Review Article

Recent Developments in the Applications of Nanofluids

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ABSTRACT

Fluids containing nanoparticle suspensions features significantly in heat transfer applications. This is attributed to their enhanced thermophysical properties which are more advanced compared to the conventional fluids. The thermophysical properties of nanofluids that makes them attractive for use in various fields include thermal conductivity, convective heat transfer coefficient, viscosity, density, heat capacity, thermal diffusivity, emissivity and optical absorption. The current paper reviews the current trends in the application of nanofluids in various fields such as nanomedicine, renewable energy applications, automotive applications, electronic cooling applications, heating buildings, space and defense and in microbial fuel cell.

Introduction

Nanofluids

Nanofluids are embryonic fluids enriched with ultrafine solid nanoparticles. The nanoparticles sizes range from $(1-100)nm$ making nanofluids behave more like a single phase fluid rather than a solid-liquid mixture. The nanoparticles used in the synthesis of nanofluids consist of chemically stable metals $(\mathrm{Al, Cu, Ag\ , Au, Fe})$, nonmetals$(\mathrm{graphite, carbon\ nanotubes})$, oxides ceramics $(\mathrm{Al2O3, CuO, TiO2, SiO2})$, carbides$(SiC)$, nitrides $(\mathrm{AIN, SIN})$, layered $(\mathrm{Al+, Al2O3, Cu+C})\mathrm{PCM}$, and functionalized nanoparticles. The host fluid used in the preparation of nanofluids are usually a conductive fluid, such as water, (or other coolants), oil (and other lubricants), polymer solutions, bio fluids and other common fluids, such as paraffin. Nanofluids were first engineered by (Choi & Eastman, 1995) of the Argonne national laboratory, USA in 1995. Nanofluids show advanced thermal-physical properties such as thermal conductivity, convective heat transfer coefficient, viscosity, density, heat capacity, thermal diffusivity, emissivity and optical absorption in comparison to the conventional base fluids (Murshed, 2025; Razzaq et al., 2025). Nanofluids can be classified as Metallic Nanofluids i.e. nanofluids prepared by dispersing nanoparticles made from chemically stable metals such as $(\mathrm{Al}, \mathrm{Cu}, \mathrm{Fe}, \mathrm{Zn}, \mathrm{Ni}, \mathrm{Si}, \mathrm{Ti}, \mathrm{Au\ and\ Ag})$ into the host fluid, Non-Metallic Nanofluids, i.e. Nanofluids prepared by suspending nanoparticles made from nonmetals into the host fluid. The nonmetals used include metal oxides $(CuO, \mathrm{Al2O3}, \mathrm{SiC}, ZnO, \mathrm{TiO2}\ )$, Semiconductors such as $(\mathrm{TiO2})$ and Carbon Nanotubes $(\mathrm{SWCNT}, \mathrm{MWCNT}, \mathrm{and\ DWCNT}\ )$, and composites materials such as nanoparticles core polymer shell composites, and Hybrid nanofluids (i.e. nanofluids dispersed with two or more different types of nanoparticles). Nanofluids owing to their advanced thermophysical properties continues to attract a lot of attention due to their possible use in numerous fields.

Applications of Nanofluids

Nanofluids can be used in various heat transfer applications due to their superior thermophysical properties compared to those of conventional fluids. The following are some of the applications of nanofluids:

a) Nanomedicine

Nanomedicine involves harnessing the power of nanotechnology in detection, diagnosis and treatment of diseases. The use of Nanotechnology in the diagnosis and treatment of cancer as an alternative to traditional methods of cancer treatment (chemotherapy, radiotherapy, and surgery) looks promising. Nanotechnology has been successfully deployed in targeted drug delivery, molecular (tumor) imaging, targeted therapy, phototherapy, gene therapy and Radiofrequency ablation of cancerous cells. With regards to nanomedicine the following areas are discussed in detail;

Nanoparticle-based cancer imaging, Nano drug delivery, Nanocryosurgery, targeted therapy, phototherapy, gene therapy and Radiofrequency ablation.

i. Nanoparticle-Based Cancer Imaging

Tumor imaging by deploying nanoparticles helps in early detection of cancerous cells *(Jin et al., 2020)* . The materials used in generating Nanoparticle imaging probe should be biodegradable, of low toxicity, be easily excreted from the body system and be able to provide strong imaging signal. Nanoparticles used to create imaging probes for cancer treatment possesses unique properties such as unique optical, magnetic and chemical properties. This results in imaging probes with increased signal density, signal amplification and quantification, improved contrast, and controlled biodistribution *(Chapman et al., 2013)*. π −Conjugated nanoprobes are used in brain tumor-related studies, due to their excellent electronic structure, optical properties and photothermal therapy to deactivate tumor cells by elevating temperature *(Ma et al., 2021; Sun et al., 2023)*. The nanoparticles currently being used to create imaging probes include gold nanoparticles, iron oxide nanoparticles, lipid nanoparticles, silica-based nanoparticles, polymeric nanoparticles and Quantum dots.

ii. Nanocryosurgery

Nanocryosurgery is a medical procedure that incorporates nanoparticles in freezing of tumor or cancerous cells. The target cells are intentionally loaded with nanoparticles of high thermal conductivity to speed up the freezing process. According to (Ammar et al., 2025; Hou et al., 2018; B. Wang et al., 2024) intentionally loading of target tissues with nanoparticles of superior thermal conductivity results in the overall decrease of the final temperature of the tumor resulting in maximum freezing rate. The nanoparticles deployed in the nanocryosurgery should be nontoxic, biodegradable and have few side-effects on the human body (Di et al., 2012) . The therapy is becoming popular in treatment and management of cancer due to its clinical advantages as opposed to the traditional methods. Diamond, magnetite ($Fe3O4$) and magnesium oxide (MgO) nanoparticles are preferred in enhancing freezing due to their good biological compatibility.

iii. Nanodrug delivery

Nanodrug delivery involves use of nanoparticle drug carriers for targeted drug delivery to the affected tissues, improving drug efficacy and minimizing the related side effects. The conventional routes currently being used for drug delivery include; oral, buccal, rectal, subcutaneous, intranasal, intramuscular, intravenous, pulmonary and transdermal which are often characterized by limitations such as instability, risk of displacement, uncontrolled release of drug, side effects such as irritation and pain, slow absorption and enzymatic deterioration. The use of magnetic nanoparticles (Graham et al., 2025; Rarokar et al., 2024; Riaz et al., 2025) as nanocarriers allows doctors to precisely deliver high local doses of drugs or radiation to the affected tissue without damaging neighboring healthy tissues. This magnetic drug delivery overcomes the major drawback of the traditional methods such as chemotherapy which is often characterized by the inability to precisely deliver and concentrate drugs to the affected tissues and organs resulting in free circulation of drugs in the bloodstream which affects other healthy tissues and organs. Nanodrug delivery trials are being conducted in the field of cancer where magnetic nanofluids (ferrofluids) are being used to guide the cancer drugs up the bloodstream to the tumors with the help of magnets. The nanocarriers currently in use include; solid nanoparticles, liposomes, dendrimers, polymeric nanoparticles, polymeric micelles, virus like nanoparticles, carbon nanotubes and mesoporous silica nanoparticles (Sultana et al., 2022) with the following drug delivery systems currently in use; nucleic acid-based drug delivery system, cell-based drug delivery system, self-nano emulsifying drug delivery system, self-micro emulsifying drug delivery system, chemical and physical stimuli-based drug delivery system, nanoneedles, patches, ultrasound drug delivery and microchip technology.

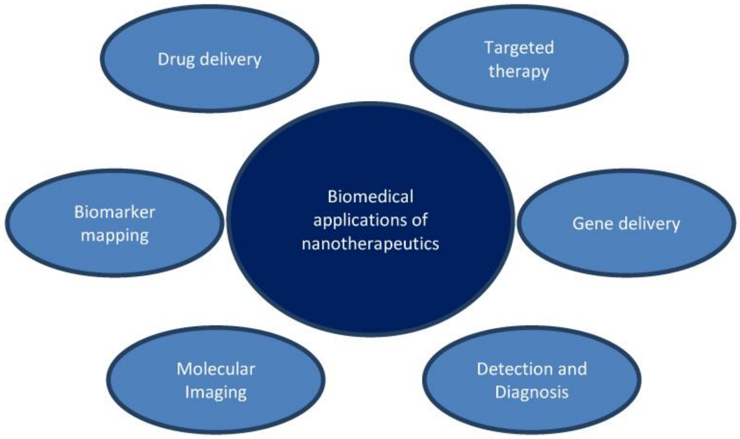

Figure 1: Biomedical application of Nanofluids

(Image source: Intechopen.com)

b) Renewable energy applications

i. Geothermal Power Extraction

During the drilling process to extract thermal or heat energy from the earth's crust where the drilling lengths usually vary from $(5 - 10km)$ and high temperatures of between $(500℃ - 1000℃)$ are involved, the major limiting factor becomes the thermal limitations of the drilling tools, sensory devices and pipes. Nanofluids due to their high thermal conductivity (fluid superconductors) plays a vital role in extraction of geothermal energy. They are deployed in geothermal well construction to cool down pipes, machineries and other equipment working under extreme high temperatures and friction conditions, in geothermal reservoir characterization, scaling and corrosion prevention and resource recovery (Meng et al., 2025). The use of nanofluids during drilling permits sensors and other electronic devices to operate under high temperature allowing access to deeper and hotter regions which boosts the amount of thermal energy extracted from the ground.

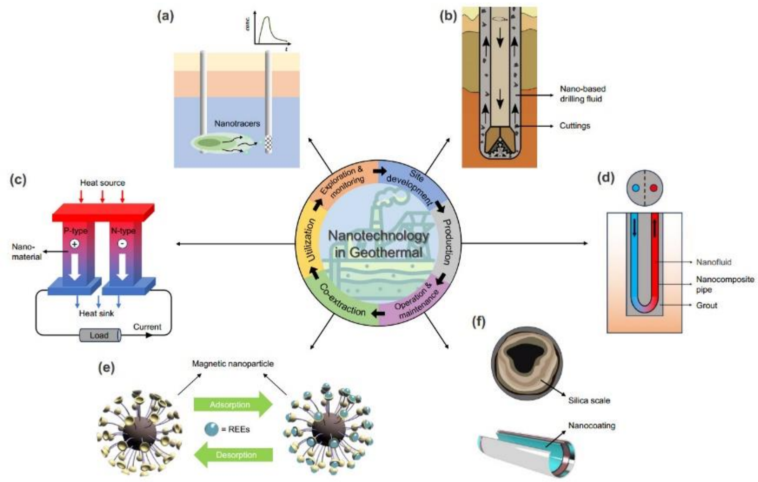

Figure 2: Various applications of nanotechnology in geothermal energy systems (Image source Canstrat Inc. (2024), Kurita Europe (2024))

ii. Solar Energy Absorption.

Solar energy being renewable and environmental friendly, its use in most engineering applications that require heating and cooling is becoming popular. These applications range from heating living spaces, solar electric power generation, and solar cookers to solar water-heating systems among others. The conventional direct absorption solar collector used in various applications such as water heating is a well-established technology but whose operation is always limited by the working fluid used. This technology when combined with nanofluids as the working fluid, the efficiency of these collectors can be enhanced (Alcázar et al., 2025; Hamzat et al., 2022; Zahra Haeri et al., 2025). The experimental study by (Eriksen et al., 2024) on direct absorption solar collector incorporating carbon black nanofluid for solar energy harvesting reported a 42% thermal enhancement at $0.01wt.\%$ nanoparticle concentration in reference to distilled water. (Nguyen et al., 2023) investigation on direct absorption solar collector utilizing carbon black nanofluid as the working fluid noted a 102% thermal enhancement when compared to pure water. (Sani et al., 2010) investigating optical and thermal properties of nanofluids containing aqueous suspensions of single-wall carbon nanohorns observed improved optical properties which led to considerable higher sunlight absorption.

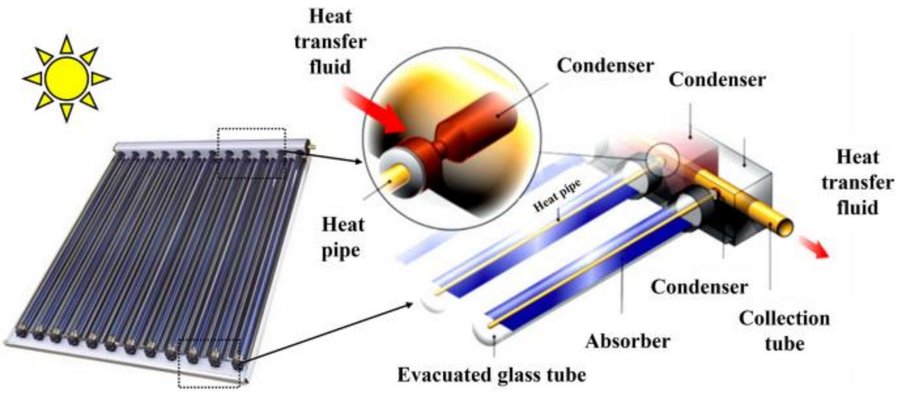

Figure 3: Nanofluid use as a heat transfer fluid in solar thermal collectors

(Image source: link.springer.com)

c) Automotive Applications

Nanofluids due to their superior thermophysical, rheological and tribological properties they are increasingly being used in automobiles as automatic transmission fluids, in engine oils, as nanolubricants and being incorporated in the automobile radiators as coolants.

i. Nanofluid coolant

The use of nanofluids as coolants would allow for smaller size and better positioning of the radiators (Ramadhan et al., 2020; Subhedar et al., 2024). The addition of nanoparticles to the standard engine coolant improves automotive and heavy-duty engine cooling rates (Hajiakbari et al., 2024) . This removes engine heat with a reduced size coolant system. Smaller coolant systems results in smaller and lighter radiators which enhances fuel economy. Improved cooling rates can also be used to remove more heat from higher horsepower engines with the same size of coolant system. In trucks with large radiators positioned in front of the engines to maximize on the cooling effect of the oncoming air, about 65% of the total energy output from the truck is used in overcoming the aerodynamic drag caused by the oncoming air and this result in increased fuel consumption (McCallen et al., 2007).

ii. Friction Reduction (Lubricants)

In automotive lubrication applications, surface-modified nanoparticles stably dispersed in engine oil have effective load-carrying capacity, good extreme pressure and friction reducing properties. (Alnajjar et al., 2025) investigating use of carbon nanotubes as lubricant additive for automotive use reported enhancement in tribological, thermophysical and rheological properties compared to the bare sample of the lubricant. They reported reduction in wear and friction, enhanced lubrication performance and enhanced low-temperature performance. (Okello et al., 2021) examining the performance of engine oil-based hybrid nanolubricants reported least coefficient of skin friction in engine oil dispersed with $(MWCNTs - TiO_2)$ hybrid nanoadditive making it suitable for automotive application. (Zhou et al., 2000) investigating tribological behavior of Cu nanoparticles in oil on a four-ball machine observed that Cu nanoparticles as oil additive had better friction-reduction and antiwear properties compared to Zinc dithiophosphate especially at high applied load.

iii. Nanofluids as Vehicular Brake Fluids

During braking in motor vehicles, the vehicle's kinetic energy is dispersed to heat energy which is transmitted throughout the brake fluid in the hydraulic braking system (Popa et al., 2010).With high demand in properties of brake oils, Aluminium- oxide and copper- oxide based brake nanofluids which have higher boiling point, higher viscosity and higher thermal conductivity compared to traditional brake fluid were manufactured using Plasma charging arc system and Arc-submerged nanoparticle synthesis systems respectively (M. J. Kao et al., 2007; M.-J. Kao et al., 2007).This enhanced Thermophysical properties of nanofluid brake oil minimizes occurrence of vapor-lock and enhances safety while driving.

d) Electronic Applications

In advanced electronic devices which are usually occasioned with high density microchips and the need to design more compact electronic devices, heat dissipation from such devices becomes a major challenge. This is because of high levels of heat generation and the reduced surface area for heat removal. A reliable thermal management system is therefore crucial for smooth operation of these devices. Two approaches can be used to achieve this, one is to find an optimum geometry of cooling devices and the other is to increase heat transfer capacity. Nanofluids due to their enhanced thermal conductivity and increased heat transfer coefficient they can be used for liquid cooling of computer processors (Nanan Kwanchai et al., 2024; Okello et al., 2020). A new cooler combined microchannel heat sink developed by (Jang & Choi, 2006) with nanofluids produced a higher cooling performance compared to using pure water as the working medium. This is because nanofluids reduce thermal resistance as well as temperature difference between heated microchannel wall and coolant. Investigations by (Rohaizan et al., 2023) on liquid cooling using nanocellulose resulted in better thermal conductivity enhancement compared to the base fluid signaling the potential use of nanocoolant in a CPU cooling system.

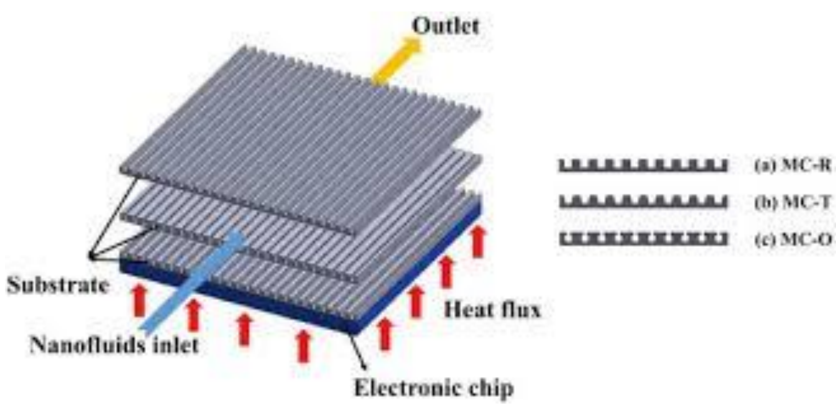

Figure 4: Nanofluids in microchannel heat sink

(Image source: ScienceDirect.com)

e) Other Applications of Nanofluids

i. Heating Buildings and Reducing Pollution

In cold regions nanofluids can be used in heating buildings. A mixture of ethylene or propylene glycol with water mixed in different proportions is commonly used as a heat transfer fluid. Study by (Alqarni et al., 2023) on shell and tube heat exchanger filled with hybrid nanofluid noted improvement in heat exchangers energy efficiency as a result of the use of nanofluid. (D. Wang et al., 2023) in their study reported a 126% increment in thermal performance of the heat exchanger which was attributed to the use nanofluid. This resulted in decrease in environmental damage, energy consumption and emissions. Investigations on shell and tube heat exchanger incorporating $(copper\ (ii) oxide/water)$ nanofluid by (Cruz et al., 2022) revealed a 48% enhancement in heat transfer which was attributed to the presence of nanofluid. The use of nanofluids in heat exchangers has shown the ability to reduce volumetric and mass flow rates, resulting in an overall pumping power savings. Nanofluids necessitate smaller heating systems capable of delivering same amount of heat energy as larger heating systems and they are less expensive. Smaller heating systems use less power and the heat transfer unit has also less liquid and therefore the material waste to be discarded at the end of its life cycle is small. This in long turn lowers pollution caused to the environment.

ii. Space and Defense

Nanofluids have a wide application in space and defense fields, where power density is very high and the components are required to be small and weightless. Due to the restriction of space, energy, and weight in space station and aircraft there is need for high efficient cooling system with smaller size (Bacha et al., 2024). This ultrahigh-heat flux cooling systems can be achieved by incorporating nanofluids (Di Lorenzo et al., 2025; Ungar & Erickson, 2011) . In military a number of devices and systems require high-heat flux cooling to the level of tens of MW/m^2 for reliable operations. Nanofluids with high critical heat fluxes have the ability to provide the required cooling in such systems and other systems such as military vehicles, submarines and high-power laser diodes.

iii. Nanofluids-Based Microbial Fuel Cell

Microbial fuel cells (MFC) uses energy found in carbohydrates, proteins and other energy-rich natural products to produce electrical power. Their excellent performance depends on electrodes and electron mediator used. (Sharma et al., 2008) constructed a novel MFC using novel electron mediators (nanofluids prepared by dispersing nanocrystalline platinum anchored CNTs in water) and CNT-based electrodes. They compared the performance of this E. coli-based MFC (CNT-based nanofluid & CNT-based electrodes) to plain graphite electrode-based MFC and CNT-based electrode showed as high as ∼6-fold increase in power density compared to graphite electrode. This result shows the ability of noble metal nanoparticles dispersed on CNT-based MFC for generation of high energies from simple bacteria like E. coli.

Conclusion

This article has reviewed the advances in the application of nanofluids which are emerging as a new breed of superconducting fluids. These fluids possess advanced thermophysical properties making them suitable for use as heat transfer fluids across various spheres of life.

Disclaimer (Artificial Intelligence)

Author hereby declare that NO generative AI technologies such as Large Language Models (ChatGPT, COPILOT, etc) and text-to-image generators have been used during writing or editing of this manuscript.

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