Available online at www.elixirpublishers.com (Elixir International Journal)

Mechanical Engineering

Elixir Mech. Engg. 51 (2012) 10674-10676

ISSN: 2229-712X

Entropy generation analysis of nanofluid flow in Coiled tube heat exchanger under laminar flow

Alireza Falahat
Department of Mechanics, Mahshahr Branch, Islamic Azad University.

ARTICLE INFO

Article history:
Received: 28 July 2012;
Received in revised form:
20 September 2012;
Accepted: 27 September 2012;

Keywords
Nanofluid,
Entropy generation,
Coiled tube, l
Aminar flow.

ABSTRACT
In this paper analytically investigated the effects of water–Al2O3 nanofluid on the entropy generation through a coiled tube heat exchanger under uniform wall temperature condition in laminar regime. Nanofluid thermo-physical properties are obtained from literature or calculated from suitable correlations. It is found that adding nanoparticles improves the thermal performance of water-Al2O3 flow and with increasing volume constriction of nanoparticle, total entropy generation at fixed Reynolds number, decreases. By increasing δ , entropy generation decreases, also with increasing τ , total entropy generation increases.

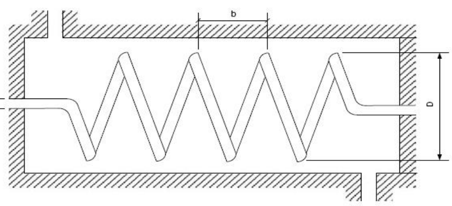
Introduction

Nanotechnology has been widely used in industry since materials with sizes of nanometers possess unique physical and chemical properties. Nano-scale particle added fluids are called as nanofluid which is firstly utilized by Choi [1]. Masuda et al. [2] showed that the thermal conductivity and the viscosity of liquids are altered dramatically by dispersing ultra-fine particles of c-aluminum oxide (Al2O3), silicon dioxide (SiO2) and titanium dioxide (TiO2). Subsequently, this finding was conclusively established from experiments of other researchers; Nanofluids have valuable applications in the area of heating buildings through the hydronic coils, cooling automotive engines through the radiators and in heat exchangers in all types of industries. In all these applications the fluid flow is generally in the turbulent regime, because higher heat transfer is achieved through the turbulent flow.

Xuan [3] and Xuan and Li [4] investigated experimentally the convective heat transfer and flow characteristics for Cu–water nanofluid flowing through a straight tube with a constant heat flux under laminar and turbulent flow conditions. Cu nanoparticles with diameters below 100 nm were used in their study. The results of the experiment showed that the suspended nanoparticle sremarkably enhanced the heat transfer performance of the conventional base fluid and their friction factor coincided well with that of the water. Furthermore, they also proposed the new convective heat transfer correlations for prediction of the heat transfer coefficients of the nanofluid for both laminar and turbulent flow conditions. Pak and Cho [5] conducted experiments to determine the heat transfer coefficient in pipe flow and viscosity for water-Al2O3 and water-TiO2 nanofluids. Their findings were that Nusselt number correlations tended to increase with increasing particle concentration and Reynolds number. However, the nanofluids tested had lower Nusselt numbers than water at equal velocity conditions. Viscosity for the tested nanofluids were substantially higher than that for water. Temperatures were not reported for the Nusselt number and heat transfer coefficient experiments.

Entropy generation minimization (EGM) is the method of modeling and optimization of the devices accounting for both heat transfer and fluid flow irreversibilities. For example Ko and Ting [6] have applied this concept to find the most appropriate flow conditions of a fully developed, laminar forced convection flow through a helical coil tube for which entropy generation is minimized. The method of EGM was originally applied to a straight tube with smooth surface in a pioneering work by Bejan [7]. The work by Shokouhmand and Salimpour [8-9] also deals with entropy generation analysis of fully developed laminar forced convection in a helical tube with uniform wall temperature.

The present paper reports an analytical study of effect of nanofluid on entropy generation in laminar flow. The entropy generation of water-AL2O3 nanofluid flow through a coiled tube under constant temperature condition is analytically investigated. Nanofluid flow is studied in laminar regime and nanoparticles volume concentration up to 4% is considered. geometry of coiled tube heat exchanger. A coiled tube has been shown in Fig. 1. In this figure, $d/2$ is inner radius of the tube and $D/2$ is curvature radius of the coil, and b is the coil pitch. The curvature ratio, δ, is defined as the coil-to-tube radius ratio, d/D. The other three important dimensionless parameters namely, Reynolds number (Re), Nusselt number (Nu), and Dean number (Dn) are defined as follow.



Tele:
E-mail addresses: a.falahat@mahshahriau.ac.ir

$$\mathrm{Re}=\frac{\rho U\, d}{\mu},\ Nu=\frac{h\, d}{k},\ Dn=\mathrm{Re}\left(\frac{d}{D}\right)^{0.5} \tag{1}$$
$$He=Dn(1+\gamma^{2})^{0.5},\ \gamma=\frac{b}{\pi D}$$

Where, U and h are average velocity and convective heat transfer coefficient respectively.

Entropy generation analysis

Taking the coil passage of length dx as the thermodynamic system, the first and second laws can be expressed as

$$d\dot{S}_{gen}=\dot{m}\,ds-\frac{\delta\dot{Q}}{T_w} \tag{2}$$

Where $\delta\dot{Q}=\dot{m}C_P\,dT$ is heat transfer rate to the fluid flowing in this system. For an incompressible fluid we have

$$T\,ds=C_P\,dT-v\,dP \tag{3}$$

Substituting ds from Eq. 3 into Eq. 2, $d\dot{S}_{gen}$ can be written as

$$d\dot{S}_{gen}=\dot{m}C_P\left(\frac{T_w-T}{T\,T_w}dT-\frac{1}{\rho C_P T}dP\right) \tag{4}$$

Pressure drop in Eq. 4 is given in the following equation.

$$dP=-\frac{f\rho U^{2}}{2d}dx \tag{5}$$

The bulk temperature variation of fluid along a duct is given as

$$T=T_w-(T_w-T_i)\exp\left(-\frac{4h}{\rho U d C_P}x\right) \tag{6}$$

Integrating Eq. 4 along the duct, total entropy generation is obtained as

$$\dot{S}_{gen}=\dot{m}C_p\left[\begin{array}{l}\ln\left(\dfrac{1-\tau.e^{-4St.\lambda}}{1-\tau}\right)-\tau(1-e^{-4St.\lambda})\\ +\dfrac{f\,Ec}{8St}\ln\left(\dfrac{e^{4St.\lambda}-\tau}{1-\tau}\right)\end{array}\right] \tag{7}$$

The non-dimensional entropy generation number Ns can be defined as

$$Ns=\frac{\dot{S}_{gen}}{\dot{Q}/\Delta T}=\frac{\dot{S}_{gen}}{\dot{m}C_P} \tag{8}$$

In these equations some parameters can be made dimensionless as follows

$$St=\frac{h}{\rho U C_P}=\frac{Nu}{\mathrm{Re}\,\mathrm{Pr}} \tag{9}$$

$$Ec=\frac{U^{2}}{C_P(T_w-T_i)} \tag{10}$$

$$\tau=\frac{T_w-T_i}{T_w} \tag{11}$$

$$\lambda=\frac{L}{d} \tag{12}$$

For analyzing entropy generation, variation of Nu and f with various parameters of flow and geometry of tube shall be known. For this purpose, the proposed correlations by Manlapaz and Churchill [10] are used as follow

$$f=\frac{16}{\mathrm{Re}}\left[\begin{array}{l}(1-0.18/(1+(\dfrac{35}{He})^{2})^{\frac{1}{2}})^{m}\\ +(1+\dfrac{\delta}{3})^{2}\dfrac{He}{88.33}\end{array}\right]^{\frac{1}{2}} \tag{13}$$

$$Nu=\left[\begin{array}{l}(3.657+\dfrac{4.343}{(1+\dfrac{957}{\mathrm{Pr}\,He^{2}})^{2}})^{3}\\ +1.158(\dfrac{He}{1+\dfrac{0.477}{\mathrm{Pr}}})^{\frac{3}{2}}\end{array}\right]^{\frac{1}{3}} \tag{14}$$

where, values of m are 2, 1, and 0 for $Dn\langle 20$, $20\langle Dn\langle 40$ and $Dn\rangle 40$, respectively.

Thermophysical Properties Of Nanofluid

Assuming small temperature variations the thermophysical properties (density, specific heat, viscosity and thermal conductivity) of the nanofluid may be calculated as a function of nanoparticle volume concentration (ϕ), base fluid and nanoparticles properties. Using the general formula for the mixtures, the following equation can be obtained to evaluate the density of nanofluid:

$$\rho_{nf}=(1-\phi)\rho_{bf}+\phi\rho_{p} \tag{19}$$

Where indices ‘‘p”, ‘‘bf” and ‘‘nf” refer to particle, base fluid, and nanofluid respectively. As mentioned in Buongiorno [11], assuming that the nanoparticles and the base fluid are in thermal equilibrium, the nanofluid specific heat is derived from:

$$Cp_{nf}=(1-\phi)Cp_{bf}+\phi\,Cp_{p} \tag{20}$$

These equations, which are based on the physical principle of the mixture rules, have been found appropriate for use with nanofluids through experimental validation by Pak and Cho [5] and Xuan and Roetzel [12].

Viscosity and thermal conductivity of water-Al2O3 nanofluid are evaluated by the model developed by Maiga et al. [13] based on experimental works of Masuda et al. [2], Lee et al. [14] and Choi et al. [15]. For water-Al2O3it was proposed:

$$\mu_{nf}=(123\phi^{2}+7.3\phi+1)\mu_{bf} \tag{21}$$

$$k_{nf}=(4.97\phi^{2}+2.72\phi+1)k_{bf} \tag{22}$$

In these equations it is assumed that the temperature variation is smaller than 10^{o} The true effect of augmentation technique (such as adding nanoparticles) on the thermodynamic performance can be evaluated by comparing the irreversibility of the heat exchanger apparatus before and after the implementation of the augmentation technique. To this end the augmentation entropy generation number is defined:

$$N_{S,a}=\frac{N_S}{N_{S,0}} \tag{23}$$

Where $N_{S,0}$ represent the degree of irreversibility when the fluid is distilled water $(\phi=0)$. According to Eq. (23) adding nanoparticle is thermodynamically advantageous when $N_{S,a}$ values are less than 1.

Results and Discussion

Fig. 2 displays the entropy generation number of water-Al2O3 nanofluid versus Re, in different volume concentrations. It is found that by increasing Re number the entropy generation number decreases, so the entropy generation decreases by increasing nanoparticle volume concentration at fixed Reynolds.

In Fig. 3, augmentation entropy generation number is plotted versus volume concentration of nanoparticles for different Re

numbers. It is shown that the augmentation entropy generation number declines linearly at fixed Reynolds number.

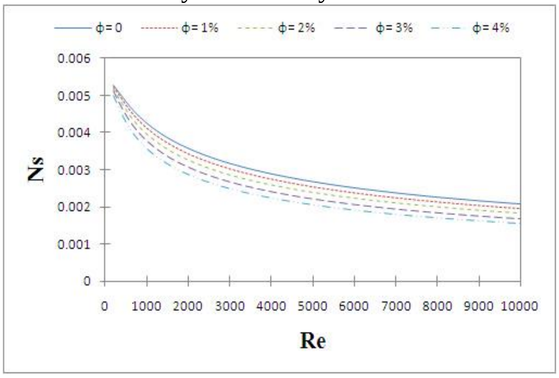


Fig. 2. Dimensionless entropy generation number versus Reynolds number

Fig. 4 illustrates the entropy generation number versus δ number where nanoparticle volume concentration ranges from 0% to 4%. It can be seen that Ns decrease with the increase of δ for pure water and declines by increasing the volume concentration of nanoparticles.

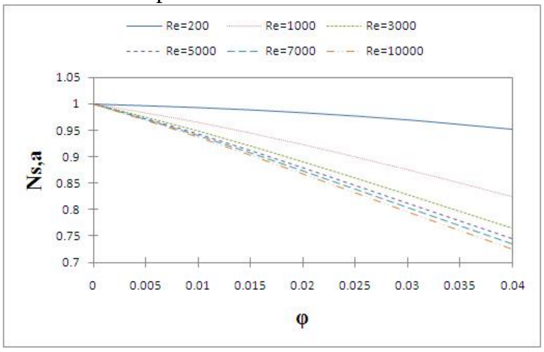


Fig. 3. Augmentation Entropy generation number versus volume concentration

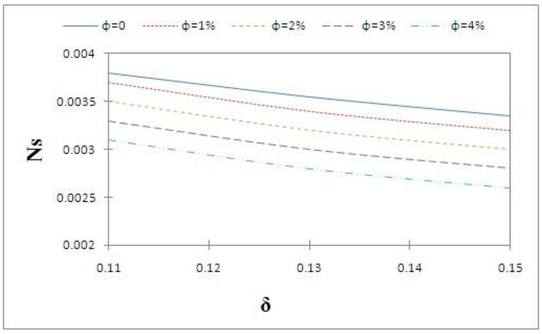


Fig. 4. Dimensionless entropy generation number versus δ

Variation of entropy generation with τ shown in Fig. 5 for water-Al2O3 for constant δ. It is shown that the entropy generation increases by τ and also adding nanoparticles in constant τ decreases.

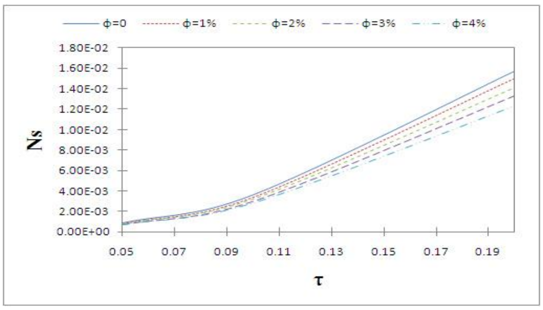


Fig. 5. Dimensionless entropy generation number versus

Conclusion

In this study, entropy generation of the nanofluids flow through a coiled tube heat exchanger under constant wall temperature is investigated. From this study some conclusions can be drawn as follow:

As Reynolds number is increased total entropy generation is decreases an also with adding nanoparticles at fixed Reynolds number, total entropy generation decreases.

When dimensionless temperature τ increases, total entropy generation increases and with increasing δ, total entropy generation in every volume constriction, decreases.

Reference:

[1] Choi S.U.S, *Enhancing thermal conductivity of fluids with nanoparticles*, Proceeding of ASME International Mechanical Engineering Congress and Exposition, San Francisco pp. 99-105, 1995.

[2] Masuda H, Ebata A, Teramae K, Hishiunma N, *Alteration of thermal conductivity and viscosity of liquid by dispersed ultra-fine particles (dispersion of Al2O3, SiO2, and TiO2 ultra-fine particles)* , Netsu Bussei, Vol. 4, pp.227–233, 1993.

[3] Li Q, Xuan Y, *Convective heat transfer and flow characteristics of Cu–water nanofluid*, Sci. China E, 45, pp. 408, 2002.

[4] Xuan Y, Li Q, *Investigation on convective heat transfer and flow features of nanofluids*, ASME J. Heat Transfer 125, 2003.

[5] Pak B.C, Cho Y.I, *Hydrodynamic and heat transfer study of dispersed fluids with submicron metallic oxide particles*, Exp Heat Transfer, Vol 11, pp. 151-170, 1998.

[6] Ko T.H, Ting K, *Entropy generation and thermodynamic optimization of fully developed laminar convection in a helical coil*, Int Commun Heat Mass Transfer, Vol,.32, 2005, pp. 214-223.

[7] Bejan A, *Entropy generation through heat and fluid flow*, New York: Wiley; 1982.

[8] Shokouhmand H, Salimpour MR, *Optimal Reynolds number of laminar forced convection in a helical tube subjected to uniform wall temperature*, International Communication and Heat Mass Transfer, Vol, 34, pp.753–61, 2007.

[9] Shokouhmand H, Salimpour MR, *Entropy generation analysis of fully developed laminar forced convection in a helical tube with uniform wall temperature*, Heat and Mass Transfer, Vol, 44, pp. 213–20, 2007.

[10] Manlapaz R, Churchill S.W, *Fully developed laminar convection from a helical coil*, Chem Eng Commun, Vol. 9, pp.185-200, 1981.

[11] Buongiorno J, *Convective transport in nanofluids*, J Heat Transfer, Vol.128, pp.240-50, 2006.

[12] Xuan Y, Roetzel W, *Conceptions for heat transfer correlation of nanofluids*, Int J Heat Mass Transfer, Vol.43,pp.3701–7, 2000.

[13] Maiga S.E.B, Nguyen C.T, Galanis N, Roy G, *Heat transfer behaviors of nanofluids in a uniformly heated tube*, Journal Superlattices Microstruct, Vol. 35, pp.543-57, 2004.

[14] Lee S, Choi S.U.S, Li S, Eastman G, *Measuring thermal conductivity of fluids containing oxide nanoparticles*, J Heat Transfer, Vol. 121, pp.280-9, 1999.

[15] Choi S.U.S, Wang X, Xu W, Thermal conductivity of nano-particle-fluid mixture. J Thermophys, Heat Transfer, Vol.13, pp.474-80, 1999.