HEAT TRANSFER IN MINI HEAT EXCHANGER USING NANOFLUIDS

L.B. Mapa[1], Sana Mazhar[2]

[1]Purdue University Calumet, Indiana; Email: mapa@calumet.purdue.edu
[2]Purdue University Calumet, Indiana; Email: mazhars1@calumet.purdue.edu

ABSTRACT

Nanotechnology is concerned with the materials and systems whose structures and components exhibit novel and significantly improved physical, chemical, and biological properties, phenomena, and processes due to their nanoscale size. Workforce development is essential to reap the benefits of nanotechnology development along with technology transfer. The emphasis should be on hands-on educational experiences by developing nano-tech laboratory demonstration experiments that could be adaptable and incorporated into existing courses in engineering and engineering technology. This paper describes a design that was developed at Purdue University Calumet to demonstrate heat transfer using nano fluids in a mini heat exchanger utilizing commercially available equipment. Theoretical heat transfer rates were calculated using existing relationships in the literature for conventional fluids and nano fluids. Experiments were conducted to determine the actual heat transfer rates under operational conditions using nanofluids and the heat transfer enhancement determined compared to fluids without nanoparticles.

1. INTRODUCTION

In the dimensional scale a nanometer is a billionth of a meter. Nanoscale science and engineering has revolutionized the scientific and technological developments in nanoparticles, nonstructured materials, nanodevices and systems. National Science Foundation (2004) defines nanotechnology as the creation and utilization of functional materials, devices, and systems with novel properties and functions that are achieved through the control of matter, atom-by-atom, molecule by molecule or at the macro molecular level. A unique challenge exists in restructuring teaching at all levels to include nanoscale science and engineering concepts and nurturing the scientific and technical workforce of the future.

The advances in nanotechnology have resulted in the development of a category of fluids termed nanofluids, first used by a group at the Argonne National Laboratory in 1995 (Choi 19952). Nanofluids are suspensions containing particles that are significantly smaller than 100 nm (Wen and Ding 2004), and have a bulk solids thermal conductivity of orders of magnitudes higher than the base liquids. Experimental studies conducted have shown (Wang *et.al.,* 1999, Lee et.al 1999, Keblinski et.al 2002) that the effective thermal conductivity increases under macroscopically stationary conditions. Lee and Choi (1996), under laminar flow conditions, nanofluids in microchannels have shown a two fold reduction in thermal resistance (Lee and Choi, 1996) and dissipate heat power three times more than that of pure water. Studies conducted using water-Cu nanofluids (Xuan and Li, 2003) of concentrations approximately 2% by volume was shown to have a heat transfer coefficient 60% higher than when pure water was used. Such advances must have a broader impact culminating in promoting teaching, training and learning. Dissemination of research results will enhance the scientific and technological understanding of nanotechnology.

This effort aims at bringing nanotechnology to the undergraduate level, especially at the applied level in engineering and technology curricula. The focus is to incorporate nanotechnology into existing course curricula such as heat transfer and fluid mechanics. The intention of the work described here is to introduce a simple experimental procedure in a heat transfer course to facilitate the understanding of the convective heat transfer behavior of nanofluids.

2. EXPERIMENT

2.1 Experimental setup

A schematic of the experimental setup used to investigate heat transfer characteristics of nanofluid in a mini heat exchanger is shown in Fig.1.

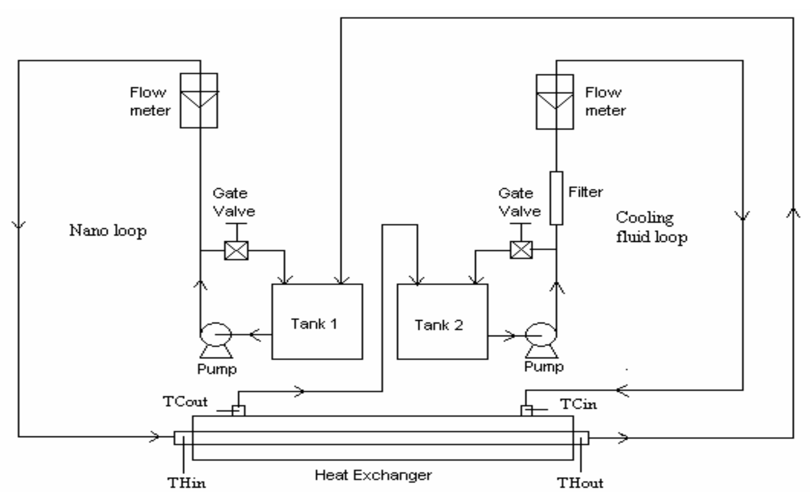

Figure 1: Mini heat exchanger.

It consists of two flow loops, a heating unit to heat the nanofluid, and temperature measurement system. The two flow loops carried heated nanofluid and the other cooling water. Each flow loop included a pump with a flow meter, a reservoir and a bypass valve. The shell and tube heat exchanger is of stainless steel type 316L, 248 mm long consisting of 37 tubes. The tube diameter is 2.4 mm with a tube wall thickness of 0.25 mm, having a designed heat transfer area of 0.05 m^2. Four J-type thermocouples were inserted on the heat exchanger to measure the bulk temperatures of inlet and exit fluid streams. An additional thermocouple was inserted in the nanofluid reservoir. All temperatures were recorded using a thermocouple scanner. The pumps used were magnetic drive centrifugal type with a maximum delivery rate of 11 l/min.

2.2 Determining properties

The transport properties of the fluids, specific heat and viscosity were calculated using the mean fluid temperature between the inlet and outlet. As the pump performance was sensitive to the fluid viscosity at a specified speed, mass flow rate of the fluid streams were determined by weighing the volume collected over a 30 second time period.

2.3 Nanofluid preparation

The nanofluid used in the experiment was 99.0+% pure copper oxide pre-dispersed in water, with an average particle size of 29nm, supplied by Nanophase Technologies Corporation, US. The nanofluid was mixed with de-ionized water to prepare experimental concentrations. It has been reported by Wen & Ding (2004) that nanofluids with less than 4% nanoparticles were found to be stable and the stability lasted over a week, no intermediate mixing was considered necessary.

3. EXPERIMENTAL RESULTS

Preliminary experiments with water were performed to gain experience in operating the set-up. The experiments were performed varying the nanofluid flow rate at a given concentration.

3.1 Base line experiment using water/water

Using de-ionized water as the heating fluid in the tube side, and water as the cooling medium on the shell side, temperature measurements were taken at fluid inlet and exit positions after steady state has been reached. Steady state was determined when the temperatures remained constant with time for a 10 min. period. The mass flow rate (kg/s) of the fluid flowing inside the tube, and heat transfer rate (W) were plotted and the result shown in Fig.2.

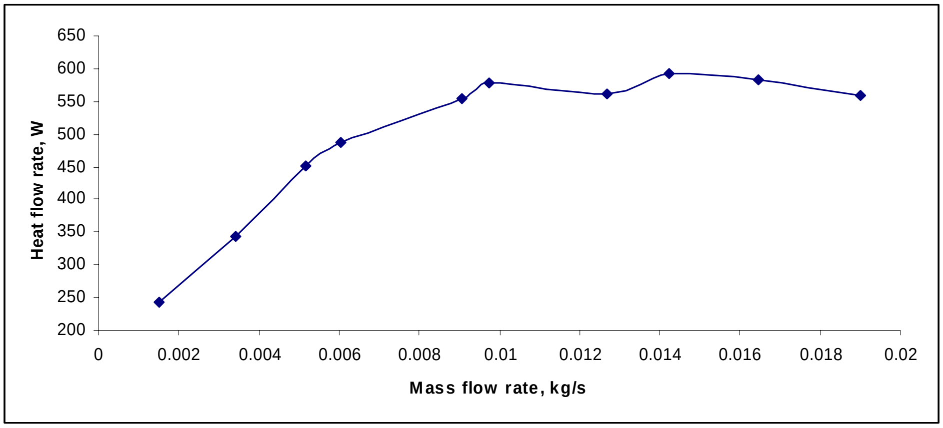

Figure 2: Heat transfer rate - water/water exchange.

3.2 Heat transfer between water/nanofluid with concentration of10x10^{-3}% volume

A very low nanofluid concentration was used as the first nano heat transfer experiment. An increase in heat transfer rate is observed at any given flow rate. The plot of mass flow rate vs. heat transfer rate is shown in Fig.3

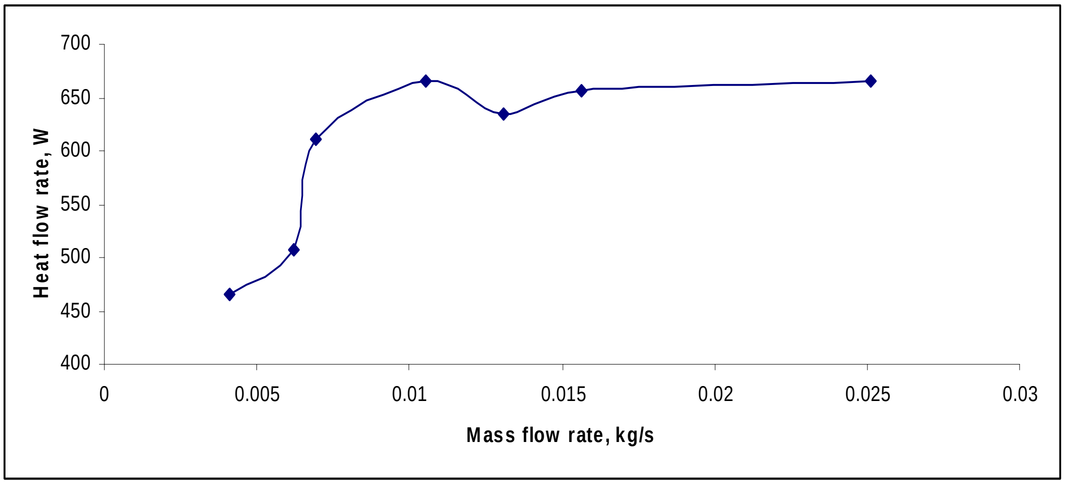

Figure 3: Heat transfer rate - water/nano concentration, 10x10^{-3} % by volume.

There is an improvement in heat flow rate due to the addition of nanoparticles even at very low concentrations. For example at a mass flow rate of 0.005 kg/s, a 5.5% increase in heat transfer rate is observed.

3.3 Heat transfer between water/nanofluid with concentration of 20x10^{-3}% volume

As the concentration of nanoparticles in the fluid increases, a further increase in the heat transfer rate is observed. The results for the higher concentration of nanofluid is shown in Fig.4

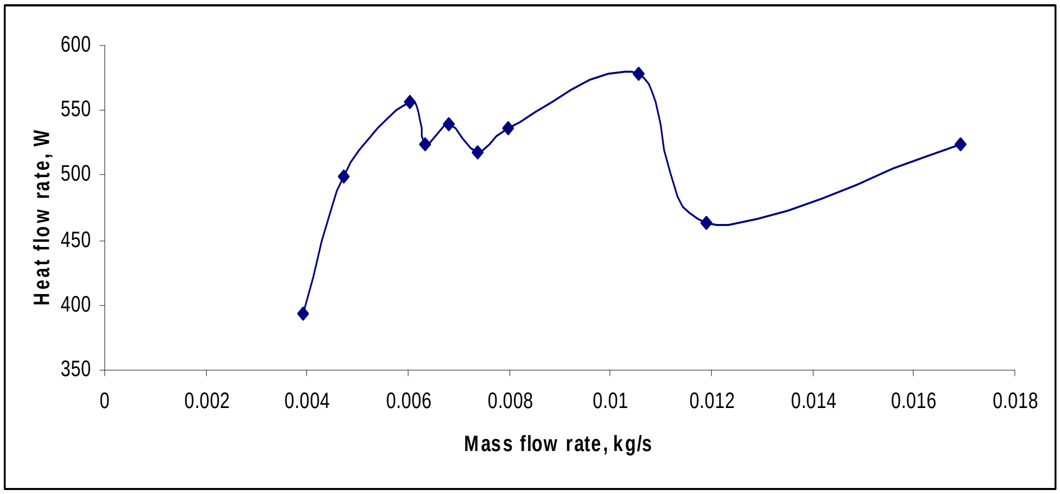

Figure 4: Heat transfer rate - water/nano concentration, 20x10^{-3} % by volume.

3.4 Heat transfer rate and Reynolds number

The relationship between heat transfer rate and Reynolds number for the water/water exchange and water/nanofluid concentration of $10x10^{-3}$ are shown in Figure 5.

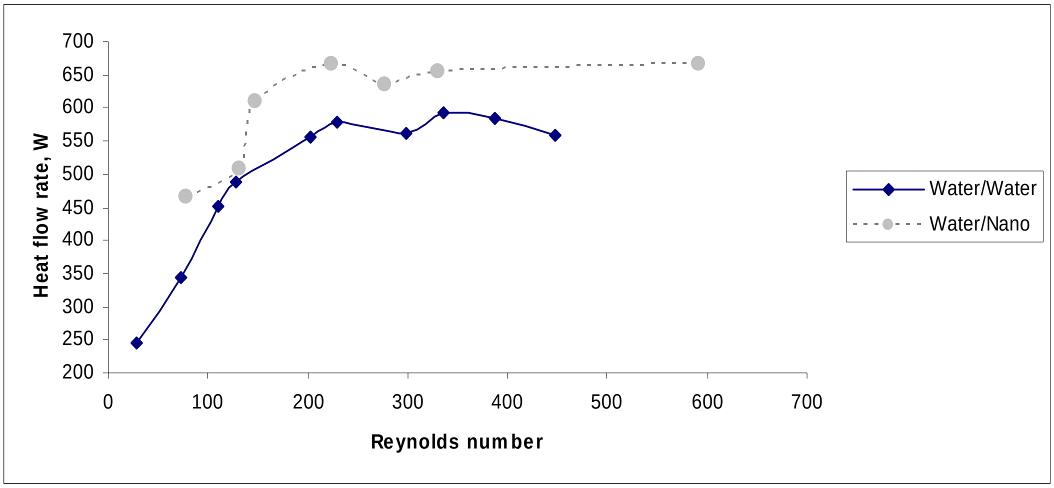

Figure 5: Reynolds number versus heat transfer rate.

3.5 Student discussion

The discussion should include answers to the following questions.

a. Is there a difference in the heat transfer rate for the different materials?
Students need to calculate the heat transfer rate at a given mass flow rate with and without the nano particles in the fluid.

b. Is there a correlation between the heat transfer rate and the concentration of nanoparticles in the fluid?
Plot concentration of nanoparticles in the fluid at several nanofluid mass flow rates and heat transfer rate

c. What affects the enhancement in the heat transfer rate using nanoparticles?
Suggested reasons are, effective thermal conductivity increase of the base fluid by the addition of nanoparticles, the increase in the local heat transfer coefficient approximated as k/δ, where k is the fluid thermal conductivity and δ, the thickness of the thermal boundary layer as suggested by Wen and Ding (2004), Brownian motion, ballistic transport of energy carriers as suggested by Keblinski et.al (2002)

d. Does the presence of nanoparticles affect the boundary layer development?
For pure fluids, the boundary layer develops smoothly and flows hydrodynamically. The introduction of nanoparticles affects the thermal developing length, which increases with increasing particle concentration.

e. Suggest recommendations to improve the experiment
Students prefer the collection of data in an automated form with a computer output.

4. CONCLUSIONS

This paper was developed with undergraduate student population in mind, especially those taking a heat transfer course. The goal was to introduce students to advances in heat transfer technology due to the introduction of innovative materials. The following conclusions are stated:

a. Introduction of nanofluid heat transfer can be introduced at the undergraduate level with existing heat transfer equipment.
b. The use of nanoparticles dispersed in de-ionized water enhances the heat transfer rate
c. Several factors increases the effective thermal conductivity of the nanofluid. The presence of nanoparticles reduces the thermal boundary layer thickness. Further research is necessary to explain non-idealities observed in the experiment.

ACKNOWLEDGEMENTS

We acknowledge the support of the School of Technology at Purdue University Calumet for providing the resources, Pete Peters of the Construction Engineering Technology Laboratory for assistance given during the fabrication of the test equipment and Dr. Edward G. Ludwig at Nanophase Technologies, Romeoville, IL for technical suggestions and providing the nanofluids used in the experiment.

REFERENCES

Nanoscale Science and Engineering, (2004). Program Solicitation NSF 04-03

Choi, S.U.S, (1995).Enhancing thermal conductivity of fluids with nanoparticles, in: Siginer, D.A., Wang, H.P., Developments and Applications of Non-Newtonian Flows, FED-vol. 231/MD-**vol. 66**, *ASME, New York*, 1995 pp.99-105

Wen Dongsheng and Ding Yulong, (2004). Experimental investigation into convective heat transfer of nanofluids at the entrance region under laminar flow conditions, *Int. J. Heat and Mass Transfer*, **47**, 5181-5188

Wang, X.W., Xu, X.F., Choi, S.U.S., (1999).Thermal conductivity of nanoparticle-fluid mixture, J.Thermophys. *Heat Transfer*, **13** (1999) 474-480

Lee.S., Choi, S.U.S. et.al., (1999). Measuring thermal conductivity of fluids containing oxide nano particles, *J. Heat Transfer, Trans. ASME*, **121**, 280-289

Keblinski,P., Philpot,S.R., et.al, (2002). Mechanisms of heat flow in suspensions of nano-sized particles (nanofluids), *Int. J. Heat Mass Transfer*, **45,** 855-863

Lee, S., Choi, S.U.S., (1996). Applications of metallic nanoparticle suspensions in advanced cooling systems, *International Mechanical Engineering Congress and Exposition*, Atlanta, USA.

Xuan, Y.M., Li, Q., (2003). Investigation on convective heat transfer and flow features of nanofluids, *ASME J. Heat Transfer*, **125**, 151-155