect PCR efficiency. Recently, PCR machines showing rapid heating-cooling responses have been developed.

The nanoparticle (NP) is a novel material and has many physical properties which are different from bulk materials. In addition to their reaction with DNA, AuNPs also interact with other bio- molecules, especially DNA polymerase. Because of the binding properties of AuNPs with proteins, interactions between AuNPs and DNA or polymerase can be applied to a variety of immunoassay. There are many strategies available for preparation of protein- AuNPs complexes.

It is reasonable to deduce that interactions between AuNPs and polymerase can be used to modulate and optimize PCR process. The reduced PCR amplification caused by excess AuNPs was due to the interaction between DNA polymerase and AuNPs, and increasing

the polymerase concentration in the system could avoid the amplification-restraining effect. [33]

Nanodrug delivery

Over the last few decades, colloidal drug delivery systems have been developed in order to improve the efficiency and the specificity of drug action. The small size, customized surface, improved solubility and multi-functionality of nanoparticles open many doors and create new biomedical applications. The novel properties of nanoparticles offer the ability to interact with complex cellular functions in new ways. Gold nanoparticles provide nontoxic carriers for drug and gene delivery applications. With these systems, the gold core imparts stability to the assembly, while the monolayer allows tuning of surface properties such as charge and hydrophobicity. Another attractive feature of gold nanoparticles is their interaction with thiols, providing an effective and selective means of controlled intracellular release. [34-35]

Carbon Nanotubes (CNT) has emerged as a new alternative and efficient tool for transportation and translocation of therapeutic molecules. CNT can be functionalised with bioactive peptides, proteins, nucleic acids, drugs and used to deliver their cargos to cells and organs. Because functionalised CNT display low toxicity and are not immunogenic, such systems hold great potential in the field of nanobiotechnology and nanomedicine. [36-37] Pastorin *et al*. have developed a novel strategy for the functionalisation of CNTs with two different molecules using the 1, 3- dipolar cycloaddition of azomethine ylides. The attachment of molecules that will target specific receptors on tumour cells will help improve the response to anticancer agents. [38]

In recent years, graphene based drug delivery systems have attracted more and more attention. In 2008, Sun et al. firstly reported the application of nano-graphene oxide (NGO) for cellular imaging and drug delivery. They have developed functionalization chemistry in order to impart solubility and compatibility of NGO in biological environments. Simple physicosorption via π-stacking can be used for loading doxorubicin, a widely used cancer drug onto NGO functionalized with antibody for selective killing of cancer cells *in vitro*. Functional nanoscale graphene oxide is found to be a novel nanocarrier for the loading and targeted delivery of anticancer drugs. [39]

Controlled loading of two anticancer drugs onto the folic acid-conjugated NGO via π–π stacking and hydrophobic interactions demonstrated that NGO loaded with the two anticancer drugs showed specific targeting to MCF-7 cells (human breast cancer cells with folic acid receptors), and remarkably high cytotoxicity compared to NGO loaded with either doxorubicin or camptothecin only. The PEGylated (PEG: polyethylene glycol) nanographene oxide could be used for the delivery of water-insoluble cancer drugs. PEGylated NGO readily complexes with a water insoluble aromatic molecule SN38, a camptothecin analogue, via noncovalent van der Waals interaction. The NGO-PEG-SN38 complex exhibits excellent aqueous solubility and retains the high potency of free SN38 dissolved in organic solvents.

Yang et al. found GO-Fe3O4 hybrid could be loaded with anti-cancer drug doxorubicin hydrochloride with a high loading capacity. This GO-Fe3O4 hybrid showed super paramagnetic property and could congregate under acidic conditions and be redispersed reversibly under basic conditions. This pH-triggered controlled magnetic behavior makes this material a promising candidate for controlled targeted drug delivery. [40-41]

Cancer treatment

Cancer treatment options include surgery, chemotherapy, radiation therapy and hyperthermia. Clinical hyperthermia falls into three broad categories, namely (1) localized hyperthermia (2) regional hyperthermia and (3) whole-body hyperthermia. Heating (41–46°C) of specific tissues or organs for tumor/cancer therapy is named as hyperthermia and can be generated by radio frequency, microwave and laser wavelengths. Blood vessels are poorly developed within the cancerous tissues and have a lower thermal resistance than healthy tissue. Tumour cells are considered more susceptible to heat than normal cells due to their higher rates of metabolism, which makes hyperthermia a very promising cancer treatment.

The cancer cells are damaged at lower temperatures than the healthy tissue but a small section of tumour may not be heated. The two most obvious reasons are either because of a locally increased level of blood flow because of a nearby blood vessel, or an inadequate concentration of implanted magnetic nanoparticles. There is a new initiative which takes advantage of several properties of certain nanofluids to use in cancer imaging and drug delivery. This initiative involves the use of iron-based nanoparticles as delivery vehicles for drugs or radiation in cancer patients. Magnetic nanofluids are to be used to guide the particles up the bloodstream to a tumour with magnets. It will allow doctors to deliver high local doses of drugs or radiation without damaging nearby healthy tissue, which is a significant side effect of traditional cancer treatment methods. In addition, magnetic nanoparticles are more adhesive to tumour cells than non-malignant cells makes magnetic nanoparticles as an excellent candidate for cancer therapy. [42] Magnetic nanoparticles are used because they provide a characteristic for handling and manipulation of the nanofluids by magnetic force as compared to other metal-type nanoparticles. [43] This combination of targeted delivery and controlled release will also decrease the likelihood of systemic toxicity since the drug is encapsulated and biologically unavailable during transit in systemic circulation. The nanofluid containing magnetic nanoparticles also acts as a super-paramagnetic fluid which absorbs energy in an alternating electromagnetic field producing a

controllable hyperthermia. By enhancing the chemotherapeutic efficacy, the hyperthermia is able to produce a preferential radiation effect on malignant cells. Nanofluids and nanoparticles have many applications in the biomedical industry, but there are some side effects in traditional cancer treatment methods. Iron based nanoparticles could be used as delivery vehicles for drugs or radiation without damaging nearby healthy tissue. Such particles could be guided in the blood stream to a tumour using magnets external to the body. Nanofluids could also be used for safer surgery by producing effective cooling around the surgical region and thereby enhancing the patient's chance of survival and reducing the risk of organ damage. Magnetic nanoparticles in biofluids can be used as delivery vehicles for drugs or radiation, providing new cancer treatment techniques. Magnetic nanoparticles absorb much more power than microparticles at AC magnetic fields tolerable to humans. Nanoparticles are more adhesive to tumour cells than normal cells, therefore, magnetic nanoparticles excited by an AC magnetic field is promising for cancer therapy. The combined effect of radiation and hyperthermia is due to the heat induced malfunction of the repair process right after radiation induced DNA damage. [44]

Nano cryosurgery

Cryosurgery is a process that destroys undesired tissues with the help of freezing. This therapy is becoming popular because of its important clinical advantages. Although it cannot be considered as a routine method of cancer treatment, cryosurgery is quickly becoming as an alternative to traditional therapies. With respect to the choice of particle for enhancing freezing, magnetite Fe_3O_4 are perhaps the most popular and appropriate because of their good biological compatibility. Particle sizes less than 10 µm are sufficiently small to start permitting effective delivery to the site of the tumor, either via encapsulation in a larger moiety or suspension in a carrier fluid. [45] Introduction of nanoparticles into the target via a nanofluid would effectively increase the nucleation rate at a high temperature threshold.

Other applications of nanofluids

Nanofluids are widely used in all other fields. The most common applications of nanofluids are as follows;

Heat Transfer Applications: Industrial cooling, coolant in nuclear reactor, extraction of geothermal power and other energy sources.

Automotive Applications: Car radiator coolant

Electronic Applications: Cooling of microchips, microscale fluidic applications

THE CURRENT AND FUTURE SCOPE OF NANOFLUIDS

Nanofluids are important because they can be used in numerous applications involving heat transfer and other applications such as in detergency. Further research still has to be done on the synthesis and applications of nanofluids so that they may be applied as predicted. Once the science and engineering of nanofluids are fully understood and their full potential researched, they can be reproduced on a large scale and used in many applications. Colloids which are also nanofluids will see an increase in use in biomedical engineering and the biosciences. [46] Nevertheless, there have been many discoveries and improvements identified about the characteristics of nanofluids in the surveyed applications and researchers are a step closer to developing systems that are more efficient and smaller. With an overview of versatile use and applications of nanofluids technology in engineering field it is obvious that it has grabbed the attention for its application in pharmaceutical research. There is wide scope for use of nanofluid technology in pharmaceutical industry. Futures scope is to develop stable and effective nanofluids by inventing non-toxic or biodegradable nanoparticles. It is strongly expected in future that nanofluid technology will become an integral part of pharmaceutical technology. Nanofluidic drug delivery system may become an identity of pharmaceutical nanotechnology.

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Source of Support: Nil, Conflict of Interest: None declared.