ANALYTICAL MODELING AND SIMULATION OF HEAT TRANSFER IN COMPACT HEAT EXCHANGERS WITH NANOFLUIDS

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ABSTRACT

Colloidal suspensions of antiparticles in a base fluid such as water, oil, or ethylene glycol are what we call nanoseconds. These intelligent fluids have the potential to significantly improve upon the functionality of standard HT media. By analyzing the synthesis of nanoseconds, the assessment ir thermostatically characteristics, and the heat transmission and pressure of nanoseconds in a tube under CHF condition, this study hopes to shed light on the topic of nanoseconds. In the laminar regime, we have explored three distinct nanoseconds: aluminium oxide/water, copper oxide/water, and a mixture two. Computers, car engines, and high-powered lasers are just some many goods that benefit from cooling systems. Single-phase liquid cooling techniques, such as micro-channel heat sinks, and two-phase liquid cooling techniques, such as heat pipes, thermosphere, direct immersion cooling, and spray cooling, have recently developed for chip or package level cooling. However, continuing miniaturization has increased heat loss and inherent poor thermal conductivity, which has impeded the development of energy-efficient HT fluids necessary for ultrahigh-performance cooling in subsequent product generations. As a result, the cooling challenge will intensify across a wide range of industries, from electronics and phonics to transportation, power generation, security, and healthcare.

Keywords: *nanostructured materials, high-powered laser, energy-efficient HT fluid, micro-channel heat sinks, HT media, aluminium oxide/water, copper oxide/water, CHF condition.*

INTRODUCTION

In a highly diluted liquid known as a nano fluid, individual nanoparticles float. These nanoparticles shouldn't have any dimensions bigger than 100 nm. This cutting-edge material has been focus of much study over the past ten years due to its distinct characteristics and behaviour in terms of heat and mass transport. HT is crucial for many industries, including heating, ventilation, and air conditioning (HVAC), transportation, power production, micro manufacturing, thermal therapy for cancer treatment, chemical and metallurgical industries, and so on. The thermal behaviour of micro fluids may open door for a revolutionary advancement in area of HT. Nano fluids are advantageous in production of nanostructured materials, engineering of complex fluids, and the cleaning of greasy surfaces due to their excellent wetting and spreading behaviour. The twenty-first century is a time of rapid technological advancement, and practically every sector economy has already seen a great deal of disruption as a result. The Nobel Prize–winning physicist Richard Feynman coined in 1959. This renowned statement served as the inspiration for development of nanoscience and technology. This idea was developed by Feynman, and it involves employing a set of robot arms of a standard size to build clone m selves that is their original size. After that, the new set of arms is used to manufacture an even smaller set, and so on, until the molecular scale is achieved. Thermal Energy Storage systems can be categorized as Sensible Heat Storage (SHS), Latent Heat Storage (LHS) and Thermo–Chemical Storage systems. Sensible Heat System (SHS) is the most common method used for storing purpose of thermal energy. However, LHS system is considered the most preferred technique for storing thermal energy. Latent heat storage system energy is engrossed or released in order to change the phase of external fluid with the presence of Phase Change Material (PCM).

LITERATURE REVIEW

Afshin Ahmadi Nadooshan (2023) Various types of heat exchangers have many applications in industrial and engineering fields to improve heat transfer rate (HTR). The techniques of heat transfer enhancement which are active, passive, and hybrid are discussed in the present review paper. One of passive methods to enhance HTR is the use of nanofluids. This article provides the governing equations of nanofluid flows and discusses their modeling methods, including single-phase and two-phase. Advanced investigations considered single-phase and two-phase flow regimes are summarized. Comparing single-phase models (SPMs) and two-phase models (TPMs), most researchers concluded that numerical modeling based on TPMs experiences a better prediction compared to the SPMs. However, there are conflicting results among the researchers and it is not confirmed which model is better. This review paper aims to analyze the examinations on SPMs and TPMs in heat exchangers to assess the impact of these studies.

Michael E. Cholette (2021) This study considers the inspection and maintenance of boiler heat exchangers, which are examples of a system composed of degrading, non-repairable components in series whose operation can be restored by removing failed components from service (albeit at a performance loss). For such systems, the increased failure risk due to component degradation may be managed through inspections and preventive removal of high failure risk components from service (again at a performance loss for remaining life of systems). In this study, a new joint inspection and preventive maintenance policy is developed, which uses condition information obtained at an inspection to optimize decisions regarding maintenance and future inspections to optimally balance the risks of system failure, future performance losses, and maintenance costs. The policy is optimized using the Markov Decision Process paradigm and is applied to a case study of a boiler heat exchanger operating in an Australian sugar factory.

Tushar Gupta (2021) Heat exchangers are the very useful component used in various domestic and industrial applications such as water heating, power plants, air conditioning, vehicle industry, food industry, pharmaceutical industry and petrochemical industry etc. The economic considerations associated with heat exchanger are the major challenge for its technological development. The performance improvement of the heat exchanger is also one of the major challenges. The energy utilization efficiency is increased and heat transfer time is reduced by enhancing the heat transfer of the heat exchanger. Utilization of nanofluid is one of the best options to enhance the heat transfer rate due to high thermal conductivity and also overcome the economic consideration associated with heat exchangers. This paper provides an overview of the utilization of nanofluid in a plate heat exchanger.

Sanjeev Kumar Gupta (2020) An intensive numerical study is performed inside the shell and tube type heat exchanger to find out the melting performance of a Phase Change Material (PCM). An axis symmetric virtual model of the thermal storage unit is created and various types of numerical schemes are implemented over it, to validate the suggested experimental results. Grid independence test of a shell-and-tube geometry, made by a horizontal cylindrical tank which is fully packed with a PCM and an inner spiral tube, is completed. Initial & boundary conditions were applied on the modeled geometry of the cylinder in which the Heat Transfer Fluid (HTF) flows from the inlet to outlet. The computational analysis of the optimized size of meshed geometry is performed to know the outcome of increasing HTF temperature during the charging process of the PCM. This reduction in charging time of PCM melting with increment HTF temperature leads towards the improvement in the efficiency of Thermal Energy Storage System (TESS).

Safiei, Wahaizad (2020) One of the essential rheological characteristics for engineering fluids that is essential for improving heat transmission is thermal conductivity. Because the addition of nanoparticles in the base fluid can further improve thermal conductivity and dynamic viscosity, nanofluid is currently receiving more attention. These are two crucial characteristics for new engineering fluids that help them perform better in mechanical and tribology applications by improving cooling and lubricating effects. Additionally, these two qualities improve as nanoparticle volume concentrations rise. Additionally, as the temperature rose, the thermal conductivity likewise rose. From the writing survey, the most extreme improvement of warm conductivity for single nanofluid is recorded 36% of MWCNTs in refined water. On the other hand, Al2O3 in water-ethylene glycol surpasses base fluid by 39 percent in viscosity.

HT Applications

Because incredible potential of NF to improve HT, researchers have been inspired in recent decades to develop concepts and techniques backed by manufacturers of ultra-compact, miniaturized, and intrinsic electronic circuits. As the need for more powerful, more versatile, and smaller circuit boards has grown, the number of transistors on electronic chips has nearly doubled, producing a localized heat flux of more than 10 MW/m2 and a total power of more than 300 W. Additionally, the boards are now smaller in size. These advances in technology may one day be able to provide for this critical requirement. Currently, "there is no existing low cost cooling mechanism that can effectively manage this amount of heat".

Analysis of HE

The outlet temperature fluid is used in thermal analysis HE. Once this temperature has been obtained, it is connected to the independent parameters as follows: Th, o, Tc, o, or q = f. For a particular flow arrangement, the six variables that are independent and the one variable that is a dependent are moved into two groups that are independent and one group that is a dependent variable. All se groups are dimensionless. Definitions and terms pertaining to equations for are able to following: -Ch dTh = Cc dTc. Whereas the sign of dTc relies on whether or not it is growing with increasing dA or dx.

HT Enhancement Using NF in HEs

The commencement of activities requiring a high heat flow has resulted in a large increase in the need for novel technologies that improve heat transmission. In the case of automotive systems, for instance, increased HT may result in fewer HEs for cooling, which would then contribute to a reduction in the overall weight vehicle. Nanotechnology is a technology that is rapidly advancing, and its applications are now being explored in the majority of technical and medical domains. The potential of NF technology has recently come to the attention of businesses, which have therefore intensified their concentration on certain industrial applications. For instance, the transportation sector, nanocars, General Motors and Ford, and a number of other companies are concentrating their research efforts on NF.

Plate Heat Exchanger

A plate heat exchanger contains an amount of thin shaped heat transfer plates bundled together. The gasket arrangement of each pair of plates provides two separate channel system. Each pair of plates forms a channel where the fluid can flow through. The pairs are attached by welding and bolting methods. Thus, this allows the main and secondary media in counter-current flow. A gasket plate heat exchanger has a heat region from corrugated plates. Fluid flows in a counter current direction throughout the heat exchanger. An efficient thermal performance is produced. Plates are produced in different depths, sizes and corrugated shapes. The distribution area guarantees the flow of fluid to the whole heat transfer surface. This helps to prevent stagnant area that can cause accumulation of unwanted material on solid surfaces. High flow turbulence between plates results in a greater transfer of heat and a decrease in pressure.

Enhancement of HT coefficient

Aside from the thermal conductivity, the researchers were most interested in the convective HT performance NF under flow circumstances. This was done better understand how the NF behave. The vast majority research studies that were conducted concluded that the use of NF resulted in a significant improvement of this feature. The improvement HT coefficient is a better indication for determining whether or not NF may be employed in HEs. Tests were carried out using Al2O3 and CuO nanoparticles in water, with the flow conditions ranging from laminar to turbulent. He discovered that the thermal conductivity gain brought about by Al2O3 particles was less than 15%, despite the fact that these particles increased heat transmission by as much as 40%. Thierry investigated the NF with alumina (Al2O3) and carbon nanotubes (CNTs) dispersed in water under a laminar out-flow mode at low temperature.

White Powdered Zinc Oxide

The impact of zinc oxide nano particle on working fluid performance in exchange was investigated by I.M. Shahrul. This technique of photography is justified by the use of polyvinylpyrrolidone (PVP), a surfactant used to stabilize zinc. The entire heat coefficient has increased by nearly 35%, the results revealed. Maximum performance is achieved with a tube flow rate of 6 lpm and a shell flow rate of 8 lpm, demonstrating the influence of flow rate. We may attribute this to the fact that the low viscosity and strong heat conductivity that foster browning action also contribute to the high performance levels observed.

RESEARCH METHODOLOGY

Heat conduction pertains to the complex phenomenon of energy transmission within a specified medium due to a noticeable discrepancy in temperature. The convoluted intricacy this phenomenon is intricately orchestrated capricious and unpredictable behaviour of individual atoms or molecules, meticulously governed by the firmly established principles encapsulated within the renowned Fourier's law. However, when subjected to demonstrate a reduced magnitude for plastic when compared to metal. The property commonly referred to as thermal conductivity, which holds great importance within field of materials, is entirely dependent on particular nature of material under consideration serves as a visual representation significant discrepancy in thermal conductivities, showcasing how thermal conductivity of a solid can surpass that of a gas by more than four orders of magnitude. The perceived phenomenon can be ascribed convoluted interplay amidst convoluted configuration of intermolecular distances and unpredictable character of molecular motion. Within domain of solid materials, intricate interplay between intricate choreography of liberated electrons and transmission of lattice vibration waves is intimately intertwined with the facilitation thermal energy transfer. The vast majority of prevailing models pertaining to thermal conductivity are derived from highly complex and convoluted principles governing Brownian motion, which are intricately interwoven with the fundamental tenets of kinetic theory. The intricate notion of Brownian motion encapsulates intricate behavioural patterns exhibited by gases that manifest unbounded translational mobility and possess a comparably scanty spatial disposition.

RESULTS

The primary objective of this investigation is to conduct an in-depth analysis convective heat transfer in a nanofluid. The study specifically examines flow nanofluid within a straight tube that possesses a circular cross-section. Furthermore, at the current juncture, a notable dearth of any well-established theoretical framework exists that can feasibly prognosticate convoluted intricacies and thermodynamic transference phenomena demonstrated by a nanofluid when it is contemplated within context of a multi-component paradigm.

Table 1: Change in viscosity of ZnO - EG nanofluid for different volume fraction and temperature

Temperature in °C	Viscosity in mNs/m2 at volume fraction			
	1%	2%	3%	4%
10	18.300	19.300	21.300	24.500
20	17.400	18.400	20.200	22.400
30	16.600	17.500	18.400	20.400
40	14.300	15.500	16.100	18.300
50	12.800	14.500	15.800	17.300

Table 2: Change in viscosity of TiO2 - EG nanofluid for different volume fraction and temperature

Temperature in °C	Viscosity in mNs/m2 at volume fraction of			
	1%	2%	3%	4%
10	20.400	22.400	23.700	25.700
20	18.400	20.400	21.500	23.800
30	17.500	19.100	20.400	21.500
40	15.600	17.300	18.300	19.700
50	13.500	15.300	16.600	18.100

From the studies conducted on the viscosity of nanofluids, it was observed that increase in temperature decreases the viscosity of the nanofluids whereas an increase in the volume fraction of the nanoparticles dispersed in the base fluid increases the viscosity of the nanofluid.

Table 3: Change in specific heat of ZnO/EG, TiO2/EG, ZnO/Water and TiO2/Water nanofluid for different volume fraction and temperature

Volume fraction	Specific heat in kJ/kg K			
	ZnO-EG	TiO_2-EG	ZnO-Water	TiO_2-Water
1	2.197	2.199	4.183	4.186
2	2.194	2.196	4.181	4.184
3	2.190	2.193	4.178	4.181
4	2.186	2.189	4.174	4.178

Suspension of these nanoparticles with good thermal properties in base fluids decreases the amount of heat required to raise the temperature which is nothing but the specific heat of nanofluid.

Compact HE Geometry

The figure displays the fundamental constituents of a compact HE, depicted as coolant tubes and fins, as illustrated within this particular diagram. Flat tubes are highly preferred over circular tubes in automotive applications due to their ability to minimise profile drag, resulting in improved aerodynamic performance.

Table 4: The 11.32-0.737-SR compact HE surface geometry properties

SL.NO	Description	Airside	Partially cooled
1.	Finpitch	4.45 fin/cm	
2.	FinMetalThickness	0.01cm	
3	Hydraulicdiameter,Dh	0.351cm	0.373cm
4.	Minfreeflow area/Frontal area,σ	0.780	0.129
5.	Total HT area / Totalvolume ,α	886 m2/m3	138 m2/m3
6.	Finarea/Totalarea,β	0.845	

The increase in the volume fraction of nanoparticles in the base fluid increases the density of the nanofluids. The reason behind this is that when the particles with high density are suspended in the liquid having low density, the density of that particular liquid gets increases because of those high-density particles. Here, the high-density metal oxide particles are suspended in the low-density water and ethylene glycol and so the density of water and ethylene glycol get increases.

CONCLUSION

Emphasis is placed on the complex dynamics of high-temperature (HT) systems and the complex flow patterns of a new class of thermal fluids called "NF." An comprehensive investigation is proposed, using both empirical and computational approaches. It is the type of the base fluid, the nanoparticle sizes, and the thermophysical parameters that determine how NF is classified. The review includes a thorough analysis of HT improvement results and a careful evaluation of the usefulness of experimental and computational NF within the context of HEs. When NF performance is compared to that of conventional fluids, these improvements become apparent. Increasing the nanoparticle volume fraction and the Reynolds number are responsible for the observed phenomena of enhanced heat transmission and pressure decrease. It is acceptable to conduct a comparative analysis of previous studies on high-temperature (HT) systems and the flow properties of NF due to the wide variety of operational conditions involving flow rates, temperatures, and complex heat exchanger designs. Numerous studies have looked at the complex interaction between NF's thermal conductivity and heat transfer coefficient.

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