Nanofluid Based Heat Exchangers in Dairy and Food Industry

Vidhi sharma[2] Gajanan P. Deshmukh[1], Narender Kumar Chandla[1] and Preeti Birwal[3]
[1]Assistant Professor, CoDST, GADVASU, Ludhiana, India
[2] Research Scholar, CoDST, GADVASU, Ludhiana, India
[3]Scientist, Punjab Agricultural University, Ferozpur Road, Ludhiana, India
*Corresponding author: vidhisharma376@gmail.com

Nanofluid is a term used to describe a type of fluid that contains nanoparticles dispersed in a base fluid. These nanoparticles can be metallic or non-metallic and are usually on the order of 1 to 100 nanometers in size. The nanoparticles used in nanofluids are typically made of metals, oxides, carbides, or carbon nanotubes. Common base fluids include water, ethylene glycol and oil. When the nanoparticles are introduced into the base fluid, they form a colloidal suspension, where the nanoparticles are uniformly distributed throughout the fluid. It is obvious from a survey of thermal properties that all thermal fluid used today as heat transfer fluids exhibit extremely poor thermal conductivity (with the exception of liquid metal, which cannot be used at most of the pertinent useful temperature ranges). Nanofluids exhibit unique properties that can differ significantly from those of the base fluid alone. One of the most notable properties is the enhanced thermal conductivity of nanofluids compared to the base fluid. The presence of nanoparticles increases the ability of the fluid to conduct heat, making nanofluids attractive for various heating and cooling applications (Ahmed, 2019).

Nanofluids have been extensively studied in recent years due to their potential for improving heat transfer efficiency in various engineering and industrial applications. Some of the areas where nanofluids have shown promise include electronics cooling, automobile engine cooling, solar thermal systems, and heat exchangers. However, it's important to consider challenges associated with nanofluids, such as the potential for nanoparticle agglomeration, stability issues, and the cost of producing and maintaining nanofluids. Researchers continue to explore ways to optimize nanofluid formulations and address these challenges to make them more practical and commercially viable for a wide range of applications.

Method of Production of Nanofluid

The production of nanofluids involves dispersing nanoparticles into a base fluid to form a stable colloidal suspension. There are several methods for producing nanofluids, and the choice of method depends on the type of nanoparticles, the base fluid, and the desired characteristics of the nanofluid. Here are some common methods used for nanofluid production:

Two-Step Method

a. Synthesis of Nanoparticles: The first step involves synthesizing the nanoparticles. This can be done through various techniques, such as chemical reduction, sol-gel, thermal decomposition, or physical vapor deposition.

b. Dispersing Nanoparticles in Base Fluid: In the second step, the synthesized nanoparticles are mixed into the base fluid using mechanical agitation, ultrasonication, or other dispersion methods. The goal is to achieve a uniform distribution of nanoparticles throughout the fluid.

One-Step Method

This method involves simultaneously synthesizing nanoparticles and dispersing them in the base fluid. For example, in a co-precipitation method, the nanoparticles are formed in situ during the mixing of precursor materials and the base fluid.

Surfactant-Assisted Method

Surfactants or surface-active agents can be used to stabilize the nanoparticles in the base fluid and prevent agglomeration. Surfactants act as dispersants, helping to maintain a stable nanofluid by reducing the attractive forces between nanoparticles.

High-Energy Ball Milling

In this method, mechanical energy is applied to the nanoparticles and base fluid mixture using high-energy ball mills. The impact and shear forces during milling break down the nanoparticles and disperse them in the fluid.

Micro fluidization

Micro fluidization involves forcing the mixture of nanoparticles and base fluid through microchannels or small orifices under high pressure. This process helps to reduce nanoparticle agglomeration and achieve better dispersion.

Electro-hydrodynamic (EHD) Method

In the EHD method, an electric field is applied to the mixture of nanoparticles and base fluid. The electric field induces flow patterns that promote dispersion and mixing of the nanoparticles.

It is essential to carefully control the process parameters during nanofluid production, such as nanoparticle concentration, mixing time, temperature, and shear rate, to obtain a stable and well-dispersed nanofluid. Additionally, surface modifications of nanoparticles and the use of additives can further improve the stability and performance of nanofluids in specific applications.

Nanofluid-based heat exchangers

Nanofluid-based heat exchangers are heat exchange devices that utilize nanofluids as the working fluid to enhance the efficiency of heat transfer between two fluids at different temperatures. These heat exchangers leverage the improved thermal properties of nanofluids, which are engineered colloidal suspensions containing nanoparticles dispersed in a base fluid (such as water, oil, or ethylene glycol). Nanofluid-based heat exchangers have gained attention in various industries, including the dairy and food industry, due to their potential to improve heat transfer efficiency.

Here's how nanofluid-based heat exchangers work and their advantages:

Enhanced Heat Transfer: Nanofluids have significantly higher thermal conductivity than conventional fluids, which allows for enhanced heat transfer rates in heat exchangers.

Reduced Fouling: Nanofluids can help reduce fouling on the heat exchanger surfaces.

Increased Heat Capacity: The specific heat capacity of nanofluids is often higher than that of the base fluid, which can further enhance the heat absorption or release capabilities of the heat exchanger.

Enhanced Thermal Stability: Nanofluids can exhibit improved thermal stability and resistance to thermal degradation, making them suitable for high-temperature heat exchange applications.

Flexibility in Design: Nanofluid-based heat exchangers can be designed with compact sizes, making them ideal for applications where space is limited or weight reduction is crucial.

Despite these advantages, there are some challenges to consider when using nanofluid-based heat exchangers:

Nanoparticle Agglomeration: Nanoparticles have a tendency to agglomerate in the fluid, which can reduce the effectiveness of the nanofluid and lead to flow blockages in the heat exchanger.

Cost and Availability: Some nanoparticles used in nanofluids can be expensive, which may increase the overall cost of the heat exchanger.

Stability Issues: Nanofluids can experience stability problems over time, leading to particle settling and changes in the fluid's properties.

Application of Nanofluid based Heat Exchanger

The enhancement of heat transfer in heat exchanger of dairy and food industries includes various unit operations (heating, cooling, frying, freezing, concentration, evaporation, drying) which results in better product safety and quality, reduction in processing time, and overall costs with improved energy efficiency. However, compact design of HT/storage/exchange equipment reduces workspace requirements and operating cost, facilitate automation, assist safe handling, and minimize heat losses. Nanofluid could be used indirect heat exchangers for pasteurization, commercial sterilization, blanching and UHT (ultra-high treatments) processing of milk, fruit juices, and other liquid foods. It can be also used in refrigeration, cold storage, and air conditioning. Nano refrigerants showed better performance (COP) and energy efficiency in domestic as well as large scale refrigeration systems. Hence, primary as well as secondary nano refrigerants can be used in dairy and food industry for cold rooms/cold transport systems. NFs have great potential to be an efficient PCM for thermal (heating cooling) energy storage and can be used in ice-bank-tanks (generally maintained in milk and food processing plant to store cooling energy) and solar panels (for readily absorbing and releasing stored energy)

Taghizadeh et al. (2016) used titanium dioxide nanoparticles TiO2) in hot water stream (@ 0.25%, 0.35% and 0.8%) in milk PHE to enhance heat transfer capability of as the working media. It was found that nanofluid at all concentrations showed higher heat transfer rate and pressure drop than that of the distilled water. Pantzali et al. (2009) studied the efficacy of nanofluids as a coolant in PHEs and reported a significant increase in the measured pressure drop and consequently in the necessary pumping power when the nanofluid is applied instead of pure fluid. Ravi et al. (2022) developed nanofluid based milking pail for colling of milk. The fresh raw milk was passively chilled from 37 to below 10 °C within 1 h and the chilled milk was maintained below this safe limit using the NePCM capsuled inside the jackets of a cylindrical milk chilling module.

Conclusion

Despite these potential advantages, it's important to note that the commercial implementation of nanofluid-based heat exchangers in the dairy and food industry is still limited. Challenges such as nanoparticle stability, cost-effectiveness, and potential health and safety concerns associated with nanoparticles need to be addressed. Extensive research and development efforts are ongoing to optimize nanofluid formulations and manufacturing processes for practical applications.

References

Ahmed, M. S. (2019). Nanofluid: new fluids by nanotechnology. In Thermophysical properties of Complex materials. London, UK: IntechOpen.

Taghizadeh-Tabari, Z., Heris, S. Z., Moradi, M., & Kahani, M. (2016). The study on application of TiO2/water nanofluid in plate heat exchanger of milk pasteurization industries. Renewable and Sustainable Energy Reviews, 58, 1318-1326.

Pantzali, M. N., Mouza, A. A., & Paras, S. V. (2009). Investigating the efficacy of nanofluids as coolants in plate heat exchangers (PHE). Chemical Engineering Science, 64(14), 3290-3300.

Prakash, R., Ravindra, M. R., Pushpadass, H. A., Sivaram, M., Jeyakumar, S., & Rao, K. J. (2022). Milk chilling using nanoparticle enhanced phase change material capsuled inside a jacketed cylindrical module: A numerical and experimental study. Innovative Food Science & Emerging Technologies, 81, 103112.

Ali, A. R. I., & Salam, B. (2020). A review on nanofluid: preparation, stability, thermophysical properties, heat transfer characteristics and application. SN Applied Sciences, 2(10), 1636.

* * * * * * * *