Novel Heat Transfer Fluids for Efficient Energy Dissipation in Dairy Industry

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The dairy industry has noticed a notable trend towards sustainable energy practices in recent years. The study of non-conventional or novel heat transfer fluids (HTFs) has drawn a lot of attention as the push for cleaner and more effective energy sources develops. These cutting-edge HTFs provide a number of advantages, including increased thermal conductivity, increased heat transfer effectiveness, and little environmental impact. In this article, the in-depth examination of emerging novel HTFs and their potential uses in the dairy industry is being discussed.

Traditional heat transfer system

Traditional heat transfer systems have been widely used in various applications, including heating and cooling systems, industrial processes, and domestic appliances. They often rely on well-established engineering practices and technologies that have proven to be effective and reliable over time.

Conventional heat transfer fluids

One of the leading causes of poor performance and escalating energy costs in various industries, including the dairy and food sector, stems from the prevalent usage of conventional heat transfer fluids. Examples of such fluids include water, steam, propylene glycol, ethylene glycol etc. These outdated fluids, although once considered the norm, are now proving to be inadequate in meeting the demands of modern energy efficiency and sustainability practices.

Hurdles faced with usage of conventional heat transfer fluids

Conventional heat transfer systems have limitations in terms of efficiency and control. They require larger amounts of energy or have slower response times compared to more advanced and innovative heat transfer technologies. The other problems associated with their application are:

- Corrosion: These fluids corrode the surfaces of heat exchangers which further leads to leakages and equipment failure.
- Scaling: The usage of water causes scaling on the heat exchanger surfaces which reduces heat transfer efficiency
- Toxicity: Few fluids such as ethylene glycol and propylene glycol are toxic in nature and can pose a health risk
- Maintenance cost: The scaling and corrosion problems further leads to higher maintenance cost and processing cost as well.

Emerging heat transfer fluids

As businesses strive to optimize their operations and minimize their environmental impact, the adoption of emerging non-conventional heat transfer fluids has emerged as a viable solution. The enhancement in performance of heat exchanger systems can be obtained using emerging fluids like NFs, phase change materials, thermal oils etc. These advanced HTFs offer a multitude of benefits, ranging from enhanced thermal conductivity to reduced energy consumption, making them an ideal choice for overcoming the limitations of conventional fluids. By transitioning away from conventional HTFs and embracing the potential of novel HTFs, the dairy industry can pave the way for improved performance, reduced energy costs, reduced processing time and a greener future.

Desired characteristics of heat transfer fluids

The desirable properties of heat transfer fluids are mentioned below:

- Low viscosity
- Low toxicity
- Cost-effectiveness
- Non-flammability
- Chemical stability
- Low environmental impact
- Wide temperature range
- Compatibility with materials
- High thermal conductivity
- Ease of handling and maintenance
- High specific heat capacity

Novel heat transfer fluids:

Advancements in materials, design, and engineering have led to the development of more efficient and optimized heat transfer systems, offering improved performance, energy savings, and enhanced control.

Nanofluids

Nanofluids (NFs) are those fluids that contain suspended nanoparticles (NPs), typically with sizes ranging from 1 to 100 nm. These NPs can be made from a variety of materials, including metals, metal oxides, and carbon-based materials. The properties of NFs depend on the type of NPs used like metal-based NPs exhibits excellent thermal conductivity whereas polymer- and carbon-based NPs shows good mechanical properties, and due to this property, they are often used in biomedical applications.

Potential and drawback of using nanofluids for heat dissipation

NFs have potential benefits of using in various processes, such as milk pasteurization, sterilization, and refrigeration. NFs can improve the thermal conductivity of the fluid, leading to more efficient heat transfer and lower energy consumption. They can also enhance the antimicrobial properties of the fluid i.e., Ag NPs. An increment of 1.6 and 9.4% was observed for heat transfer rate and convective heat transfer coefficient, respectively by incorporating 0.3% volume concentration of Al-Ag NPs in propylene glycol-water (20:80) hybrid NFs. The production and processing of NPs, as well as their dispersion in the base fluid, can contribute to the overall cost of NFs. The stability and settling issues of NFs pose challenges in their long-term use and can impact their reliability in heat transfer applications.

Phase change materials

Phase change materials (PCMs) are substances that exhibit the ability to store and release large amounts of thermal energy during phase transitions, such as melting or solidification, while maintaining a nearly constant temperature (Fig. 1). The examples of PCMs include Paraffin waxes, fatty acids, and salt hydrates. Paraffin waxes have high heat storage capacities and low costs, while fatty acids have a high thermal conductivity and can withstand high temperatures. Salt hydrates are commonly used as PCMs due to their high melting and freezing temperatures.

A more advanced form of novel heat transfer fluid is NPs incorporated PCM. These NPs, which are frequently formed of metals, oxides, or compounds derived from carbon, give the PCMs special features like higher heat conductivity and increased stability.

Benefits and disadvantages of employing phase change materials for energy transport

Using PCMs, which has the following advantages, one can harness latent heat for increased energy efficiency.

➢ Greater energy efficiency: Because PCMs can store and release significant amounts of energy, the quantity of energy required for heating may be reduced.

- Better temperature regulation: PCMs can maintain a constant temperature, lowering the possibility of temperature changes and resulting in high-quality products.
- Smaller equipment: By storing thermal energy in PCMs, the size of the equipment required for heating can be reduced.

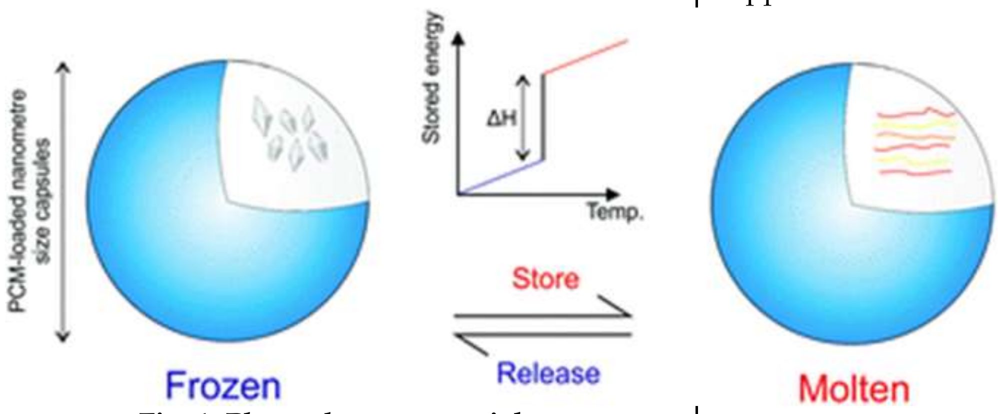

Fig. 1: Phase change materials

The inclusion of NPs in the PCM matrix improves the efficiency of heat transport and permits quick and effective energy storage and release during phase transitions. These fluids are ideally suited for a wide range of applications, including thermal energy storage, electronics cooling, and heat exchangers, thanks to the synergy between the NPs and PCMs, which results in improved thermal management capabilities.

An effective method for increasing overall system performance and optimising energy use in a variety of industries is the use of PCMs with NPs included (NePCMs). Researchers developed a stable and cost-effective NePCM (TiO_2 NPs in water) with 14.75% enhancement in thermal conductivity as compared with pure PCM. The wt.% fraction of 0.60% was optimized for safer storage of milk in cold chains. The main disadvantage of using these fluids is their higher production cost and higher pumping power required for recirculation.

Thermal oils

Thermal oils, also known as heat transfer oils, are specially formulated fluids designed to transfer heat efficiently in various industrial processes and systems. The primary function of thermal oils is to absorb heat from a heat source, such as a burner, electric heater, or heat exchanger, and transport it to a heat sink or heat-using process. They are often supplemented with additives to enhance their performance, such as antioxidants to inhibit oxidative degradation and anti-wear agents to protect equipment surfaces. Thermal oil-based NFs are advanced heat transfer fluids that combine a base thermal oil with NPs, such as metal oxides or carbon nanotubes. Thermal oil-based NFs also exhibit better stability at elevated temperatures, reducing the risk of thermal degradation and enhancing overall system performance.

Types of thermal oils

Thermal oils are specifically designed to withstand high temperatures and provide efficient and reliable heat transfer. Some commonly used thermal fluids include mineral oils, synthetic oils, silicone oils etc.

The various types of thermal oils with their properties are given in Table 1 and the choice of fluid depend on the specific applications and operating conditions.

Prospects and Limitations of Utilizing thermal oils for thermal migration

Thermal oils are often used in systems that operate at temperatures near 300°C. It has a high boiling point and low vapor pressure, making it a safer and more efficient to use. The use of thermal oils for heating applications in place of conventional

HTFs possess many benefits, major ones are (i) high thermal stability, and (ii) better heat transfer properties.

Table 1. Different properties of different types of thermal oils

Sr. No	Type of oils	Properties
1	Mineral oil	Most commonly used thermal fluids Cost-effective High thermal stability Non-toxic Temperature range: 20°C to 350°C Suitable for most heating applications in the food and dairy industry. Example: Shell heat transfer oil S2
2	Synthetic oils	Higher thermal stability Temperature range: -80°C to 400°C Preferred for high-temperature applications Example: Dowtherm A, Therminol 55
3	Silicone oils	Low-temperature heating applications Temperature range: -50°C to 200°C Chemically inert, and non-toxic High thermal stability Example: Silatherm® S

They can sustain their performance across a wide temperature range thanks to their high thermal stability. It qualifies them for use in high-temperature processes like pasteurization, frying, and baking. Due to their high boiling point and low vapour pressure, thermal oils provide excellent thermal stability, preventing fluid deterioration and lowering the possibility of heat exchanger fouling. Because of their high thermal conductivity and heat capacity, thermal oils can move heat fast and effectively. This makes them the perfect option for processes like sterilization, homogenization, and freeze-drying that call for quick heating or cooling.

The dairy industry benefits from employing thermal oil-based NFs due to their improved heat transfer properties, which enable more effective processing and lower energy consumption. Faster heating and cooling rates are made possible by NPs' high thermal conductivity, which boosts productivity and shortens processing times in the food industry. These NFs have more thermal stability than water, enabling applications requiring precise temperature control during milk processing. The dairy industry can employ NFs in applications demanding high temperatures since their use can increase heat exchanger efficiency and reduce fouling and maintenance needs.

The use of thermal oil-based NFs is not without significant drawbacks, though. One significant drawback is their higher cost compared to traditional fluids like water. Another potential concern is the increased complexity in NFs handling and maintenance, as NPs may settle over time and require periodic agitation or mixing. Due to their higher viscosity, thermal oil-based NFs may require modified or specialized equipment for efficient circulation and heat transfer. Proper disposal and waste management protocols need to be followed for NFs to minimize any potential environmental impact.

Comparison between traditional and novel heat transfer fluids

After analysing the pros and cons of using emerging novel heat transfer fluids, comparison can be made between traditional and novel heat transfer fluids as shown in Table 2.

Table 2. Comparison between traditional and novel heat transfer fluids

Differences	Traditional Heat Transfer Fluids	Novel Heat Transfer Fluids
Examples	Water, Glycols	Nanofluids, phase change materials, thermal oils
Thermal conductivity	Moderate to high	High
Viscosity	Moderate to high	Low
Specific heat capacity	Moderate to high	Moderate to high
Operating temperature range	Limited	Wide
Chemical stability	Good	Good
Toxicity	Low	Low
Flammability	Non-flammable	Non-flammable
Material compatibility	Compatible with common materials	Requires compatibility testing
Cost	Low to moderate	High
Environmental Impact	Less	High, requires evaluation
Ease of handling and maintenance	Easy	Require additional measures

Conclusion

The usage of emerging non-conventional (novel) heat transfer fluids in place of conventional heat transfer fluids presents promising opportunities and challenges for the dairy industry. These innovative fluids, such as thermal oil-based NFs or other advanced formulations, offer advantages such as enhanced heat transfer efficiency, improved temperature control, and reduced energy consumption.

In the dairy industry, the application of these novel fluids can lead to more efficient milk processing, faster heating and cooling rates, improved productivity, and enhanced heat exchanger performance. However, it is imperative to address the problems brought on by their increased cost, the potential for NP settling, and health and safety concerns. Continued work should also concentrate on determining their compatibility with food-grade materials, guaranteeing regulatory compliance, and analysing their environmental impact. By taking care of these issues, the dairy sector can improve its operations and contribute to the sustainable and effective production of food by taking advantage of the potential advantages provided by newly developed novel heat transfer fluids.

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