# Biomedical Applications of Nanofluids in Drug Delivery

**Debojyoti Mandal, Keshav Anand, and Pranav Kumar Prabhakar**

**Abstract** In the past few years, clinical studies and scientific research projects have found a wide range of applications for infusions of various nanoparticles or nanocomposites. Emulsions or dispersion of nanomaterials in liquid are known as nanofluids, and they can be utilized to improve heat exchange directly in a wide range of industrial purposes, including heat transfer, transit, semiconductors, healthcare, and the food sector. Nanofluids are these useful formulations that enable the dispersion and action of nanoparticles in uniform and stable environments. The benefits of nanofluids in biological techniques in various sectors have been covered in several research. Few review studies that provide an overview of the several biomedical uses for nanofluids, including both diagnosis and treatment, have been documented. In comparison to their solid counterparts, nanofluids' physicochemical qualities alter significantly due to the growing interest in using them in nanomedical applications. Nanofluids have recently been used in biomedical activities, including drug transport and antimicrobial treatments. The paper's primary focus is on nanosuspensions, which are nanofluids that contain solid particles. The primary class of nanofluids, nanosuspension, is the subject of most applications. Therefore, this study provides comprehensive information on the main biological uses of nanofluids in scanning, antimicrobial properties, and drug-delivery systems. Magnetic nanofluid systems are essential for targeted medication delivery, hyperthermia, and differential diagnosis. Additionally, the use of nanofluids as a potential antibacterial agent to combat antibiotic resistance is a possibility. This study might help outline cutting-edge, practical strategies for achieving success in modern medical practice.

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## 1 Introduction

Nanofluid, a suspension of nanoparticles, shows promise as a fluid used for enhancing heat transfer and finding numerous other uses because of its high ability to conduct heat and unique rheological properties (Mashali et al. 2019). To define this emerging area of nanotechnology-focused field thermal systems with thermodynamic properties superlative to that of conventional particle fluid suspensions, The term "nanofluids" (which refers to suspensions of fluid containing nanoparticles) was introduced by Choi in 1995 (Jawaid et al. 2019; Lee and Choi 1996). In the last few years, there has been notable advancement in the field of nanofluid technology, a new and highly significant interdisciplinary field at the intersection of nanotechnology, nanomaterials, and thermal engineering (Yu and Xie 2012). To create a nanofluid, a small quantity of nanoparticles are dispersed in a base fluid such as water, ethylene glycol, etc., either with or without methods to stabilize the mixture. Nanofluids aim to achieve high thermal properties at low levels (about 1%volume) by dispersing as well as suspending nanoparticles (around 10 nm in size) in host fluid (Ebrahimi et al. 2010).

Nanoparticles, or particles with size and shape on the nanometre scale, can be found in a fluid known as a nanofluid. These materials are composed of nanoparticles that are suspended in a base fluid (common base fluids include water, ethylene glycol, and oil) that have been engineered to have the properties of a colloidal suspension (Ebrahimi et al. 2010; Sharma et al. 2011). The most common types of nanoparticle materials that are utilized in nanofluids include metals, oxides, & carbon nanotubes. Earlier research has indicated that the thermo-physical characteristics of nanofluids, including electrical properties, thermal diffusivity, rheology, and convection thermal transfer coefficients, are drastically enhanced when compared to the base fluids like water or oil (Duangthongsuk and Wongwises 2008). Nanofluids offer numerous potential applications in heat transfer, which include: microfluidics, fuel cells, pharmaceutical operations, hybrid-powered engines, home refrigerators, cooling systems, convective heat transfer, nuclear reactor coolant, grinding, machine tools, space science, defence, vessels, as well as the reduction of boiler flue gas temperature (Choi 2009; Liu et al. 2005).

Dispersions of nano-sized particles are very different from nanofluids in several ways. Nanofluids have higher thermal conductivities than more common cooling liquids like water, kerosene, ethylene glycol, and microfluids (Kamel et al. 2016). So, nanofluids can be used in applications that involve heat exchange because they don't get in the way of flows and don't cause much of a pressure drop as they move. There is a wealth of information on the preparation, characterization, and stabilisation of nanofluids because this area has previously been part of colloidal science (Yu and Xie 2012).Nanofluids are much more stable than microfluids for implementations where heat is transferred because of the robust Brownian motion of nanosized particles suspended in base fluids. This is one of the obvious benefits of using nanofluids over that of the microfluid (Arulprakasajothi et al. 2010). Nanofluids are promising coolants due to their high critical heat flux, high thermal conductivity, and high heat transfer capabilities. Research has shown that the addition of even a small quantity of nanoparticles to a base fluid significantly improves its thermal efficiency. Extreme stability as well as significant thermal conductivity are two crucial characteristics for heat transfer systems (Keblinski et al. 2005).

Very few review articles focus solely on the potential medical uses of nanofluids. Some papers have provided an overview of the many applications of nanofluids across many disciplines. On the topic of the medical uses of nanofluids, some authors have included a few paragraphs (Saidur et al. 2011). Another review article exists, but it does not focus on the medical uses (Choi 2009). In keeping with the earlier-discussed definition of a nanofluid, this article explores the use of nanofluids in delivery of drugs, antimicrobial therapeutic interventions as well as medical applications. In this following article, a comprehensive survey of the procedures as well as implementations of nanofluid in a wide variety of biomedical fields is presented. In these types of reviews, one of the topics that is discussed in a condensed and overarching manner is the various biomedical applications (Sheikhpour et al. 2020).

## 2 Nanofluid Preparation

Nanofluid preparation involves more than just adding nanoparticles to a solvent. Stabilization and adequate mixing are prerequisites for producing nanofluids with uniformly dispersed nanoparticles in specific environmental settings. There are many different ways to make nanofluids, but the two most common are:

### *2.1 One Step Method*

To avoid the hassle of dehydration, storage, transporting, and distributing nanoparticles, this method uses a different technique. The Physical Vapor Deposition (PVD) method, which involves the specific condensation as well as humidification of nanoparticles within the base fluid, is used to create a stable nanofluid (Choi 2009; Rafiq et al. 2021). This technique yields nanoparticles that are both pure and uniform in size. As a result, less nanoparticle accumulation occurs. Two major drawbacks of the one-step approach are its high price and the fact that it leaves behind reactants in the nanofluids (Ali and Salam 2020; Rafiq et al. 2021). The particles, which can be broken down to agglomerations of nanomaterials, are created and dispersed inside the base fluids all in a single step (Fig. 1). Though the method's high price tag is a drawback, it does increase nanofluid stability (Fig. 1).

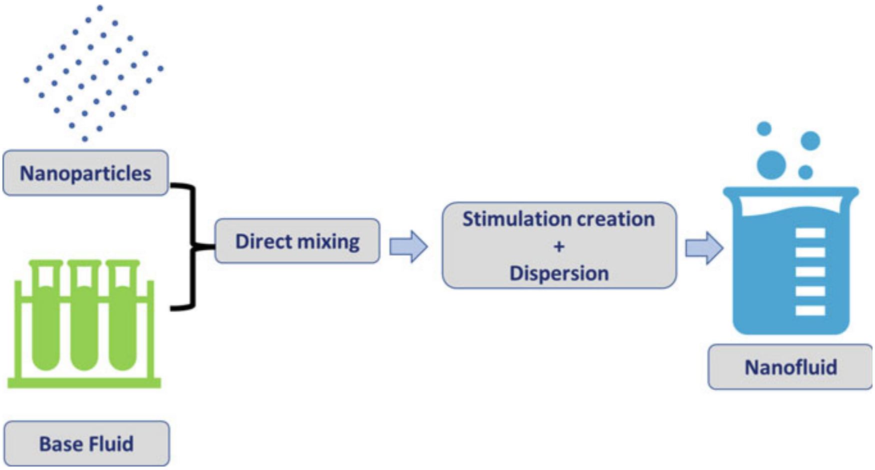


**Fig. 1** Method of one-step technique to produce nanofluid

## *2.2 Two-Step Method*

This method is the most efficient and economical way to get ready for nanofluid production on a large scale. In this method, the nanomaterials are first obtained through a variety of processes; once they have been obtained, the nanoparticles are then circulated throughout the main solvent i.e. base fluid to create the desired nanofluid (Sanjeevi and Loganathan 2020). This method of production is both low-cost and highly efficient. The aggregation of nanoparticles is the most significant drawback of the two-step method (Ali and Salam 2020). Surfactant is added because the substance is unstable. This is the standard procedure used in the commercial world to prepare nanofluid. When it comes to the preparation of nanofluid for research, the vast majority of scientists favour using this method. The most common approach to preparing nanofluids entails a two-stage process (Ali and Salam 2020; Yu and Xie 2012). Dry powders of nanoparticles, nanofibers, other nanomaterials are initially manufactured using chemical or physical processes and then used in this technique. The second stage of processing entails incorporating the nano powder into a fluid with the aid of high-shear mixing, homogenization, ball milling, and ultrasound agitation. Those are the five different types of agitation (Bairwa et al. 2015; Talaei et al. 2011).

The two-stage process, in contrast to the simpler one-stage method, is the standard in industry for mass-producing nanofluids (Paul et al. 2011; Sajid and Ali 2018).The first step of the two-stage procedure involves producing the nanoparticles through a number of synthetic processes; then, after being distributed into the base fluid, the nanoparticles are collected. Figure 2 is a schematic diagram that illustrates the two-stage approach for creating nanofluids. The vast majority of the researchers prepared the nanofluid using this technique (Esfe et al. 2015; Geng et al. 2020).

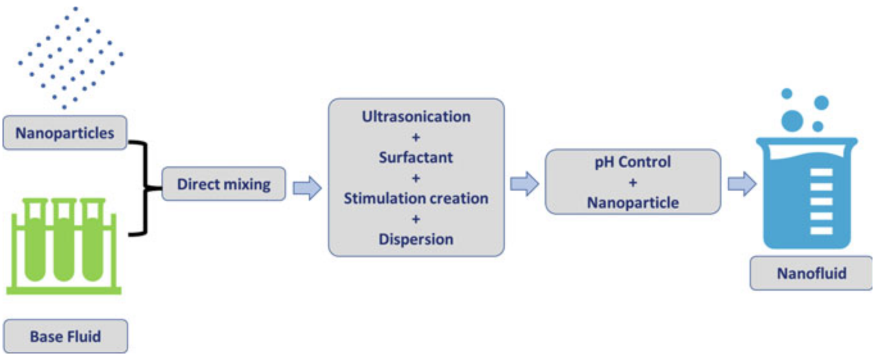


**Fig. 2** Method of two-step technique to produce nanofluid

## 3 Characterization of Nanofluids

Scanning electron microscopy,"transmission electron microscopy, x-ray diffraction, dynamic light scattering, thermogravimetric analysis, and zeta potential"are among the techniques used for the assessment in the process of characterising nanofluids (Hernaiz et al. 2019; Kolappan et al. 2020; Otanicar et al. 2010; Vonarbourg et al. 2006).

- The DLS analysis calculates the average size of nanoparticles that are dispersed throughout the base liquid.
- The thermogravimetric analysis (TGA) is used to study how melting and heating affect the thermoelectric durability of nanoparticles.
- The value of the zeta potential is closely linked to the consistency with which nanoparticles are spread out in base fluid.

## 4 Advantages of Nanofluid

The incorporation of nanoparticles into the system even a minute volume fraction results in a significant improvement in heat transfer. Researchers are still looking into the benefits of using nanofluids and the factors that contribute to the improvement in heat transfer (Hernaiz et al. 2019; Sharma et al. 2022; Yu et al. 2010).

The following list provides examples of some of the benefits:

- The fluid's effective thermal conductivity is enhanced thanks to the nanomaterials which are distributed throughout it. The nanoparticle volume fraction has a direct bearing on the effective thermal conductivity of a material. It rises in proportion to the increase in the nanoparticles per volume that are present (Xie et al. 2011; Yu et al. 2010).

- More heat can be transferred from the particles to the fluid because of the larger specific surface area (Xie et al. 2011).
- When compared with traditional fluids, reduced particle clogging promotes system miniaturisation by reducing the likelihood of clogging (Otanicar et al. 2010).
- A higher degree of dispersion stability combined with a predominately Brownian motion of the particles. Dispersed nanoparticles, on the other hand, amplify the turbulence and the mixing fluctuation (Reddy and Murugesan 2017).
- Adjustable properties, such as heat capability and surface hydrophilicity, can be achieved by adjusting the fragment concentration in order to satisfy the requirements of a variety of applications (Arulprakasajothi et al. 2010).
- Power required to pump the mixture is less than that required for the pure liquid to achieve the same level of heat transfer intensification (Arulprakasajothi et al. 2010).

## 5 Application in the Biomedical Field (Fig. 3)

### *5.1 Cancer Treatment*

In the arena of cancer treatment and drug carriers, there is a new effort that makes use of several attributes of specific nanofluids (Gavas et al. 2021). As part of this initiative, nanoparticles based on iron will be tested in cancer patients to see how well they work as drug carriers for drugs or radiation. The plan is to use magnetic nanofluids to transport the particles through the circulatory system and into the tumour (Tang et al. 2020). As a result, doctors will be able to treat cancer with relatively high doses of medication or rays without harming surrounding healthy cells, which is a common drawback of current treatments (Wong and Leon 2017).

Further, in human-safe alternating current magnetic fields, magnetic nanoparticle adheres more strongly to nanoparticles absorb more energy than microparticles and have a greater affinity for cancer cells than normal cells. When compared to other nanoparticles made of metal, magnetic ones have a unique property that makes them ideal for manipulating nanofluids using only magnetic fields. In an interchanging electromagnetic force, magnetic nanoparticle-laden nanofluid functions as a super-paramagnetic fluid, absorbing energy to generate hyperthermia that can be modulated. Since hyperthermia selectively kills cancer cells, it can boost the efficacy of chemotherapy (Chiang et al. 2007).

Mekheimer et al. had designed nanofluid baes on gold nanoparticle with the intention of researching the consequences of heat transmission with blood circulation comprising gold nanoparticle in a space between the two coaxial tubes. In the end, they came to the conclusion that gold nanoparticles increase the temperature distribution, which makes it capable of destroying cancer cells (Mekheimer et al. 2018).

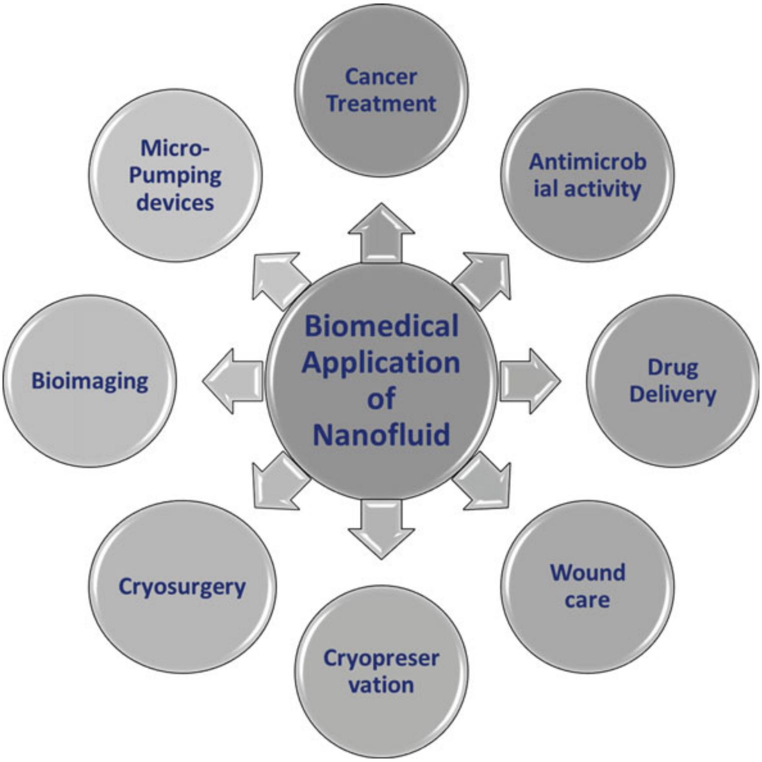


**Fig. 3** Biomedical applications of nanofluids

Magnetic nanoparticles have been implanted into a bloodstream leading directly to the tumour's tissues. Peristaltic waves acting on the blood vessel's elastic walls cause the nanoparticles to move (Das et al. 2022). As a result, studying the flow of nanofluids under such conditions can notify the development of effective new therapies for cancerous tissues. Abdelhalim et al. mathematically modelled the slip peristaltic flow of nanofluid, and performed an analytical study of its properties. Their research provides some insight on the nano—fluids dynamics that are utilised in the clinical field that treat the cancerous tissues by using magnetic nanoparticles while the blood vessels are being peristaltic (Ebaid and Aly 2013).

The treatment of breast cancer with zinc oxide nanoparticles was the subject of research conducted by Abdolmohammadi and colleagues. The results of an investigation into cytotoxicity have been compiled. According to the findings of the in vitro study, ZnO NPs are non-toxic hold promise as potential cancer chemotherapy agents (Abdolmohammadi et al. 2017).

Sundar et al. (2019) report medical applications for cobalt oxide ($Co_3O_4$) and its composites. Cobalt compounds are safe to use in medicine because of its magnetic properties. Magnetic particles can be used to track down tumours, and cobalt composites have proven to be the most effective material for this purpose.

There have been a number of other studies done on nanofluids for the treatment of cancer, and these studies show that the potential effect has room for further application (Ebaid and Aly 2013; Su et al. 2011).

## *5.2 Antimicrobial Activity*

Organic antibacterial substances are typically less stable than their inorganic counterparts, particularly when exposed to extreme temperatures or increased pressure (Cloutier et al. 2015). As a direct result of this, inorganic materials like metals and metallic oxides have obtained a lot of focus over the course of the past decade as a direct result of their capability to withstand tough operating condition. Anti—bacterial NPs are of specific importance because of their capacity to endure severe procedure circumstances (Sirelkhatim et al. 2015). This is in contrast to organic natural antimicrobial agents, which lose their consistency under extreme temperature or pressures, so antibacterial NPs are able to withstand these conditions without being affected. The antibacterial property of nanofluids made of zinc oxide nanoparticles, which are non-toxic to human cells has been analysed primarily by contrasting it to the performance of other nanofluids (Vandebriel and Jong 2012).

ZnO nanofluids have been shown to exhibit antibacterial behaviour, which has been convincingly demonstrated (Zhang et al. 2007). Jalal et al. applied a sustainable technique for making ZnO nanoparticle. ZnO nanoparticle suspensions' antibacterial activity against Escherichia coli (*E. coli*) was determined by measuring the reduction ratio of bacteria after being exposed to the nanoparticles. Bacterial survival rates decrease with increasing ZnO nanofluid concentrations and exposure times (Jalal et al. 2010). Additional research has revealed that ZnO nanomaterials have broad-spectrum antibacterial effects against many different microorganisms. There is some speculation that the size of the ZnO particle as well as the existence of standard visible light are important factors in determining its antibacterial activity (Jones et al. 2008).

Copper and copper oxide nanoparticles have been shown to possess antibacterial properties against a diverse range of bacteria, including strains that are both gram-positive and gram-negative (Mahapatra et al. 2008; Usman et al. 2013). The size of the nanoparticles and the temperature at which they are produced can affect the antibacterial potency of the nanoparticles. Smaller CuO nanoparticles exhibit greater antibacterial activity. Additionally, CuO nanoparticles can penetrate the bacterial cell wall (Padil and Černík 2013). It is hypothesised that such NPs attach to the enzymes within the cell and impede the processes that are necessary for its survival (Akbar and Butt 2015).

Leung and colleagues' research (2014) revealed that the toxicity of MgO nanofluids towards E. coli may occur even in the absence of oxidative stress and the generation of reactive oxygen species (ROS). This led them to propose a new hypothesis regarding the mechanism behind MgO's toxic effects, which involves damage to the cell membrane despite the lack of lipid peroxidation, which was previously thought to be responsible (Leung et al. 2014).

According to Dong et al., the antibacterial pathway of $Mg(OH)_2$ NPs of metal-based compounds. They had drawn the conclusion that MgO nanoparticle is an efficient antimicrobial entity against the foodborne pathogens which include E. coli and Salmonella sp. (Dong et al. 2010).

### *5.3 Drug Delivery*

Over the past few decades, investigations have been carried out on nanofluids (NFs) for drug delivery purposes to enhance their efficacy and specificity. The nanoparticles' properties and traits in the nanofluid, including their small size, customisable surfaces, and multifunctionality, enable the NPs to interact with complex cellular functions in novel ways (Tripathi and Bég 2014; Wang et al. 2020).

NPs have been studied for their potential use as drug delivery systems. The use of gold nanoparticles is advantageous in drug and gene delivery applications due to their non-toxic nature as carriers (Ghosh et al. 2008). The monolayer in such systems allows for the optimizations of physicochemical characteristics like charge and hydrophobicity, while the gold core provides stability to the arrangement as a whole (Ghosh et al. 2008; Han et al. 2007). The main goal of any delivery of drugs system is to ensure the drug is released precisely where it needs to be. The first studies on drug delivery systems focused on the drug's dissolution pathway, its sensitivity to pH and temperature, polymeric materials, nasal delivery, as well as oral drug delivery (Gupta et al. 2002; Park 2014). Over the past few years, numerous researchers have contemplated the application of nanofluids is drug delivery systems because of the potential benefits they offer, including improved therapeutic properties and safety, reduced toxicity, and increased biocompatibility (Sawant et al. 2021). In the production of nanofluids for drug delivery, it is essential for the system to have the capability of producing enclosed drug and discharge properties, as well as having a prolonged storage life and compatibility with living organisms. Regarding nanofluidic medications, the electric charge of the nanoparticles that are dispersed in the fluid is one of the critical factors to take into account (Sheikhpour et al. 2020).

Madanipour et al. used the Moiré deflectometry methodology for investigating the absorption coefficient of gold NPs in water due to its importance in biomedical applications (Madanipour et al. 2015). Graphene-based nanofluid have been shown to have the potential to be utilised in anti—cancer medication delivery systems, according to a comprehensive study (Jampilek and Kralova 2021).

In the quest for more stable and effective drug release in medical nanofluids, thermal conductivity (TC) could perhaps play a significant role. Amin Kazemi-Beydokhti and his colleagues looked into the ways in which the TC values of a medical nanofluid changed. It was discovered that elevating the temperature increases the TC, while lowering the pH improves the thermophysical conditions for drug release. These results provide compelling evidence that TC may play a critical role in the design of clinical nano—fluids for anticancer therapy (Kazemi-Beydokhti et al. 2015).

To improve drug specificity and efficiency, magnetic nanofluids (MNFs) are widely used in contemporary drug delivery methods (Hamad et al. 2021). It has been shown that MFs have an influence on nano-drug delivery methods. Das and colleagues examined the movement of conducting nanofluids through a porous tube under peristaltic flow while being exposed to a magnetic field (MF). The implementation of a magnetic field enables nanoparticles (NP)-based medications to be guided to a specific area inside the body. The multitude of advanced applications of this model makes it a valuable drug delivery system in the realm of biomedical engineering (Das et al. 2019). Shahzdi et al. examined the use of NFs as drug agents in copper and hybrid NFs by employing mathematical modelling. And had cluded NFs as potential agent in biomedical field (Shahzadi and Kousar 2019). In order to determine whether or not the cytotoxicity of ZnO quantum dots nanoparticles in the shape of ZnO nanofluids is evident, Fakhroueian et al. tested them on four different types of cancerous cell lines. ZnO quantum dots are suitable for use as drug agents due to their ability to destroy cancer cell lines (Fakhroueian et al. 2018).

## *5.4 Wound Care*

In recent years, there has been a prevalence of cutting-edge treatment options for wounds. Wound healing at various stages has been aided by the use of nanostructured systems (Tottoli et al. 2020). Assessment of biomedical interoperability, assessment of anti-microbial efficacy, and assessment of in vivo efficacy utilising full-thickness skin models are all crucial steps in the creation of innovative systems for wound healing (Chakrabarti et al. 2019; Kalashnikova et al. 2015). During treatment, it's not uncommon for skin lesions to become infected, so finding a good dressing is crucial (Negut, Grumezescu, Grumezescu).

Anghel and colleagues carried out a study investigating the use of iron nanofluids in wound care with the aim of preventing the colonization of *Candida albicans* and the formation of biofilm. The dressing patches were soaked in a nanofluid containing the targeted nanoparticles, composed of a blend of active magnetic nanoparticles such as iron oxide. The primary outcome of this study was that combining the unique characteristics of iron oxide nanoparticles and Satureja hortensis oil could lead to the creation of a novel product that hindered the growth of biofilms and fungi (Anghel et al. 2013).

## *5.5 Cryopreservation*

Nanofluids give the impression of having the ability to significantly enhance heat transfer rates in awide variety of uses, including those in the areas of instrumentation as well as bio-medicine (Baby et al. 2011; Wong et al. 2017). When compared to base fluids like oil or water, the thermos-physical characteristics of nanofluids, which including heat capacity, temperature gradient, rheology, as well as heat transfer coefficients, have been found to be significantly improved (He et al. 2008; Krishna et al. 2020; Verma and Tiwari 2015).

Traditional methods of vitrification typically involve the application of cryoprotectants in extremely high concentrations (commonly greater than 4 M), which are frequently toxic. In order to bypass this obstacle, The concentration of cryoprotectant that he and his colleagues had used was only 2 M, which is the same concentration that is typically utilised for the conventional slow-freezing procedures. They had created an ultra-modern quartz micro-capillary system that was based on nanofluid for the novel cryopreservation of mammalian cells. According to the findings of their research, vitrification of murine embryonic stem cells in the presence of a small levels of intracellular cryoprotectants could be an approach that is both practical and successful for the purpose of cryopreserving these cells. This technique was used to vitrify murine embryonic stem (ES) cells, and the results were comparable to those obtained with non-frozen control cells in terms of the viability rate. The expression of three distinct proteins, which included a variety of transcription factors, served as a verification that the pluripotent murine ES cells derived from post-vitrification embryos maintained their undifferentiated properties (Ilyas et al. 2017).

## 5.6 Cryosurgery

Cryosurgery is considered as one of the most efficient methods for entire treatment of tumour cells and for maintaining control over those cells. Liquid nitrogen as well as solid carbon dioxide are used in this process (Cooper and Dawber 2001). The creation of ice crystals is a result of artificially creating a very cold environment; this decrease in liquid water could cause the cell wall of the intended cell to rupture (dehydration) (Singh and Bhargava 2014). However, there are drawbacks to using this method, including the potential for collateral damage to healthy tissues due to improper freezing. Highly conductive NPs are loaded into the tumour tissue to enhance its freezing capacity (Hou et al. 2018; Singh and Bhargava 2014). Using simulations of phase change bio-HT at the cellular level, Yan and Liu (2008) determined the temperature difference between traditional cryosurgery and nano cryosurgery. As a result of the encouraging findings, they reasoned that nanocyrosurgery concepts could pave the way for novel approaches to tumour treatment in the future.

## 5.7 Bioimaging

Because of their unique combination of magnetic and physicochemical parameters, nanofluid-based NPs have been proposed as a promising tool for biological imagining applications and cancer detection (Hosu et al. 2019). Because of their unique optical properties, adaptability in surface modification, and capacity to transport a wide range of sensing and therapeutic components, nanofluid-based nanoparticles have recently found application in bioimaging (Nune et al. 2009). Moreover, Nanomaterials should be nontoxic with the biomedical platform being tested, demonstrate exceptional optical characteristics, decent light absorption, and be able to report on the rapid fluctuations of the biological process. Nanoparticles used in bioimaging can be categorised as either self-emitting specific optical signals (such as quantum dots or carbon dots) or requiring fluorophore labelling to be visualised (Pratiwi et al. 2019).

The utilization of nanofluids based nanomaterials in electromagnetic resonance imaging is one of the most fascinating applications that can be found in the field of diagnostic medicine (MRI) (Sheikhpour et al. 2020; Wang et al. 2022). In MRI, the utilization of magnetic nanoparticles improves contrast as well as sensitivity. When it comes to increasing contrast in MRI scans, superparamagnetic nanoparticles (SPMNPs) are among the most effective options. Inorganic compounds, gold, and nanoparticles of gadolinium could all be components of these agents (Shokrollahi 2013).

In their study on magnetic particle imaging, Euting et al. looked into the possibility of using a biocompatible as well as reliable form of ferromagnetic carbon NF. The magnetization of superparamagnetic material was compared to that of ferromagnetic material. This study provided evidence that ferroMNFs could be useful like a contrast agent and demonstrated their practicability. Based on the research results, the use of ferromagnetic NPs leads to images that are less blurry and have more edge imaging interpretation (Euting et al. 2012).

The utilization of iron oxide nanoparticles within assessment as well as diagnosis of atherosclerosis was investigated and reviewed by Talev et al. They discussed the use of NPs for the purpose of molecular imaging of atherosclerosis (Talev and Kanwar 2020).

Through the use of nanosecond pulsed laser ablation, Yogesh et al. successfully synthesised graphene oxide NPs and studied their properties for use in bioimaging. And the results suggest that graphene oxide NPs are suitable for bioimaging because they are biocompatible and emit a photoluminescent signal (Yogesh et al. 2020).

## 5.8 Micro-Pumping Devices

Devices that utilise microfluidics and nanofluidic are used extensively in the field of biomedicine (Hamad et al. 2021). Nanofluids play an integral role in micro-pumps, which can be either passive or active depending on its functionality (Attia and Alcock 2010). Traditional active pumps can't be used in NFs because the hydraulic resistance they'd cause in such a tiny space would be too great. active pumps are not appropriate for utilization with NFs due to the very high hydraulic obstruction they present in a nanochannel and the extremely small volume that can be accommodated by the channel (Attia and Alcock 2010; Liang et al. 2018). As a direct consequence of this, researchers started looking for different options. A nanofluidic high-pressure micropump along with incredible accuracy and the capability to provide up to 20 MPa was developed by Liang and colleagues (2018).

In their research, Serkan and colleagues proposed the application of a novel, mobile permanent magnetic actuator (PMA) configuration to manipulate magnetic nanofluids for driving chemical substances within circular micro-sized channels. The results indicate that the suggested PMA system meets the criteria for flow rates in analytical applications, such as administering low-flow drug delivery, sorting cells, and monitoring microorganisms (Doganay et al. 2020).

Electrokineti-cmicroperistaltic pumps are essential pieces of biomechanical equipment that assist in the localised administration of medication to diseased areas of the body. Mathematical modelling and analysis of various significant aspects of this kind of fluid flow inside a rectangular channel with wall properties had been the primary focus of Ahmed and co-workers' research. Further in their research, they model the transport of a CNT-water nanofluid and perform an analytical analysis of the resulting flow problem. In the context of pharmacological engineering, the application of their research involved the creation of a system for transporting or targeting the delivery of drugs using peristaltic micropumps and magnetic fields (Zeeshan et al. 2021).

## 6 Challenges

Over the course of the last few decades, scientists have uncovered a plethora of nanofluids' potential properties (Yang et al. 2020). However, there are a number of issues that could serve as roadblocks in the process of commercializing nanofluids. Therefore, the scientist ought to place a greater emphasis on finding solutions to these problems. It seems that nanofluids could be useful in a wide range of applications; however, the advancement of this field is being hampered by a number of factors like (Assael et al. 2019; Puliti et al. 2011; Saidur et al. 2011; Sreelakshmy et al. 2014).

- Discordance between findings from various labs
- The inaccurate labelling of suspensions
- As a result of not having a firm theoretical grasp on what causes the reported alterations in properties.

Most studies in the literature (Elias et al. 2014; Senthilraja et al. 2015) found nanofluids with an insufficient stability period, suggesting that the stability of these materials is an issue. Notable is the fact that most research concentrates on thermo-physical properties like thermal conductivity, rheology, composition, temperature transfer coefficient, etc. Chen et al. (2008), Nabil et al. (2018), Timofeeva et al. (2009), Zeng and Xuan (2018). Further, more emphasis should be placed on stabilisation, which is a key issue in ensuring the credibility of the research findings, especially when they are put to use in the real world. There is a dearth of studies examining the properties and behaviour of nanofluids at extreme temperatures (Amiri et al. 2016; Esfe et al. 2017) in the existing literature. Understanding the mechanism of effectiveness of nanofluid at both low and high temperatures may benefit from research into these fluids at both extremes of temperature. Most interestingly, there are no findings regarding the total prices of the various kinds of nanofluids. Because nanofluids have novel properties, conventional fluids are really being phased out and replaced by various types of nanofluids (Assael et al. 2019; Sidik et al. 2014). In the event that a significant quantity of conventional fluids is changed out for nanofluids, the resulting heat transfer equipment can be made relatively more straightforward and of a more compact size, which can result in cost savings. In the meantime, the method of preparation, properties, etc., all contribute to the high cost of various nanoparticles (Esfe et al. 2017). The total cost of using various nanofluids alongside the required infrastructure in a wide range of real-world settings is an intriguing topic that could be explored in future research. The following are a few of the more notable points.

1. **High viscosity**—The higher the amount of particles that are suspended in the nanoparticle-water mixture, the higher the viscosity of the suspension. Therefore, there is a limit to how much the particulate mass fraction can increase and this could be considered as one of the drawbacks of nanofluid application (Sheikhpour et al. 2020; Yang et al. 2020).
2. **High cost**—One potential barrier to nanofluids' widespread industrial use is their more expensive production. One-step or two-step processes can be used to create nanofluids. Nonetheless, high-tech instruments are essential for either approach (Huaxu et al. 2020).
3. **Lower specific heat**—In comparison to base fluid, nanofluids have a lower specific heat, which is the most significant disadvantage of nanofluid (Lee and Mudawar 2007).
4. **Production challenges**—Nanoparticles are synthesised in their entirety through reduction reactions and ion exchange. Also, it is challenging, if not impossible, to purge the base fluids of their various other ions as well as reaction products. The advantages of high-surface-area nanoparticles are diminished because of the particles' propensity to clump together. In order to combat this issue, particulate displacement preservatives are typically added to the nanoparticle-carrying base fluid. However, doing so can alter particle surface properties, as well as nanofluid manufactured in this manner may have unacceptably high impurity levels (Saidur et al. 2011).

## 7 Future Scope

There is a wide variety of uses for nanofluids currently, and this number is expected to grow in the future. The development of nanofluidic systems that are capable of delivering energy in a manner that is both effective and efficient ought to be the primary focus of research. Concerns have been raised about the safety of the production and use of nanofluids in the present day, and these issues will also be the subject of research in the future. It's possible that in the future, research will focus on both the modification of nanoparticles in nanofluids and their applications in biomedical areas. Nanofluids have the potential to assist in the delivery of drugs in a targeted manner, which will allow the pharma industry to achieve significant advances.

## 8 Conclusions

Nanofluids have many potential uses, but one of the most important is in the medical and biomedical fields. In this article, a survey of the implementations of nanofluids is conducted. These applications include delivery of drug, medical care, disease diagnosis, antimicrobial implementations, wound care and so on. The papers about the above case were reviewed, and one's contents and results described and analysed, with a focus on these novel topics.

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