Powder Technology 297 (2016) 448–456

Contents lists available at ScienceDirect

Powder Technology

journal homepage: www.elsevier.com/locate/powtec

An experimental study on the effect of conflict measurement criteria for heat transfer enhancement in nanofluidics

R. Sajedi *, M. Jafari, M. Taghilou

Faculty of Mechanical Engineering, University of Tabriz, Tabriz, Iran

ARTICLE INFO

Article history:
Received 14 February 2015
Received in revised form 4 May 2015
Accepted 4 June 2015
Available online 30 June 2015

Keywords:
Experimental
Nanofluid
Appropriate criterion
Heat exchanger

ABSTRACT

This work is devoted to find an appropriate criterion for thermal judging of nanofluidics. The importance of this issue arises from the possible misleading which asserts an existence of extra heat transfer for nanofluid compared to the base fluid, neglecting the hydraulic effects such as increasing the pressure drop. To clarify the issue, an experimental apparatus with ability of making fixed Reynolds number and constant pumping power was constructed and thermal behavior of silicon oxide/water nanofluid and distilled water are investigated in the turbulent regime. In this regard, heat transfer coefficient inside the finned air cooled heat exchanger is evaluated. Results are provided for different inlet temperatures and different nanofluid concentrations for two criteria of fixed Reynolds number and constant pumping power. Results show that the criterion of fixed Reynolds number between nanofluid and base fluid may lead to a misleading of extra heat transfer. Indeed we are obligated to increase the flow velocity to compensate the viscosity increment to make the constant Reynolds number. Hence, the existence of extra heat transfer would be comparatively related to growth of convection rather than nanoparticles effect. But it is confirmed that the criterion of constant pumping power does highly appear the real effect of nanoparticles on the heat transfer enhancement.

1. Introduction

Increasing the global competition in optimal production and the role of energy in the final price of the products, along with limitation of non-renewable energy resources, lead to the development of new and efficient methods in energy consumer/converter equipment such as heat exchangers. Efficiency enhancement in the heat exchangers, involves with geometrical parameters, flow regime and also thermal conductivity and convective heat transfer coefficient of carrier fluid. Metals in their solid form have higher thermal conductivity than fluids. For example, thermal conductivity of copper at room temperature is about 700 times that of water and 3000 times of engine oil. Hence, fluids containing suspended solid metal and solid metal oxides are expected to have higher thermal conductivity than pure fluids.

Increasing the thermal conductivity of fluids as a result of adding particles with millimeter and micrometer sizes have been known over a hundred years [1]. But the use of these particles is not so possible due to practical problems such as fast settling, severe erosion, increasing the pressure drop, and the impossibility of its use in very small ducts. In this regard, recent advances in material technology provide the produce of nanometer-sized particles (nanomaterial) to overcome these problems. The results of adding these nanoparticles into the base fluid, creates the nanofluid [2].

Over the past two decades extensive researches have been done to understand the thermal and hydrodynamic characteristics of nanofluidics. Such that in 2013 only about 1000 articles are indexed in ScienceDirect, which are still studying the thermal performance of different nanofluidics [3]. In these studies the performance of air cooled and liquid cooled heat exchangers in a variety of nanofluidics have been studied. Vermahmoudi et al. [4] examined the characteristics of finned air cooled heat exchanger with nanoparticles in the water base fluid. They investigated heat transfer characteristics of a heat exchanger by adding Fe_2O_3 nanoparticles into the water in the laminar flow regime. They showed that the use of Fe_2O_3 nanoparticles in the water increases the convective heat transfer coefficient. Also, increasing the temperature of nanofluid from 50 °C to 80 °C reduces the overall heat transfer coefficient. Results indicated an increase in the overall and the rate of heat transfer by increasing the nanofluid and air Reynolds numbers. It was found that the use of nanofluid with volumetric concentrations of 0.65% will respectively increase the heat transfer coefficient and the rate of heat transfer by 5.13%, 5.11% compared to the base fluid. Naraki et al. [5] presented an experiential examination on the characteristics of laminar heat transfer in an air cooled heat exchanger with CuO nanoparticles in the water base fluid. They studied the overall heat transfer coefficient of a particular type of car radiator, considering volumetric flow rates of nanofluid and air flow, and changing the concentration and inlet temperature of the nanofluid. Results revealed that the use of 0.4% CuO nanofluid (volumetric) grows the overall heat transfer coefficient, by 8%. They also showed that the overall heat transfer coefficient

* Corresponding author at: Faculty of Mechanical Engineering, University of Tabriz, Iran, 5166616471. Tel.: +98 919 341 6488.
E-mail address: Ramin_sajedi91@ms.tabrizu.ac.ir (R. Sajedi).

http://dx.doi.org/10.1016/j.powtec.2015.06.018
0032-5910/

of a radiator with nanofluid is weakened with increasing the inlet temperature, and improved with increasing the both nanofluid and air volumetric flow rates. Peyghambarzadeh et al. [6] studied the cooling effect of aluminum oxide/water nanofluid in a car radiator at turbulent regime. They examined the effect of various parameters such as air and nanofluid Reynolds numbers and inlet temperature of nanofluid. They considered five different concentrations in the range of 0.1%–1% (volumetric). Their results exposed that the inlet temperature has no considerable effect on the overall heat transfer coefficient, and increasing the nanofluid Reynolds number improves the radiator cooling performance. Leung et al. [7] performed their research on the radiator of a TBD–232 V–12 turbocharged diesel engine and used copper/ethylene glycol nanofluid to increase the thermal efficiency. According to the results, the maximum amount of heat transfer enhancement is observed about 4% for the case of 2% volumetric nanofluid, when the air Reynolds number is 6000 and nanofluid Reynolds number is set to 5000. It was roughly estimated that for 4% increase in overall heat transfer, the frontal area size decreases by 18.7%. Ebrahimi et al. [8] investigated the forced convection heat transfer in a car radiator with the silicon oxide nanoparticles. They considered the influence of inlet temperature, flow rate and different volume fraction of nanoparticles on the radiator heat transfer. Results disclosed that increasing the inlet temperature, Reynolds number and volume fraction of nanoparticles magnifies the Nusselt number. Vajjha et al. [9] presented a numerical study on the two common nanofluidics in an air cooled heat exchanger. They considered three-dimensional modeling of laminar flow of copper oxide and alumina particles in the water–ethylene glycol base fluid. Volumetric concentration of alumina nanofluid was chosen in the range of 1%–10% and copper oxide nanofluid was in the range of 1%–12%. Results indicated an increase in convective heat transfer coefficient of nanofluidics with increasing the Reynolds number and nanoparticles concentrations.

Peyghambarzadeh et al. [10] presented an experimental work to determine the thermal behavior of the pure water, pure ethylene glycol and their mixtures in a car radiator. They also added the Al_2O_3 nanoparticles into the fluid and studied the thermal performance of the nanofluid at different inlet temperatures and different flow rates in the range of 2–6 L/min. They reported that the Nusselt number for the nanofluid would be enhanced up to 40%. Hung et al. [11] investigated the feasibility of alumina (Al_2O_3)/water nanofluid for cooling systems. They provided nanofluidics with different weight fractions, and performed the experiments at three different fluid flow rates of 1.8, 2.1 and 2.4 L/min. Results showed that the use of nanoparticles will increase the rate of heat transfer compared with distilled water by 40% at weight fraction 1.5 wt.%.

An important point which is overlooked by many researchers in studying the thermal properties of nanofluidics is choosing the proper criterion for evaluating the effectiveness of nanofluidics. Pak and Cho [12] were the first researchers who studied the effectiveness of alumina nanofluid instead of water based fluid using two criteria of fixed Reynolds numbers and constant volumetric flow rates between nanofluid and base fluid. Their study showed that the turbulent heat transfer coefficient of 3% (volumetric) alumina nanofluid in a fixed Reynolds number can be increased by 75%, while at the same flow rate the heat transfer coefficient is reduced by 12%. Yu et al. [13] used several criteria to measure the effectiveness of water base nanofluid instead of base fluid to investigate heat transfer enhancement. At this study the fixed Reynolds number, constant volumetric flow rate and constant pumping power were considered, and results showed that the constant pumping power is the best method to evaluate the nanofluidics effectiveness. Using a constant flow rate was found to be generally suitable criterion, but the use of fixed Reynolds number as a benchmark assessment was concluded to be incorrect. Haghighi et al. [14] studied the thermal characteristics of nanofluidics and base fluid in the turbulent regime by making two simultaneous setups and conducting experiments on both alumina and titanium oxide nanofluidics with a volume fraction of 9%. Results admit that the Nusselt number for nanofluidics can be calculated using the equations presented for single-phase base fluids, considering the thermo physical properties of nanofluidics. They considered three criteria: fixed Reynolds number, constant volumetric flow rate and constant pumping power. Consistent with Yu et al. [13] it was shown that the use of constant pumping power is an accurate measure to compare the thermal performance of the base fluid and nanofluid. It was also understood that by considering the same Reynolds number for nanofluid and base fluid, convective heat transfer coefficient is improved 15%, while for the same pumping power, no significant difference has been found between heat transfer coefficient of alumina nanofluid and base fluid. Nevertheless, it was dramatically found that for the same pumping power heat transfer coefficient of the titanium dioxide nanofluid decreases by 10% compared to the base fluid.

Regarding to the criteria of Yu et al. [13] and existence of inconsistency between the large numbers of papers, which compare their results in a fixed Reynolds number for nanofluidics and base fluids, this work, tries to obtain and highlight a proper comparative measure, using results of constant pumping power and fixed Reynolds number. For this reason, experimental setup with ability to supply constant pumping power and fixed Reynolds number was constructed in the heat and fluid flow research laboratory of University of Tabriz. Silicon oxide nanoparticles in the water base fluid was tested in a turbulent flow regime and experimental data for alumina oxide/water nanofluid at volume concentrations of 0.5%, 1% and 2.5% has been used to compare with water at four different operating temperatures.

2. Preparation of nanofluid

Suspension stability and its thermo-physical properties strongly depend on the particles size, shape, type and also physical properties

Table 1
Physical properties of SiO_2.

Chemical formula	SiO_2
Color	White
Morphology	Spherical
Specific surface area (SSA)	193 m^2/g
True density	2220 kg/m^3
Average pore size	20–30 nm

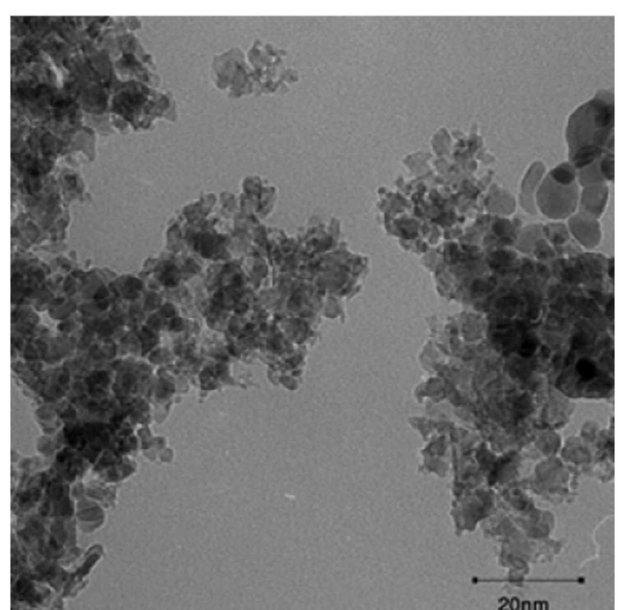

Fig. 1. TEM image of nanoparticles.