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# Analysis of nanofluid effects on thermoelectric cooling by micro-pin-fin heat exchangers

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## HIGHLIGHTS

- Two micro-pin-fin heat exchangers (MPFHEXs) were used on a thermoelectric module.
- Effects of nanofluid on the coefficient of performance (COP) were studied.
- Using nanofluid on the hot (cold) side increases COP at low (high) Reynolds number.
- Decreasing nanoparticles diameter increases cold side COP at high Reynolds number.

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ABSTRACT

In this study, two micro-pin-fin heat exchangers (MPFHEXs) were modeled and used on both hot and cold surfaces of a thermoelectric module to analyze the effects of $Al_2O_3$–water nanofluids on the performance of thermoelectric module. The results showed that in low Reynolds numbers adding low volume fraction of nanoparticles to the base fluid in hot surface heat exchanger leads to significant increase in coefficient of performance (COP) of the thermoelectric module and decreases total entropy generation; in high Reynolds numbers adding nanoparticles to the base fluid of cold surface heat exchanger increases the COP and decreases the total entropy generation. Furthermore decreasing the nanoparticles diameter has no effects in low Reynolds numbers but in high Reynolds numbers, it results in significant increase in COP and decreases total entropy generation in cold surface heat exchanger; however, in hot surface heat exchanger, reverse trend is observed.



## 1. Introduction

After the discovery of Peltier effect in 1834, thermoelectric modules have been known as effective devices for power generation and cooling systems. They are series of p-type and n-type semiconductors that have been sandwiched between ceramic plates. Based on the Seebeck effect, temperature difference between these semiconductors generates the electricity current that can be used for power generation. Also due to Peltier effect in thermoelectric cooling, heat pumps away from the hot side to the cold side. This happens in a situation that there are no moving mechanical parts or fluid movements. During recent years many researchers have attempted to increase the efficiency of these devises. Chein and Huang [1] investigated a thermoelectric cooling application and showed that the performance measured by thermoelectric cooling capacity and coefficient of performance (COP) increased by increasing the thermoelectric cold side temperature. Also the performance decreases with increasing temperature difference between hot and cold sides. Chein and Chen [2] experimentally and theoretically studied an integrated thermoelectric cooling device with a microchannel heat sink that was used to cool a fixed amount of water in a tank. Their results demonstrated that to achieve lower temperatures, input electric current should be increased. Nnanna et al. [3] carried out an experimental study of the thermal performance of a thermoelectric module by using nanofluid-based heat exchanger and showed that there was a lag-time in thermal response between the module and heat exchanger. There was no temperature difference for nanofluid between hot side and cold side but this difference is not zero for deionized water. Campbell et al. [4] investigated a thermoelectric chiller for electronics cooling using segregated, serial, and parallel heat exchanger cooling arrangements and showed that serial and parallel loops have lower water temperatures and needed only one pump in comparison with segregated loop that required two

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pumps. David et al. [5] introduced an optimization method for improving thermoelectric heat pump performance based on coupling the thermoelectric phenomena to heat transfer and pressure drop phenomena in the heat exchangers. They determined the optimal geometrical dimensions of the heat exchangers and optimal operating conditions for given fluid temperatures.

Micro heat exchangers have potential applications for thermal management in many industries. Tuckerman and Pease [6] introduced the concept of microchannels in 1981. Peles et al. [7] analytically and experimentally analyzed pressure drop and heat transfer characteristics over a bank of micro-pin-fins and showed that lower thermal resistances could be achieved by using micro-pin-fin heat sinks in comparison with microchannels. Siu-Ho et al. [8] investigated pressure drop and heat transfer characteristics of a single phase micro-pin-fin heat sink and showed that with increasing the Reynolds number, friction factor decreases and near the inlet of the heat sink local heat transfer coefficient is higher and decreases along the flow direction. Jasperson et al. [9] compared micro-pin-fin and microchannel heat sinks by considering thermal-hydraulic performance and manufacturability and showed that micro-pin-fin heat sink has higher convection for flow rates over 60 g/min and higher pressure drop. Rubio-Jimenez et al. [10] studied numerically the micro-pin-fin heat sinks with variable fin densities and shapes. They demonstrated that flat-shaped fins had the best performance and in comparison with rectangular microchannel heat sinks, micro-pin-fin heat sinks had temperature gradient that was four times lower. Rubio-Jimenez et al. [11] investigated an offset micro-pin-fin heat sink with variable fin densities and compared it with the results in their previous work [10]. They recommended this type of micro-pin-fin heat sinks for cooling systems with thermal resistances larger than 0.1 K/W. Other investigations in this issue can be found in Refs. [12,13].

In 1995 Choi at the Argonne National Laboratory introduced the term of nanofluid for the suspension of nanoparticles in the coolants like water, ethylene glycol, and oil. Many researchers have reported the beneficial usage of nanofluids in cooling systems. For example nanofluids have higher thermal conductivity compare to the base fluids [14,15]. The others showed that the use of nanofluids made a significant enhancement in heat transfer coefficient or Nusselt number for convection heat transfer [16–19]. Some researchers reported nanofluids properties like viscosity and showed that they strongly depended on both temperature and particle volume fraction [20]; nanofluids containing smaller diameter nanoparticles have higher viscosity and Nusselt number [21]. Pantzali et al. [22] investigated the effects of nanofluids in laminar and turbulent regimes experimentally and showed that in turbulent regime nanofluids are beneficial if and only if the increase in their thermal conductivity is accompanied by a marginal increase in viscosity, but in laminar regime they are advantageous. Seyf and Mohammadian [23] numerically investigated the thermal performance of a counter flow microchannel heat exchangers and showed that the nanofluid increase both pumping power and thermal performance; the increase in volume fraction led to increase in thermal performance of the system. Seyf and Feizbakhshi [24] numerically studied the effects of nanofluids in micro-pin-fin heat sinks and showed heat transfer enhancement and higher pressure drop with increasing volume fraction of nanoparticles and Reynolds number. Mohammadian et al. [25] investigated the laminar forced convection and entropy generation in a counter flow microchannel heat exchanger with and without nanofluids in hot and cold channels and reported that the capability of heat transfer of $Al_2O_3$–water nanofluids is higher when nanoparticles are used in cold channels.

In this study two micro-pin-fin heat exchangers (MPFHEXs) were modeled and used on both hot and cold surfaces of thermoelectric module (Fig. 1). Effects of nanofluids on coefficient of performance (COP) and entropy generation are studied for three different cases: (1) Case I: nanofluids on both side heat exchangers, (2) Case II: nanofluids on hot side and water on cold side heat exchangers, and (3) Case III: nanofluids on cold side and water in hot

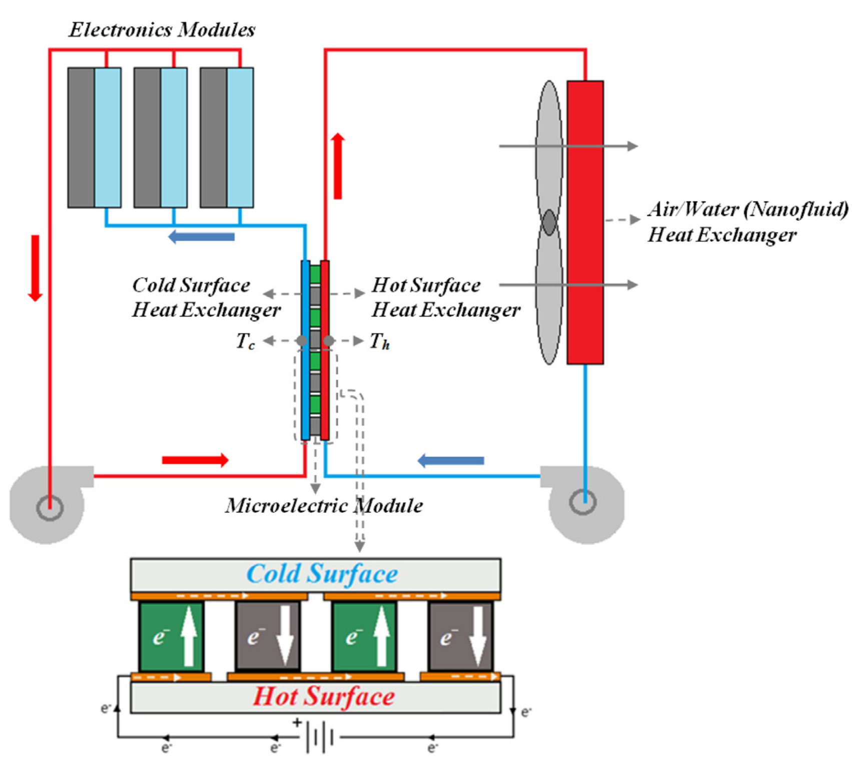


**Fig. 1.** Schematic of thermoelectric module in a cooling system.