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A Review of Thermal Fluid System and Thermal Transport

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Abstract

A solar thermal system's efficiency, cost, and dependability are all significantly impacted by the heat transfer fluids used in the system. In this study, we use a novel figure of merit that takes into account the fluid's thermal storage capacity, its convective heat transfer properties, and its hydraulic performance to rank different types of heat transfer fluids including oils and molten salts. Safety, freezing point, and thermal stability considerations are also covered. Using a comparative study, we look at the advantages and disadvantages of several fluids for use in solar thermal heat transfer systems, such as water-steam combinations (direct steam), ionic liquids/melts, and suspensions of nanoparticles (nanofluids).

Keywords: Fluid transport, Thermal fluid system, Nano fluid.

Introduction

Depending on the specific application, heat transfer fluids may be used to collect and transmit heat from solar absorbers, store thermal energy in an intermediate form to buffer the diurnal nature of solar radiation, or exchange heat with the power cycle to generate electricity. Many performance and practical restrictions affect the selection of heat transfer fluid due to the wide variety of uses for which they are used. Concentrated solar power (CSP) systems necessitate heat transfer fluids with specific properties,

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including low freezing points (near room temperature) to prevent freeze-ups during the night, high operating temperatures (>400oC) to boost power cycle efficiency and low vapour pressures at high temperatures to cut down on labour costs. Fluids are preferred for heat transmission if they meet the following criteria: low viscosity, high volumetric heat capacity, and high thermal conductivity. They should not harm the ecosystem, not corrode, be risk-free to use, and not break the bank, among other desirable qualities. There is still a lot of work being done in the field of solar heat transfer fluid development since pure substances and regularly used fluids like synthetic oils and molten salts seldom match all of the practical and performance requirements. Common areas of study include composite fluids, including suspensions of submicron-sized solid particles in liquids, and mixtures, like multi-component salts (i.e., nanofluids). In recent years, considerable advancements have been made in the study of mixes and composite fluids, which may lead to major improvements in solar thermal applications.

Transport properties of fluids

Mass, energy, or momentum may be transferred from one part of a material to another as a result of temperature, composition, or velocity gradients, all of which are considered transport processes. Isolating a sample from its environment when chemical composition, temperature, or velocity varies leads to the transport mechanisms acting to finally make the sample uniform across these dimensions. These transport mechanisms are also known as non-equilibrium processes due to the need for a non-uniform condition to create them. After being cut off from its environment, a material will eventually reach equilibrium with itself, and the pace at which this happens is determined by its transport qualities and the magnitude of the initial gradient of the quantity being equilibrated, in this case temperature. The regulations that regulate transport procedures are quite straightforward for a vast category of items. Although many transport qualities exist in theory, only three are really significant from a scientific and technological perspective. Mass, momentum, and energy movement are all governed by these three quantities: diffusion coefficient, viscosity, and thermal conductivity.

Importance of Transport Properties

How rapidly, for instance, a fluid moving through a heated pipe may be heated is characterised by the speed of the transport processes outlined above, and hence the magnitude of the transport qualities. In Figure 1, we see how heat is delivered to a fluid travelling over a plate maintained at a constant temperature throughout its length by means of (energy) conduction in the direction of the steepest temperature gradient perpendicular to the wall.

It's obvious that, at a certain perpendicular distance from the plate, the fluid temperature rises the farther down the plate it flows. So, if we wanted to get the fluid up to a certain temperature, we'd have to specify the plate's length of time in degrees Celsius. Adjusting the fluid's parameters (here, its thermal conductivity) would result in a change to the necessary plate length.

This is an illustration of a heat exchanger, a typical component of industrial chemical plants and residential water heaters. Of course, in reality, this idea is refined quite a bit, but it still holds true that the size of the heat exchanger needed to attain a certain condition for the fluid is determined by the latter's transport qualities. This is why, from a home water heater to a methanol synthesis reactor in a chemical plant, the transport qualities of liquids and gases, among other quantities, are essential for the effective and efficient design of any piece of machinery.

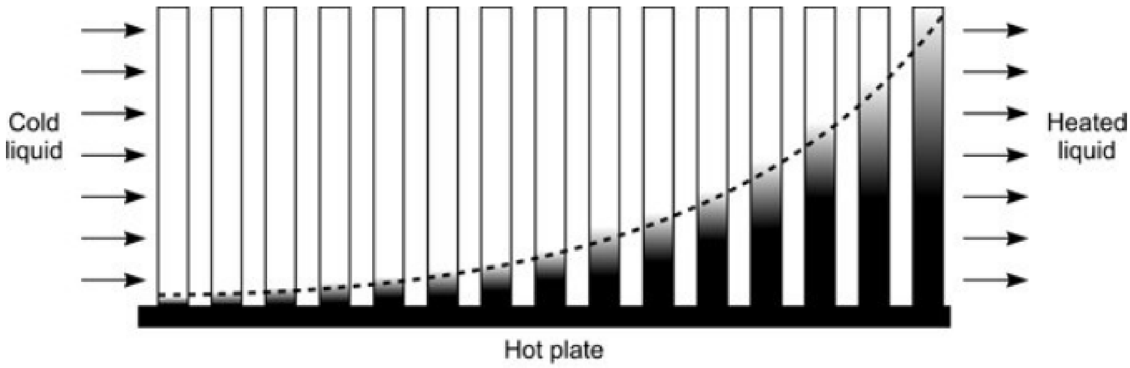

Figure 1. Cold liquid heated by passage over a hot plate

Motivation of Improving Thermal Conductivity of Fluids

There has been undeniable growth in the electronics, communication, and auto-computing sectors in recent years, and this trend will continue into the 21st century. Today's rapidly evolving technologies have introduced a new challenge: the need to effectively cool mechanical, electrical, and electronic components. Heat dissipation demands are rising as microelectronic devices get quicker and smaller, as engines provide more power, and as optical equipment produce brighter beams. However, although radiation, conduction, and convection may all be utilised for cooling, the use of fluids to harness the high heat flow associated with boiling and convection is among the most popular and efficient strategies. Heat transfer fluids are used in a wide variety of commercial and non-commercial settings, including as automobiles, aeroplanes, power plants, air conditioners, computer and electronic components, and more. However, the design of cooling systems is constrained by the heat transfer fluids' poor thermal conductivity. As equipment power increases while size decreases, thermal management has risen to the forefront of technological issues and component design priorities. Improving the heat transfer capabilities of the fluids and building innovative cooling devices (such as expanding the surface through fins, microchannels, integrated spot cooling, and miniaturised cryodevices) are two strategies to satisfy the cooling needs. However, there is a limit to how much improvement in heat transmission can be achieved by the use of more traditional means, such as improving the design of cooling systems. There is an immediate need for novel heat transfer fluids with improved thermal conductivity and cooling capacity due to the rising efficiency standards for machines and other equipment. Traditional heat transfer fluids are being studied and developed to enhance their heat-transporting characteristics.

Thermally conductive liquid metals have been the subject of intense study because of their unique heat transfer properties. Certain subfields of engineering that deal with very high heat fluxes make use of liquid metals as heat transfer fluids. Nuclear engineering, for instance, frequently necessitates rapid heat removal from reactors. In order to get the largest possible thermodynamic advantage, liquid metal is also employed in gas turbines, where the requirement for efficient blade-cooling systems is as significant as it has ever been. A hallmark of liquid metals is their exceptional heat conductivity, setting them apart from more common HTFs like water, oils, and glycols.

Heat Transfer Coefficient

By developing semi-empirical correlations for various flow regimes, the total heat transfer performance may be calculated based on the predicted flow patterns. Correlations for convective heat transfer have been created by researchers for saturated flow boiling within horizontal tubes at high Reynolds numbers.

Single-phase convective heat transfer is used to heat feed-water or superheated vapour as it flows into or out of the tube. The Dittus-Boelter correlation may be used to calculate the heat transfer coefficient in this preheating or superheated region. The flow pattern may be identified after the phase transition has taken place. Since flow must quicken in response to a drop in fluid density during vaporisation, the rise in the heat transfer coefficient in the stratified flow zone is mostly attributable to the augmentation of convective heat transfer. Shah outlined the process by which the convective heat transfer coefficient in single-phase flow is multiplied by an enhancement factor to arrive at the stratified flow heat transfer coefficient:

$$h_{2ph} = E_{Shah} h_{1ph} = 3.9 Fr_{le}^{\;0.24} \left(\frac{x}{1-x} \right)^{0.64} \left(\frac{\rho_l}{\rho_g} \right)^{0.4} h_{1ph}$$

where h_{1ph} is determined using the Dittus-Boelter relationship and the revised Reynolds number

$$\mathrm{Re}_l = \frac{G(1-x)D_h}{\mu_l}.$$

Nanofluid

When applied to many fields of science and engineering, nanotechnology has the ability to bring about revolutionary breakthroughs that are now beyond the reach of existing technologies. Many subfields of chemistry, electrochemistry, and biomedicine are included under the umbrella term "nanotechnology."

Among the various technical uses for nanotechnology, heat transfer and electrocatalysis are only two examples of how useful nanofluids may be.

Dilutions of functionalized nanoparticles with a diameter of less than 100 nm are known as nanofluids. When these nanoparticles are diluted into the process fluid, they dramatically alter the fluid's thermal and viscosity characteristics. Research conducted in the past has shown that the incorporation of micro particles into various processes significantly improves heat transmission.

In this research, we investigate the combined effects of temperature and viscosity on nanofluids. The effective viscosity and effective thermal conductivity of nanofluids, among other transport parameters, are the primary research interests. Past academics' transport models were compared across a wide range of theoretical and practical experiments.

Advantages of nanofluid

An increase in heat transfer is observed for a relatively low nanoparticle volume fraction. The benefits of nanofluid and the reasons for this improved heat transfer are still being studied by scientists. According to the findings of numerous studies,

- The nanoparticles boost the fluid's effective thermal conductivity. The volume fraction of nanoparticles affects their effective thermal conductivity. As the nanoparticle volume fraction grows, so does this effect.
- With a larger surface area, nanoparticles are able to interact with the surrounding fluid more strongly.
- By generating Brownian movements, the distributed nanoparticles enhance the interaction and collision rates between the fluid and the particles.
- The nanoparticles dispersed throughout the system heighten the turbulence and the mixing fluctuation.
- When compared to pumping power required for a base fluid to achieve the same level of heat transfer, the latter is preferable.
- Using nanofluid, solar energy absorption may be improved.
- Compared to other colloid suspensions, it has more stability.

Techniques of enhancing nanofluid stability

A digital density metre or similar laboratory density and concentration measurement equipment may provide three-digit precision for measuring the density of nanofluid over time. Specimens of nanofluid are kept in a temperature-controlled bath of circulating fluid and their densities are measured under a variety of operating conditions. However, before measuring the target nanofluid, one must first calibrate and perform a benchmark test.

The density of various nanofluids was measured by certain researchers using an Anton-Paar digital density metre. A variety of techniques have been developed to improve the stability of nano- fluids. Some of the most noteworthy techniques include sonication and the addition of a dispersant. The least expensive solution is the addition of a dispersant.

Literature Review

(Javvadi et al., 2020) Despite extensive theoretical and experimental research, scientists still don't fully understand its complex operational mechanism, which involves a coupling effect between hydrodynamics and thermodynamics. The report provides a high-level overview of the thermo-hydro dynamic features of this apparatus. This article will provide a quick overview of tube cross-section, working fluid volume, and internal diameter.

(Vivar & Everett, 2014) Different fluid characteristics are needed for various functions, including heat transport, optical adaptation, spectrum filtering, and so on. In this survey, we take a look at the liquids needed by solar concentrators that use active cooling.

(Hodel, 2004) We use a novel figure of merit to compare the thermal storage capacity, convective heat transfer properties, and hydraulic performance of different heat transfer fluids such as oils and molten salts. Safety, freezing point, and thermal stability considerations are also covered.

(Ali & Salam, 2020) Different effects, including particle size, shape, surfactant, temperature, etc., on thermal conductivity were given, as were the thermophysical and heat transmission properties of nanofluid. Possible uses of nanofluids are highlighted in the current research, including those in heat exchangers, transportation cooling, electronic equipment cooling, refrigeration, transformer oil, industrial cooling, the nuclear system, machining operations, solar energy and desalination, military, and more. Only a few of the difficulties and obstacles were dealt with.

(Han, 2008) The inefficient transport of heat is mostly due to the poor thermal conductivity of heat transfer fluids. Research has been conducted to try to enhance the thermal transport qualities of the fluids by introducing more thermally conductive particles into liquids, since the efficiency of expanding surfaces and revamping heat exchange devices to raise the heat transfer rate has reached a limit.

(Umer et al., 2012) When nanoparticles are present, the effective transport qualities of the fluid as a bulk material might change dramatically. Understanding how the inclusion of nanoparticles alters fluid dynamics requires both experimental and theoretical research. In this study, we provide a concise overview of the impacts of nanofluids on both viscous and thermal transport.

(McKay & Franklin, 2011) Unfortunately, thermal fluid system incidents are more prevalent than we may think and can have devastating consequences. Recent occurrences have re-emphasized the need of taking precautions against fire and explosion while working with thermal fluid systems. About 4,000 businesses in the UK use thermal fluid systems, therefore these accidents affect them directly.

(Schmidt et al., 2003) This class is the last of a trilogy covering the principles of thermodynamics, fluid mechanics and heat transport. Its goal is to help students gain a more thorough understanding of the concepts introduced in the introductory courses, broaden their understanding of certain topics, and better connect the fundamentals to real-world engineering applications.

(Mylona et al., 2014) We stress the magnitude of the challenge posed by meeting that demand over a broad temperature and pressure range for a growing number of pure components and their combinations as industrial products have gotten more complex.

Conclusion

The impact of nanoparticles on fluid transport characteristics is briefly discussed in this work. Previous investigations are reviewed, and the available experimental and theoretical correlations/models for nanofluid transport characteristics are examined. It has been proven analytically and experimentally that different types of nanoparticles, sizes of nanoparticles, volumes of nanoparticles, and fluid types all have different effects on transport characteristics.

One of the key physical parameters used in engineering equations is density. Previous research has shown that increasing the nanoparticle volume fraction in a nanofluid results in a higher effective density. Studies have shown that the effective viscosity of nanofluids grows with particle dimension and particle concentration but shrinks with temperature. In terms of effective thermal conductivity, nanofluids exhibit an increase when particle concentration and temperature are raised. Previous research has shown that when temperature increases, the effective specific heat capacity of nanofluids decreases as more and more particles are diluted out of solution.

The settling of nanoparticles in the fluid, as documented by several studies, has a negative impact on process efficiency. Therefore, in certain applications, the addition of suspension ingredients at low concentrations or enough agitation is essential. Nanofluids' use is mostly determined by their stability and the relative ease with which they may be manufactured. There is a lack of understanding of the many fluids (two or more) that must be combined with nanoparticles for a variety of industrial applications. We know very little about nanoparticles in binary or tertiary combinations.

Industrial cooling applications, such as in the electric power sector, are already making use of nanofluids, which effectively save energy and lower emissions. Nanofluids play a crucial function in the tyre industry by rapidly cooling the rubber after processing. Besides these examples, nanofluids have found employment in nuclear reactors, the extraction of geothermal electricity, and in many automobile applications. If we can find a way to slow the rate at which nanoparticles settle out of fluids, we can reduce the amount of energy needed to transfer heat between them.

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