Entropy Generation Analysis of EG-Al_2O_3 Nanofluid in Helical Tube and Laminar Flow

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***Abstract*— In this paper, effects of adding nanoparticle on the entropy generation of EG–Al_2O_3 nanofluid flows through a helical tube under uniform wall heat flux condition in laminar regime investigated analytically. It is found that adding nanoparticles improves the thermal performance of EG -Al_2O_3 flow with Re numbers less than 3000. The entropy generation by adding nanoparticles in constant δ and different δ investigated. It is found that with the increasing δ values, total entropy generation decreases at fixed volume concentration. Moreover optimum conditions (based on the entropy generation sense) for laminar nanofluid flows are obtained.**

***Keywords*—** Helical Tube, Nanofluid, Entropy Generation and Laminar Flow

I. INTRODUCTION

A nanofluid is a suspension of ultrafine particles in a conventional base fluid which tremendously enhances the heat transfer characteristics of the original fluid. Many types of particle, such as metallic, non-metallic and polymeric, can be added into fluids to form slurries.

Masuda et al. [1] showed that the thermal conductivity and the viscosity of liquids are altered dramatically by dispersing ultra-fine particles of c-aluminum oxide (Al_2O_3), silicon dioxide (SiO_2) and titanium dioxide (TiO_2). Subsequently, this finding was conclusively established from experiments of other researchers; notably, Choi [2], Wang et al. [3] and Eastman et al. [4]. For the same Nusselt number of fluid flow in a given flow passage, if the thermal conductivity increases then the convective heat transfer also increases in the same proportion. 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.

Li and Xuan [5] and Xuan and Li [6] 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. Das et al. [7] have investigated the increase of thermal conductivity with temperature for nanofluids with water as the base fluid and nanoparticles of Al_2O_3 or CuO as the suspension material using the temperature oscillation technique.

Maiga et al. [8] have presented numerical results for laminar and turbulent convective heat transfer of nanofluids through a uniformly heated tube using the Fluent code. They investigated both water-Al2O3and ethylene glycol–Al2O3 nanofluid flows and they found that the inclusion of nanoparticles to a base fluid increases the wall-heat-transfer and shear stress in both laminar and turbulent regimes.

Pak and Cho [9] conducted experiments to determine the heat transfer coefficient in pipe flow and viscosity for water-Al_2O_3 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 was substantially higher than that for water. Temperatures were not reported for the Nusselt number and heat transfer coefficient experiments. Williams et al. [10] experimentally determined Nusselt numbers for water-Al_2O_3 and water-ZrO_2 nanofluids under turbulent flow conditions, and had similar findings.

Many researchers have studied the entropy generation of thermal systems to find their optimum design condition. EGM (entropy generation minimization) is the method of modeling and optimization of the devices accounting for both heat transfer and fluid flow irreversibilities. For example Ko and Ting [11] 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 aim of present paper the entropy generation of nanofluid flow is computed and the optimum condition for flow parameters is specified. The entropy generation of EG-AL_2O_3 nanofluid flow through a Helical tube under constant wall heat flux condition is analytically investigated. nanofluid flow is studied in laminar regime and nanoparticles volume concentration up to 5% is considered.

II. GEOMETRY OF HELICAL TUBE

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:

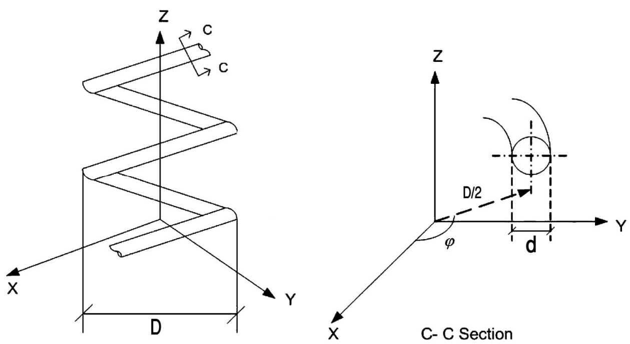

Fig. 1. Geometry of the helical tube

$$\mathrm{Re} = \frac{\rho U d}{\mu},\ Nu = \frac{h d}{k},\ Dn = \mathrm{Re}\left(\frac{d}{D}\right)^{0.5} \quad (1)$$

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

III. SECOND LAW ANALYSIS

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

$$\dot{m}\, dh = q'\, dx \quad (2)$$

$$\dot{S}'_{gen} = \dot{m}\frac{ds}{dx} - \frac{q'}{T+\Delta T} \quad (3)$$

where $\dot{m}$, q' and $\dot{S}'_{gen}$ are the mass flow rate in the coiled tubes, the heat transfer rate and the entropy generation rate per unit coil length, respectively. By using the thermodynamic relation

$$T\, ds = dh - v\, dp \quad (4)$$

$\dot{S}'_{gen}$ can be written as

$$\dot{S}'_{gen} = \frac{q'\Delta T}{T^2(1+\frac{\Delta T}{T})} + \frac{\dot{m}}{T\rho}\left(-\frac{dp}{dx}\right) \quad (5)$$

The pressure drop is [12]:

$$dp = -\frac{f\rho U^2}{2d}dx \quad (6)$$

Based on the relationship between friction factor f and pressure drop, and the heat transfer coefficient $\overline{h}$ and Nusselt number, $\dot{S}'_{gen}$ can be expressed by

$$\dot{S}'_{gen} = \frac{(q')^2}{T^2\pi\, Nu\, k + T q'} + \frac{32\dot{m}^3 f}{T\rho^2 d^5 \pi^2} \quad (7)$$

The only difference between the final form and the derivation of Bejan [13] is that the $\Delta T/T$ term in Eq. (5) has been retained in the present derivation for accuracy, although the effect of the term may not be significant since its value is relatively minor when ΔT is much smaller than T.

The non-dimensional entropy generation number N_S [13, 14] is defined as $\dot{S}'_{gen}/(q'/T)$ and can be determined from Eq. (7) as:

$$N_S = (N_S)_T + (N_S)_P \quad (8)$$

Where

$$(N_S)_T = \frac{1}{Nu\,\theta_1 + 1} \quad (9)$$

$$(N_S)_P = \frac{f\,\mathrm{Re}^5}{\theta_2} \quad (10)$$

θ_1 and θ_2 are two dimensionless duty parameters, defined as

$$\theta_1 = \frac{\pi k T}{q'} \quad (11)$$

$$\theta_2 = \frac{32\dot{m}^2\rho^2 q'}{\mu^5\pi^3} \quad (12)$$

The friction loss in flow through helical coiled tubes has been studied by Ito [15] and the following correlation has been recommended to predict the friction factor:

$$f = 0.37\left(\frac{64}{\mathrm{Re}}\right)Dn^{0.36} \quad (13)$$

Janssen and Hoogendoorn [16] have experimentally studied the heat transfer in a single helical coiled tube subjected to a constant heat flux and presented the data as

$$Nu = 0.7\,\mathrm{Re}^{0.43}\,\mathrm{Pr}^{\frac{1}{6}}\,\delta^{0.07} \quad (14)$$

Where the Eckert number and Stanton number is defined as:

$$Ec = \frac{U^2}{C_p\left(\frac{q'}{\pi d h}\right)} \quad (15)$$

$$St = \frac{h}{\rho U C_p} \tag{16}$$

IV. THERMOPHISICAL 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:

$$\rho_{nf} = (1-\phi)\rho_{bf} + \phi\rho_p \tag{17}$$

Where indices ''p'', ''bf'' and ''nf'' refer to particle, base fluid, and nanofluid respectively. As mentioned in Buongiorno [17], assuming that the nanoparticles and the base fluid are in thermal equilibrium, the nanofluid specific heat is derived from:

$$Cp_{nf} = (1-\phi)Cp_{bf} + \phi\, Cp_p \tag{18}$$

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 [9] and Xuan and Roetzel [18].

Viscosity and thermal conductivity of ethylene glycol-Al_2O_3 nanofluid are evaluated by the model developed by Maiga et al. [19] based on experimental works of Masuda et al. [20], Lee et al. [21] and Choi et al. [22]. For water-Al_2O_3it was proposed:

$$\mu_{nf} = (306\phi^2 - 0.19\phi + 1)\mu_{bf} \tag{19}$$

$$k_{nf} = (28.905\phi^2 + 2.8273\phi + 1)k_{bf} \tag{20}$$

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:

$$N_{S,a} = \frac{N_S}{N_{S,0}} \tag{21}$$

Where $N_{S,0}$ represent the degree of irreversibility when the fluid is distilled ethylene glycol $(\phi = 0)$. According to Eq. (21) adding nanoparticle is thermodynamically advantageous when $N_{S,a}$ values are less than 1.

V. RESULT AND DISCUSSION

Fig. 2 displays the entropy generation number for laminar flow of EG-Al_2O_3 nanofluid versus Re, in different volume concentrations. It is found that by increasing Re number the entropy generation number first decreases and then increases, so there is a Re number for each volume concentration of nanoparticle in which the entropy generation is minimum. The Re number in which the entropy generation is minimum, decreases by increasing nanoparticle volume concentration from about 10000 for pure water to 5000 for $\phi = 5\%$. Also it is clear from Fig. 2 that adding nanoparticles to the laminar flow of nanofluid has different effects on the entropy generation before and after minimum entropy generation region.

Fig. 3 represents the effects of adding nanoparticles on augmentation entropy generation number at different Re numbers. As it can be seen at low Re numbers $(\mathrm{Re} < 5000)$ the augmentation entropy generation number is less than unity which means that using nanoparticles at these Re numbers is efficient and increases the thermodynamic performance, whereas at high Re numbers $(\mathrm{Re} > 7000)$ the use of nanoparticles results in raising the entropy generation sharply. It is found that these optimum Re numbers are between 5000 and 11000 (respectively for $\phi = 5\%$ and $\phi = 1\%$).

In Fig. 4, augmentation entropy generation number is plotted versus volume concentration of nanoparticles for different Re numbers. It is shown that for small Re numbers

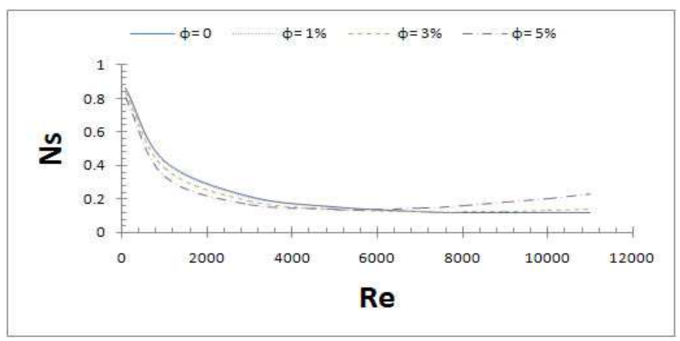

Fig. 2. Entropy generation number in laminar flow

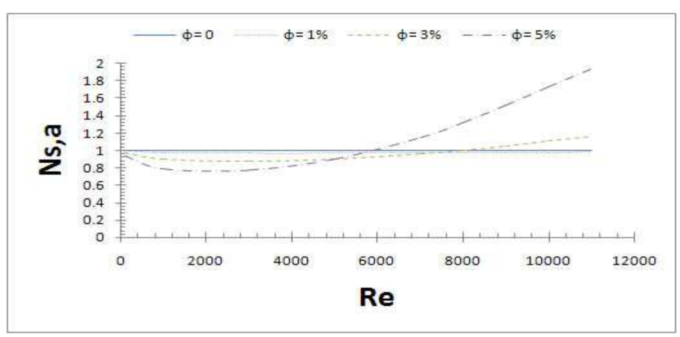

Fig. 3. Augmentation entropy generation number in laminar flow

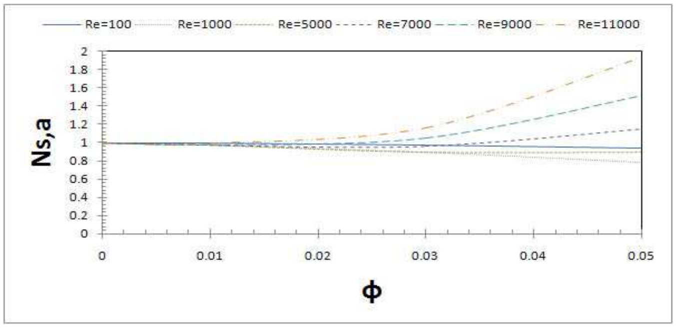

Fig. 4. Augmentation Entropy generation number in laminar flow versus volume concentration

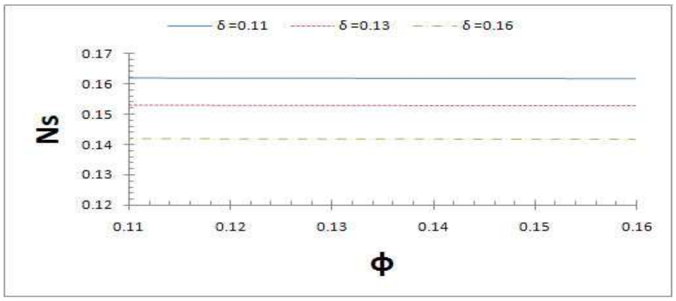

Fig. 5. Augmentation entropy generation number in laminar flow versus ϕ in deferent δ

$(\mathrm{Re} < 5000)$, the augmentation entropy generation number declines linearly. By increasing the Re number at $\mathrm{Re} = 7000$ the effects of fluid flow irreversibility becomes more important and the advantageous of decreasing heat transfer irreversibility is wasted by increasing the fluid flow irreversibility.

Fig. 5 illustrates the entropy generation number versus volume concentration number in laminar flow where helical tube radius ratio δ ranges from 0.11 to 0.16. It can be seen that Ns decrease with the increase of δ at fixed volume concentration.

VI. CONCLUSION

In present paper, entropy generation of the nanofluids flow through a helical tube under constant wall heat flux is investigated. Based on the results obtained in this paper it can be concluded that in the sense of thermodynamic performance, adding nanoparticles to the base fluid is efficient only when the heat transfer irreversibility is dominant. In laminar flow of EG-Al_2O_3 nanofluid, it is found that in $\mathrm{Re} = 3000$ the entropy generation is optimized for each specified nanoparticle volume concentration. Entropy generation decrease with the increase of δ at fixed volume concentration also at fixed δ, with increasing of volume concentration, entropy generation almost remain constant.

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