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Recent Trends in Enhanced Heat Transfer Research and Development using Nanofluids

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Abstract: Advances in technology miniaturization with increasing power density call for new technologies for enhancing heat transfer. Enhancement of heat transfer with use of nanofluids has been a hectic topic of research and development since the term "nanofluid" appeared in 1995, mainly because most reported thermal properties of nanofluids are superior to their base fluids that may not allow the fulfilment of the present cutting-edge technology needs. Significant progress in this field has been achieved in the past two decades. This plenary talk provides a comprehensive review on the recent trends in the study of nanofluids for heat transfer enhancement. Applications to cooling technology, renewable energy and energy systems, and building technology are detailed. Challenges and areas for future research are identified.

Extended Abstract

Heat transfer enhancement is referred to the improvement of thermal performance of any heat exchanging medium, component, device, or equipment. It could mean that the heat transfer rate of a given surface is increased, the peak temperature of a hot spot is reduced, the critical heat flux for boiling heat transfer is soared, the thermal conductivity, specific heat capacity or latent heat of an energy storage medium is raised, etc. A variety of techniques or methodologies can be applied to such effects.

In the literature, the methodologies for augmenting heat transfer were generally classified into three categories [1]: passive techniques, active techniques, and compound techniques. The passive ones do not require external power through techniques such as extended surfaces, rough surfaces, treated surfaces, coiled tubes, swirl-flow devices, fluid or particle additives; while the active techniques require external power to bring about the effect, including mechanical aids, surface vibration, fluid vibration, electric or magnetic field, jet impingement, etc. Compound enhancement combines two or more of the above techniques to produce an effect that is larger than any of the enhancement techniques operating separately [2]. Bergles [3] considered the compound techniques as the fourth-generation heat transfer technology or third-generation enhancement. The current state-of-the-art enhancement techniques through nanoscale technology, e.g., surface phonon polaritons [4], near-field enhancement [5], molecular or atomic level engineering [6, 7], as well as heat transfer manipulations via metamaterials [8] may be considered as the fourth-generation enhancement or fifth-generation heat transfer technology. Nevertheless, the three distinguishable categories persist.

As devices in modern technology continue to require increased power capabilities with reduced spatial profiles, it is critical to explore a multitude of methods for enhancing heat transfer. For example, rapid cooling of such devices is a crucial issue in high-tech industries such as microelectronics. Conventional approaches by using fins and microchannels have already stretched to their limits. Therefore, there is an urgent need for new methods and innovative concepts to achieve ultra-high heat flux removal or supply. Heat transfer enhancement is now a major area of research and development in thermal management, electronics packaging, energy and power industry, building technology, high-end military equipment, and aerospace technologies, etc. It was estimated that at least 10% of the archival heat transfer literature was directed towards enhancement [2]. As the heat transfer research in the micro- and nano-scales also contributes to this effect and has been increasing in the past decade, the research in enhancement expands substantially.

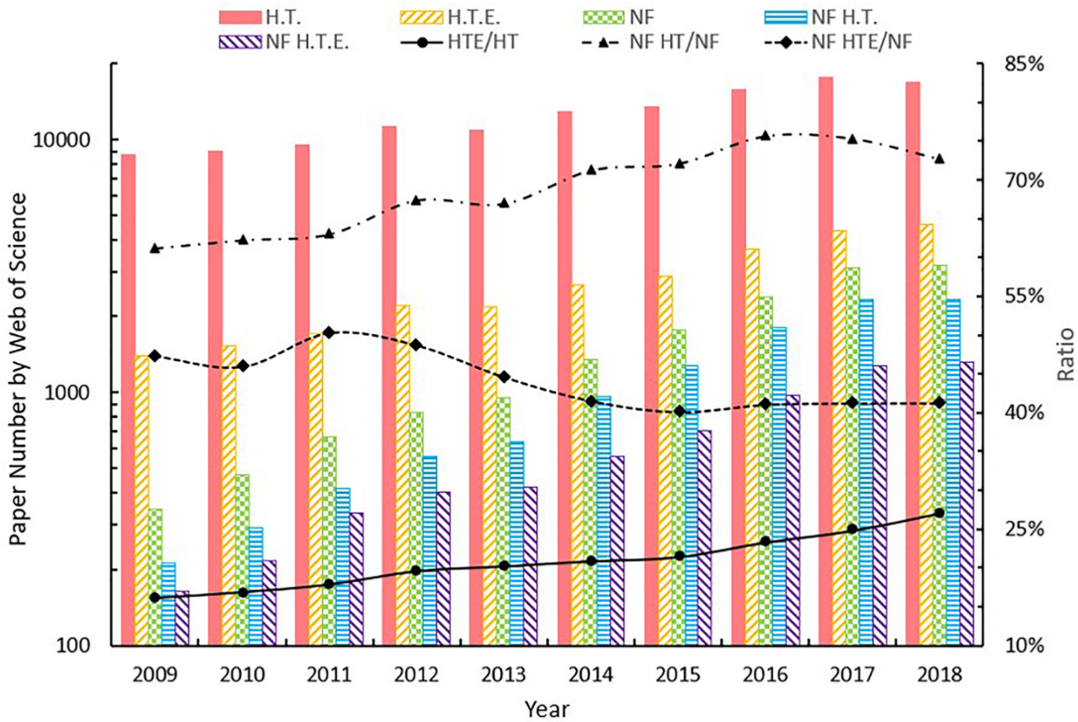

Fig. 1. Paper numbers searched from Web of Science for the period 2009-2018.

Given the overwhelming amount of technical information and the explosive growth in this field, it would be a formidable task to look at everything. The speaker initially intended to write a comprehensive review on "recent trends in heat transfer enhancement research and development". Instead he found that the contents for the single topic on nanofluids for enhancing heat transfer are sufficient to form a paper. A topic search in the Web of Science with keywords "nanofluid" or "nanofluids" resulted in 2388, 3109, and 3201 papers for the year of 2016, 2017, and 2018, respectively. Fig. 1 presents the paper number data acquired from topic searches from the Web of Science on June 12, 2019 for each year from 2009 to 2018. The research on heat transfer (search #1 with keyword "heat transfer") has seen a steady increase with increasing indexed papers from 8723 in 2009 to 16934 in 2018, a 94.1% increase in 10 years. The weight ratio of heat transfer enhancement (search #2 with keywords "heat transfer enhancement", or "heat transfer augmentation", or "heat transfer intensification", or "enhanced heat transfer", or "augmented heat transfer", or "intensified heat transfer") over heat transfer (search #1) research is also steadily increasing from 16.0% in 2009 to 27.1% in 2018. In the same period, the research on nanofluids (search #3 with keywords "nanofluid" or "nanofluids") has been hiked from 345 in 2009 to 3201 in 2018, an increase of 827.8%; whereas weight ratio of heat transfer enhancement with nanofluids (search #4 with combination of search #2 and search #3) over the nanofluid research varies in a narrow range of 40% (in 2015) and 50.2% (in 2011). Fig. 1 also plots the percentage ratio of heat transfer research in nanofluids (search #5 with combination of search #1 and search #3). Clearly the research on nanofluids has been dominantly focused on heat transfer.

In recent years, numerical and experimental studies combining nanofluids, ribs, and/or inserts for enhancing heat transfer have been conducted [9]. Effective thermal conductivity, viscosity and specific heat capacity of nanofluids were measured [10]. Numerical modelling of nanofluids flow and heat transfer in microchannels for enhanced cooling technology has been performed [11]. Effects of Lorentz forces (Li et al., 2019) and magnetic field on nanofluid flow have been considered [12, 13]. Nanofluids have also been applied to enhance heat transfer in heat exchangers [14], heat pipes [15] and solar energy [16, 17], etc. Kakac and Pramuanjaroenkij [18] has recently conducted a review on convective heat transfer enhancement with nanofluids.

With a primary focus on assessing the recent trends and challenges and potentials for continuous growth in heat transfer enhancement using nanofluids, the speaker will present this plenary talk in conjunction with the thermophysical properties, models, and applications of nanofluids for enhancing heat transfer. Finally, some challenges and areas for future research will be envisioned.

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