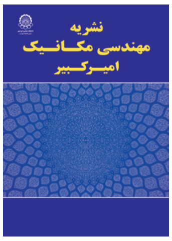

Amirkabir Journal of Mechanical Engineering

Amirkabir J. Mech. Eng., 50(2) (2018) 111-114
DOI: 10.22060/mej.2017.12450.5340

Experimental Investigation of the Forced Convection Heat Transfer of Nanofluids in Curved Tubes

S. Maleki-Delarestaghi[1], M. Nazari[1*], A. Shakeri[2]

[1] Mechanical Engineering Department, Shahrood University of Technology, Shahrood, Iran
[2] Mechanical Engineering Department, Khajeh Nasir Toosi University of Technology, Tehran, Iran

ABSTRACT: In this paper, the forced convective heat transfer of Alumina/water nanofluid is experimentally investigated in uniform-temperature curved tubes in the range of 0<De<800. The curved tubes are horizontally installed inside a cubic reservoir which contains phase-change water. A review of the literature shows that analyzing the forced convective heat transfer in uniform-temperature curved tube needs more investigations. In this experimental study, Alumina/water nanofluid with the volume fraction of 0.1 and different curved tubes with the curvature of 0.116, 0.074 and 0.042 are employed. The Nusselt number is calculated after measuring the temperature of the fluid at entrance and exit. Also, the pressure drop of nanofluid inside the curved tubes has been measured. The accuracy of the experimental results has also been validated by the available theoretical data in the literature. The obtained results are reported by using the confidence interval error bars. The results show a maximum increase of 15% in Nusselt number in the presence of Alumina/water nanofluid in comparison to the base fluid. Effects of curvature on heat transfer rate are also studied which show a considerable growth in the convective heat transfer in the tube with small curvatures.

Review History:

Received: 25 January 2017
Revised: 20 May 2017
Accepted: 16 July 2017
Available Online: 2 August 2017

Keywords:

Convective heat transfer
Nanofluids
Curved tubes
Experimental study

1- Introduction

Increasing efficiency and improving energy consumption in industries have always been of interest to researchers. Improvement of heat transfer in the heating and cooling systems is no exception. Thermal equipment performance is improved by the use of active methods and inactive methods. The use of curved tubes is an inactive method to improve the transfer of the heat. The flow in the curved tubes has many complications compared to the flow in the direct tube. In the curved tube, the secondary flows created by the centrifugal force, mix the flow and improve the heat transfer. On the other hand, the inherent weak thermal conductivity of the commonly used fluids in the heat transfer in the industry is a serious limitation to improve the performance and compression of this engineering equipment. One of the ways to improve heat transfer is via using solid particles in the fluid (nanofluid). Laboratory studies have shown that nanofluids not only increase the thermal conductivity but also increase the convection heat transfer coefficient relative to the base fluid. One of the limiting factors caused by increasing volume fraction of nanoparticles is the pressure drop in the tubes and the increase in the pump power [1]. In addition to laboratory studies, some have studied the theory and numerical simulation of the flow and heat transfer of the nanofluids in different geometries and boundary conditions. Flow geometry in most of these simulations is a straight tube and few studies are available on the flow of the curved tubes. In this research, the potential of using new methods such as nanofluid and geometric deformation to improve heat transfer systems is investigated. Research shows that limited studies have been conducted on the convection heat transfer of the forced nanofluid in the curved tube and the effect of geometric parameters on their performance improvement. Thus, this research is one of the first laboratory research in this field, due to the use of curved tubes in various engineering, this comparison coincides with the three curved tubes with a 180 degree bend, equal to the type and area of the outer surface, and the ratio of different curvatures considering the pressure drop and the effect of the curvature ratio and the presence of nanoparticles in the base fluid on the heat transfer and pressure drop are discussed. To increase the accuracy of the tests, each test is performed at least three times, and the results are displayed in a 97% confidence interval.

Corresponding author, E-mail: mnazari@shahroodut.ac.ir

2- Experimental System

In this article, forced convection heat transfer of operating fluid (water and water nanofluids – 0.1 Vol% alumina) within the curved tube through rectangular cube tank with constant temperature boundary condition is investigated. Three curved tubes with a curvature ratio of 0.042, 0.074 and 0.116 and the same outer surface area for testing have been used. The schematic image of the tested system is shown in Fig. 1.

3- Equations

The viscosity μ, density ρ, specific heat C and thermal conductivity K of the nanofluid are shown in Eqs. (1), (2), (3) and (4), respectively [2,3]:

$$\mu_{nf} = \mu_w (1+2.5\varphi) \tag{1}$$

$$\rho_{nf} = (1-\varphi)\rho_w + \varphi\rho_{np} \tag{2}$$

$$C_{p,nf} = \frac{\varphi\rho_{np} C_{p,np} + (1-\varphi)\rho_w C_{p,w}}{\rho_{nf}} \tag{3}$$

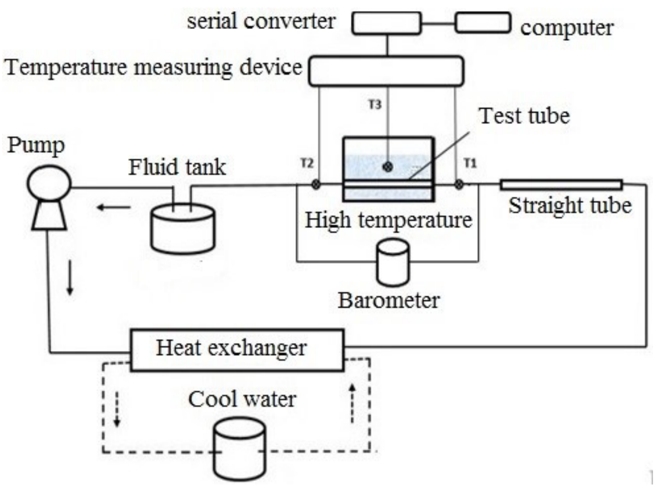

Figure 1. Schematic diagram of the experimental system

$$\frac{K_{nf}}{K_w}=\frac{K_{np}+2K_w+2\varphi(K_{np}-K_w)}{K_{np}+2K_w-\varphi(K_{np}-K_w)} \quad (4)$$

$$h=\frac{q}{A\,\Delta T_b} \quad (5)$$

$$q=\dot{m}C_{peff}(T_{out}-T_{in}) \quad (6)$$

The bulk current temperature is calculated by the Long Mean Temperature Difference (LMTD) method:

$$\Delta T_b=\ln\frac{T_w-T_{in}}{T_w-T_{out}} \quad (7)$$

$$Nu=\frac{hD}{K_{eff}} \quad (8)$$

$$\mathrm{Re}=(\frac{\rho}{\mu})_{eff}UD \quad (9)$$

$$\mathrm{De}=\mathrm{Re}(\frac{r}{R})^{0.5} \quad (10)$$

R is the radius of curvature and (r/R) is the curvature ratio of curved tube.

4- Results and Discussion

Using Table 1, the maximum uncertainty percentage for temperature, pressure drop, flow rate, heat absorbed by fluid and Nusselt number is 0.5, 0.0016, 0.065, 5.56, and 4.7% respectively [4].

Table 1. Accuracy and range of measuring instruments

Measuring instruments	The range of changes	Accuracy
Temperature sensor	-100 to +100 °C	± 0.1 °C
Pump	171.4 to 1714.3 ml/min	± 0.1 ml/min
Pressure drop measuring device	0 to 620 mbar	± 0.001 mbar

By examining the centripetal acceleration (V^2/R) for all three curved tubes, it can be said that the centripetal acceleration of the fluid particles is increased by decreasing the curvature ratio which also increases the heat transfer. According to the performed experiments, it can be concluded that increasing the Dean number as well as adding the nanofluid to the system increases the heat transfer rate which results in a further decrease in the fluid outlet temperature and, consequently, an increase in the fluid transfer in the tube. On the other hand, with the increase of the Reynolds number, since the fluid has less chance of heat transfer, the output temperature of the tube decreases, while the use of a nanofluid increases the amount of heat transfer in a certain Reynolds, and therefore increases the output temperature.

5- Pressure Drop

Experimental observations show that the pressure drop in a tube with a curvature ratio of 0.042 is greater than the other two tubes. Fig. 2 shows both the heat transfer effect and the pressure drop in the curved tube. It is clearly seen that an optimal point (with the highest value $(\frac{\mathrm{Nu_{nf}/Nu_w}}{\Delta \mathrm{P_{nf}}/\Delta \mathrm{P_w}})$) can be extracted for each curved tube with different curvature ratios.

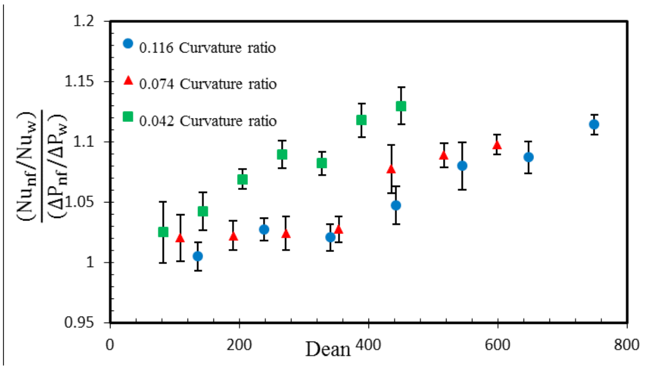

Figure 2. The increase in the Nusselt number on the rate of increase of pressure drop in terms of the Dean number

6- Validation of the Darcy Friction Coefficient

Using the Blasius equation (Eq. (11)) experimental friction coefficient of the curved tube is calculated. To validate the friction coefficient obtained from the pressure drop of the two ends of the curved tube, the Ito theory [5], which was defined for the curved tubes is used for the comparison.

$$\Delta P=f_r(\frac{L}{d})(\frac{\rho v^2}{2})\rightarrow f_r=\frac{2d\,\Delta P}{L\,\rho v^2} \quad (11)$$

Fig. 3 shows the experimental results of the nanofluid and water friction coefficient against theoretical results. The maximum error of 28% and a minimum of 97% are reported by this diagram as compared to the theoretical results.

7- Conclusions

In this research, the effect of the curvature ratio and the presence of nanoparticles on heat transfer and pressure drop have been studied which show that the addition of nanopowder to base fluid and the reduction of the curvature ratio significantly increase the heat transfer in the curved

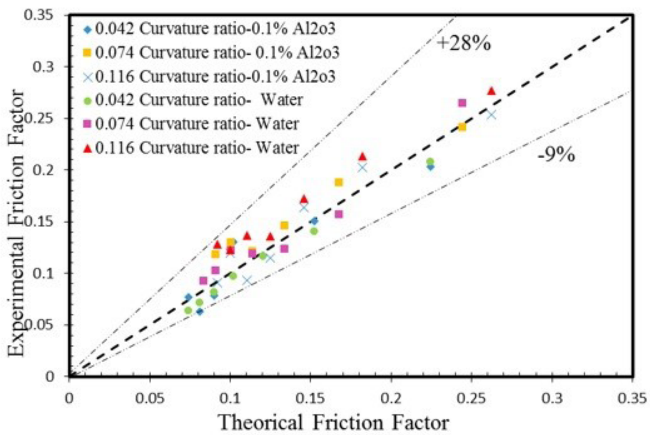

Figure 3. Comparison of the friction coefficient error between theoretical and experimental values

tube. It seems that random movements, convection and collision of nanoparticles in the tube with a lower curvature ratio and longer lengths lead to a change in the temperature profile. Also, the penetration and dispersion of nanoparticles along the wall lead to a rapid increase in the transfer of heat from the wall to the fluid mass. Meanwhile, the simultaneous effects of heat transfer and pressure drop in three different curvature ratios are presented and compared.

References

[1] A. Akbarinia, Impacts of nanofluid flow on skin friction factor and Nusselt number in curved tubes with constant mass flow, *International Journal of Heat and Fluid Flow*, 29(1) (2008) 229-241.

[2] A. Einstein, *Investigations on the Theory of the Brownian Movement*, Courier Corporation, 1956.

[3] J. Maxwell, *Electricity and Magnetism*, v. 1, in, Oxford, Clarendon Press, 1892.

[4] S. Bell, *Measurement good practice guide no. 11 (issue 2), A Beginner's Guide to Uncertainty of Measurement*. National Physical Laboratory Teddington, Middlesex, United Kingdom, (2001).

[5] H. Ito, Friction factors for turbulent flow in curved pipes, *Trans. ASME, J. Basic Engng*, D, 81 (1959) 123-134.

Please cite this article using:

S. Maleki-Delarestaghi, M. Nazari, A. Shakeri, Experimental Investigation of the Forced Convection Heat Transfer of Nanofluids in Curved Tubes, *Amirkabir J. Mech. Eng.*, 50(2) (2018) 347-358.

DOI: 10.22060/mej.2017.12450.5340