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Numerical study of convective heat transfer of nanofluids: A review

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ABSTRACT

The recent development of nanotechnology led to the concept of using suspended nanoparticles in heat transfer fluids to improve the heat transfer coefficient of the base fluids. Specifically, numerical studies are reviewed in this study to get a clear view and detailed summary of the influence of several parameters such as type of nanoparticle and host liquid, particle volume concentration, particle size, particle shape, Brownian diffusion and thermophoresis effect on hydrodynamic and thermal characteristics of convective heat transfer using nanofluids. In addition, the paper provides detailed information about the most of commonly-used correlations which are utilized to predict the effective thermophysical properties of nanofluids. Finally, the main aim upon which the present work is based is to give a comprehensive review on different CFD approaches employed in numerical simulation of nanofluid flow, address the pros and cons of each approach, and find the suitable technique which gives more credible results as compared to experimental results.

Contents

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1. Introduction

Over the last few years, energy consumption has increased drastically; therefore, scientists have developed new energy-saving strategies to overcome the threat of energy shortage [1]. Heat exchangers are widely used in industrial systems in the field of energy conservation, conversion and recovery. Thus, it is obvious that providing more efficient heat exchanging systems can mitigate the energy concerns considerably.

1.1. The rise of compact thermal devices

Better heat removal can be achieved by decreasing the area to volume ratio of thermal devices which is one of the most important factors in thermal design [2]. This idea motivated Tuckerman and Pease [3] to propose microchannel heat sink (MCHS) about two decades ago. After that, many researches [4–6] proved the effectiveness of using micro-channel heat exchangers for thermal enhancement purposes. Lately, due to the advancement of micro fabrication technology, microchannels and microtubes are manufactured and utilized in industries such as microelectronics, aerospace, biomedical, robotics, telecommunications and automotive [7].

The main reasons for development of miniaturized and light weight heat exchangers are given as follows [8,9]:

- Space and size limitations.
- Energy and material savings.
- Ease of unit handling.
- Growing need for heat transfer augmentation with increasing energy demands.
- Cooling requirement of microscale and microelectronic devices.

Several studies [10–14] have proposed various methods to improve the thermal–hydraulic performance and reduce unit sizes of conventional heat exchangers. However, in order to have more efficient and cost-effective heat exchangers, several approaches have been investigated over the years. Passive technique, employing ribs or grooves on the inner surface of heat exchangers, has been one of the frequent approaches to break the laminar sub-layer and create local wall turbulence due to flow separation and reattachment between successive corrugations, which reduces the thermal resistance and significantly enhances heat transfer. Although many studies available in the open literature have proven the significant effect of geometry modification on heat transfer enhancement in recent years, this technique has already reached its limit. Presently available heat transfer working fluid such as water, engine oil (EO), ethylene glycol (EG), propylene glycol (PG) are widely used in many industrial fields like heating or cooling processes, chemical production, microelectronics, power generation, air-conditioning, and transportation. These conventional heat transfer fluids have inherently low thermophysical properties as compared with solids. Hence, there is a pronounced need to develop alternative heat transfer fluids with higher cooling capability which can improve the compactness and effectiveness of heat exchangers.

1.2. Nanofluids

As discussed in the previous section the issue of heat removal from small scale devices which can generate a high amount of heat flux has attracted substantial attention from researchers. To ensure that the heat exchangers deliver their best performance, working fluids with greater thermal conductivity are required. Since solid particles have larger thermal conductivity than conventional fluids [15], dispersing these particles into the base fluid is anticipated to increase the thermal conductivity of the whole mixture. Therefore, in order to overcome the limited heat transfer capabilities of common fluids, Maxwell first proposed a theoretical work which showed the possibility of enhancing the thermal conductivity of liquids by mixing micron-sized solid particles [16]. Later, Ahuja [17] experimentally analyzed the suspension containing aqueous sodium chloride and glycerin (as the base fluid) and micrometer-sized polystyrene particles. He observed thermal conductivity enhancement three times greater compared to the base fluid. However, problems such as rapid sedimentation caused by these particles have kept this concept far from practical use. Recent advances in nanotechnology resulted in appearance of a new generation of fluid called nanofluid (colloidal mixture of nanoparticles smaller than 100 nm), a term proposed by Choi and Eastman [18]. Nanofluids have unique thermal transport properties and superior performance that are unavailable in traditional heat transfer fluids. Compared to conventional solid–liquid suspensions for enhancing heat transfer, nanofluids show a higher potential for increasing the heat transfer rates in heat exchangers for the following reasons [19]:

- High heat transfer surface between particles and fluids and therefore high effective thermal conductivity.
- High dispersion stability with predominant Brownian motion of particles.
- Reduced pumping power as compared to pure liquid to achieve equivalent heat transfer intensification.
- Less particle clogging as compared to convention slurries, thus suitable for use in microsystems.
- Adjustable properties, including thermal conductivity and surface wettability, by varying particle concentrations to suit different applications.

Saidur et al. [20] conducted a comprehensive review of the applications of nanofluids and suggested specific areas in which nanofluids can be used as follows:

Heat exchanger [21], cooling of electronics [22,23], solar water heating [24], nuclear reactor cooling [25–27], refrigeration (domestic refrigerator [28,29], chillers [30,31]), engine cooling/vehicle thermal management [32–34], cooling and heating in buildings [35], cooling of diesel electric generator [36], diesel combustion [37,38], detection of knock occurrence in a gas SI engine [39], biomedical applications [40–43], fuel cell [44–46], new sensors for improving exploration, boiler flue gas temperature reduction, nanofluids in cameras, micro devices, and displays, application as a coolant in machining [47], cooling welding equipment, drilling speed [48,49], transformer cooling [50–55], space, defense and ships.

1.3. Objectives of the review and the focus of the paper

In recent years, a noticeable number of review papers have been provided on the convection heat transfer and fluid flow characteristics of nanofluid. These papers cover the following areas: natural convection [56], forced convection [57], entropy