ENTROPY GENERATION OF PSEUDO-PLASTIC NON-NEWTONIAN NANOFLUIDS IN CIRCULAR DUCT UNDER CONSTANT WALL TEMPERATURE

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ABSTRACT

In this paper the second law analysis of thermodynamic irreversibilities in pseudo-plastic non-Newtonian nanofluids through a circular duct under uniform wall temperature thermal boundary have been carried out for laminar flow condition. This nanofluid consists of sodium carboxymethyl cellulose (CMC)–water and two different types of nanoparticles; namely, CuO and Al_2O_3*. Entropy generation is obtained for various Power law number, various volume concentration of nanoparticles, various dimensionless temperature and various Reynolds number. It is found that with the decreasing Power law number and duct length values, total entropy generation at fixed Reynolds number decreases and with increasing wall temperature values, total entropy generation increases, also entropy generation decreases with increasing volume concentration of nanoparticles.*

KEYWORDS: *Entropy generation; Non –Newtonian fluid; Power law number; Laminar flow.*

1.0 INTRODUCTION

Improvement of convective heat transfer is very important for many thermo-fluid systems. The heat convection can passively be enhanced by fluid thermo physical properties. One way of improving the thermal conductivities of fluids is to suspend small solid particles in the fluid. Pak and Cho (1998) presented an experimental investigation of the convective turbulent heat transfer characteristics of Al2O3 nanofluids. The heat transfer for the nanofluids increases with the increase of volume concentration and Reynolds number.

Masuda et al. (1993) showed that the viscosity and the thermal conductivity of liquids are changed by dispersing very-fine particles of some nanoparticles like Al2O3, SiO2 and TiO2 .

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Das et al. (2003) have investigated the increase of thermal conductivity with temperature for water- Al2O3 and water-CuO nanofluids by the temperature oscillation technique.

Entropy generation or exergy destruction is very important for design of thermo-fluid devises and for optimization, entropy generation must be decreased. For minimizing the entropy generation inside a duct has been extensively studied (Bejan, 1996, 1972, 1996a, 1996b). Oztop et al. (2009) have investigated the entropy generation in rectangular ducts with semicircular ends cross section with two boundary conditions: constant wall temperature and constant wall heat flux. Ozotop et al. (2009) investigated the entropy generation in for hexagonal duct ducts with constant heat flux boundary condition. Also, entropy generation in ducts with various cross sectional geometries under constant wall heat flux and laminar flow investigated by Sahin, (1996, 1998a, 1998b). Falahat and Vosough (2012) computed entropy generation in a coiled tube under constant heat flux for both laminar and turbulent regimes using alumina–water nanofluids. They found that by adding 1% volume fraction of nanoparticles to the base fluid, entropy generation decreases about 3% in laminar flow. Also, they obtained an optimal Reynolds number for the turbulent flow for which the entropy generation was minimized. Falahat (2011) made a study on entropy generation in s confocal elliptical ducts under constant heat flux. Moghaddami et al. (2011) obtained optimum Reynolds number which minimized entropy generation for water–Al2O3 and ethylene glycol-Al2O3 nanofluids using a circular tube under constant heat flux.

The main aims of this work to investigate a second law analysis for forced convection of non-Newtonian nanofluids in circular cross section duct with constant wall temperature boundary condition. This base fluid is CMC–water with two different types of nanoparticles: CuO and Al2O3.The effects of power-law nanofluids viscosity, Reynolds number, nanoparticles volume fraction, dimensionless temperature and length of pipe on entropy generation are investigated.

2.0 METHODOLOGY

2.1 Physical model and thermo physical properties of non-Newtonian nanofluids

A geometrical configuration of the present problem has been shown in Figure 1. The geometries consist of circular duct with constant wall temperature. The flow in this work is considered laminar, steady, fully developed and incompressible.

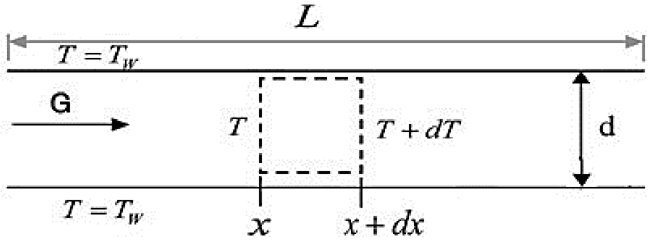

Figure 1. Geometrical configuration

The nanofluid in this channel is non-Newtonian and assumed that the fluid phase and nanoparticles are in the thermal equilibrium state and they flow with the same velocity. The CMC–water with low concentration (0.1–0.4%) is used as a base fluid of the nanofluid. The viscous properties of the CMC–water are given in Table 1. Jin et al. (2000) have shown that the thermo physical properties of the CMC–water (<6%) is similar to water. n is the Power-law number of the non-Newtonian base fluid. For Newtonian fluid, n equals 1, n < 1 is descriptive of the pseudo-plastic fluid while n > 1 describes the Dilatant fluid.

Table 1. Viscous properties of CMC–water (Jin et al., 2009)

Physical property	n	m
CMC-water (0.0%)	1.00	0.000855
CMC-water (0.1%)	0.91	0.006319
CMC-water (0.2%)	0.85	0.017540
CMC-water (0.3%)	0.81	0.0313603
CMC-water (0.4%)	0.76	0.0785254

Thermo physical properties of the nanofluid are obtained from the flowing relations is available in the literature, as discussed by Khanafer et al. (2003).

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

$$(\rho c_p)_{nf} = (1-\phi)(\rho c_p)_{bf} + \phi(\rho c_p)_p \tag{2}$$

$$\frac{k_{nf}}{k_{bf}} = \frac{k_p + 2k_{bf} - 2\phi(k_{bf} - k_p)}{k_p + 2k_{bf} + \phi(k_{bf} - k_p)} \tag{3}$$

$$\mu_{nf} = \frac{\mu_{bf}}{(1-\phi)^{2.5}} \tag{4}$$

Table 2. Thermophysical properties of pure fluid and nanoparticles (Santra et al, 2008; Raptis et al, 2004)

Physical properties	CMC-water (0.0-0.4%)	Al_2O_3	CuO
C_P(J/kg K)	4179	765	535.6
ρ (kg/m^3)	997.1	3970	6500
k (W/m K)	0.613	40	20

2.2 Mathematical Modeling

On the basis of average heat transfer and fluid friction, the equation of entropy generation rate is presented by Sahin (1998) as follows:

$$\dot{S}_{gen} = GC_p \left[\ln\left(\frac{1-\theta.e^{-4St.N_L}}{1-\theta} \right) - \theta(1-e^{-4St.N_L}) + \frac{f\,\theta Ec}{8St} \ln\left(\frac{e^{4St.N_L}-\theta}{1-\theta} \right) \right] \tag{5}$$

Where, the non-dimensional entropy generation number Ns can be defined as

$$Ns = \frac{\dot{S}_{gen}}{\dot{Q}/\Delta T} = \frac{\dot{S}_{gen}}{GC_P} \tag{6}$$

In above equations some dimensionless parameters can be defined as

$$St = \frac{h}{\rho U C_P} \tag{7}$$

$$Ec = \frac{U^2}{C_P(T_w - T_i)} \tag{8}$$

$$\theta = \frac{T_w - T_i}{T_w} \tag{9}$$

$$N_L = \frac{L}{d} \tag{10}$$

For Power-Law model, average velocity, friction factor, Reynolds number (Coulson, and Richardson, 1999) and Nusselt number (Chhabra and Richardson, 2008) are defined as

$$U = \left[\frac{n}{3n+1} \right] \left[\frac{d}{4m} . \frac{f\rho U^2}{2d} \right]^{1/n} \left(\frac{d}{2} \right) \tag{11}$$

$$f = \frac{64}{\text{Re}} \tag{12}$$

$$\text{Re} = \frac{\rho U^{2-n} d^n}{8^{n-1} m \left(\frac{3n+1}{4n} \right)^n} \tag{13}$$

$$Nu = 1.75 \left[\frac{3n+1}{4n} \right]^{\frac{1}{3}} \left[\frac{GC_{Pnf}}{K_{nf}\,L} \right]^{\frac{1}{3}} \tag{14}$$

3.0 RESULTS AND DISCUSSIONS

The effect of the Power-law Number, volume concentration of nanoparticles, Reynolds number and length of duct for different nanofluids on the dimensionless entropy generation are investigated in circular duct under constant wall temperature. The surface temperature of duct is 350K.

The present results was also validated against the results of Sahin, 2008. Figure 2 shows the total dimensionless entropy generation of water with respect to Reynolds number. It can be seen from the comparison that both solutions are in a good agreement with each other. Two reasons for the discrepancies are due to different thermo physical properties and different Nusselt number. Sahin (2008) used Nusselt number for tube under constant wall temperature (Nu=3.66) but the present study utilized the Equation (14).

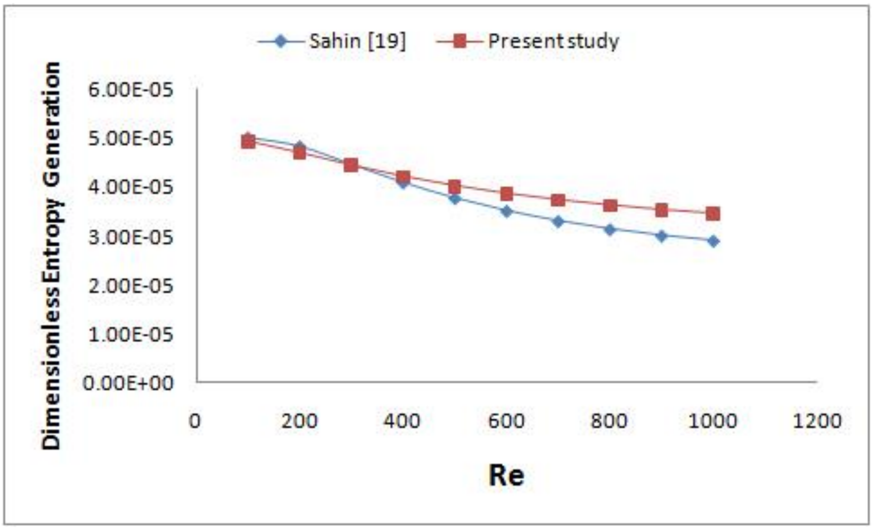

Figure 2. Comparing the present results with the results of Sahin 2008 (n=1, θ=0.01 and φ=0)

The effect of Power-law Number and volume concentration of Al_2O_3 nanoparticles on dimensionless entropy generation have been shown in Figure 3. It can be seen that dimensionless entropy generation decreases with decrease of Power-law Number in fixed volume concentration of nanoparticles and also it decreases with increase of volume concentration of nanoparticles.

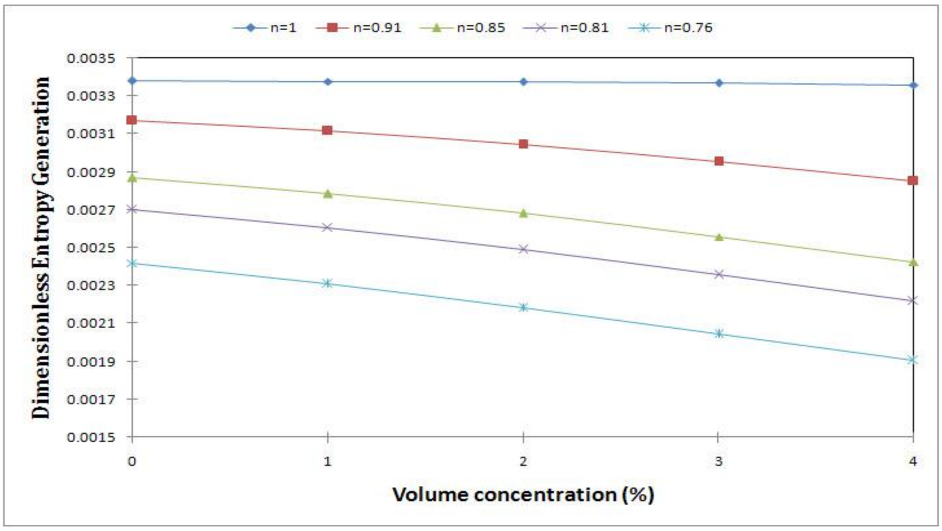

Figure 3. The effect of n and volume concentration of Al2O3 on dimensionless entropy generation (θ=0.08, Re=500)

Figure 4 shows the effect of dimensionless temperature and volume concentration of nanoparticles on dimensionless entropy generation. As the dimensionless temperature increases, the dimensionless entropy generation increases for each volume concentration of nanoparticles. Also, entropy generation decrease with increase of volume concentration of nanoparticles for each dimensionless temperature.

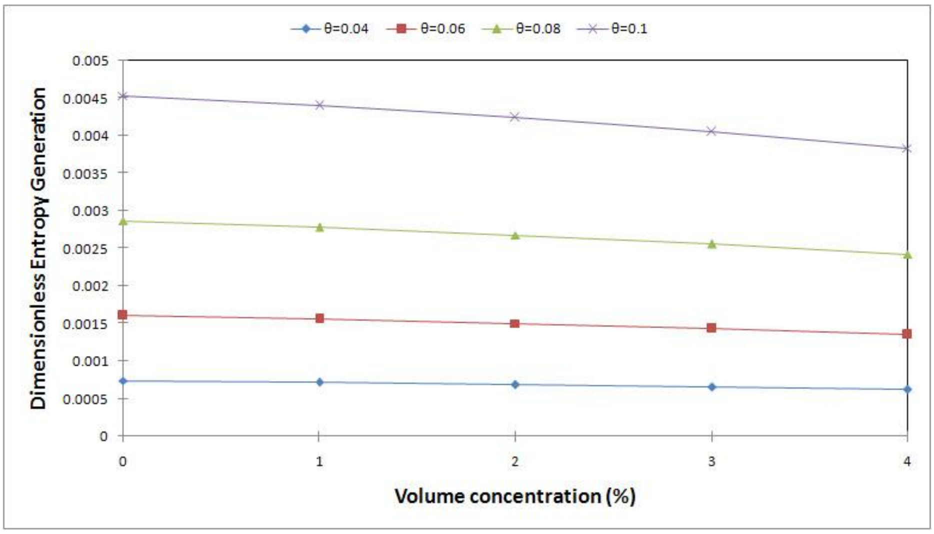

Figure 4. The effect of dimensionless temperature and volume concentration of Al2O3 on dimensionless entropy generation (n=0.85, Re=500)

Figure 5 shows the effect of Reynolds number and nanoparticles volume fraction on dimensionless entropy generation. It can be seen that dimensionless entropy generation decreases with the increase of Reynolds number for each nanoparticles volume fraction.

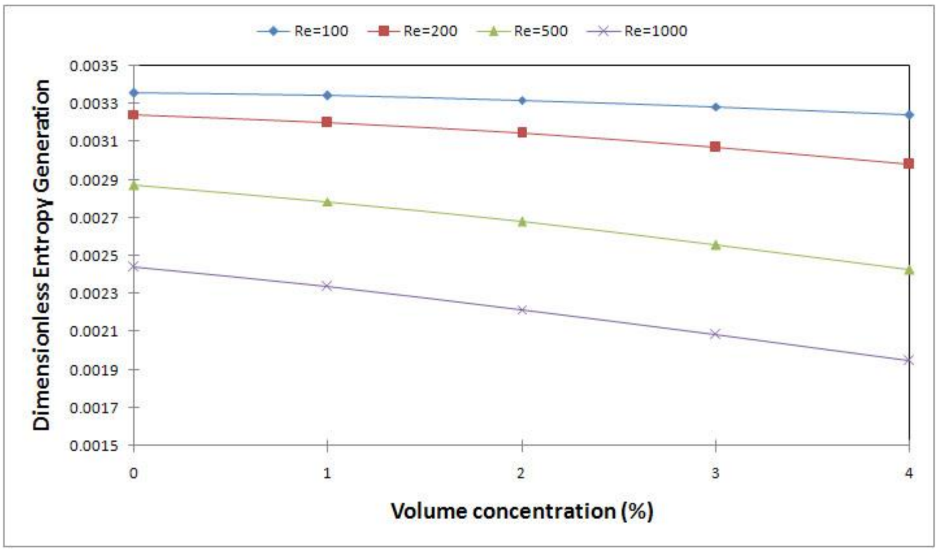

Figure 5. The effect of Reynolds number and volume concentration of Al_2O_3 on dimensionless entropy generation (n=0.85, θ=0.08)

Figure 6 shows the effect of different nanoparticles types (Al_2O_3 and CuO) and volume concentration of nanoparticles on dimensionless entropy generation. When volume concentration of nanoparticles is increased, the dimensionless entropy generation decreases in two nanoparticles types. The CuO /CMC-Water nanofluid with higher volume fraction of nanoparticles and higher volume of CMC may be a good choice as a working fluid because of their dimensionless entropy generation rate is lower than the Al_2O_3/CMC-Water nanofluids.

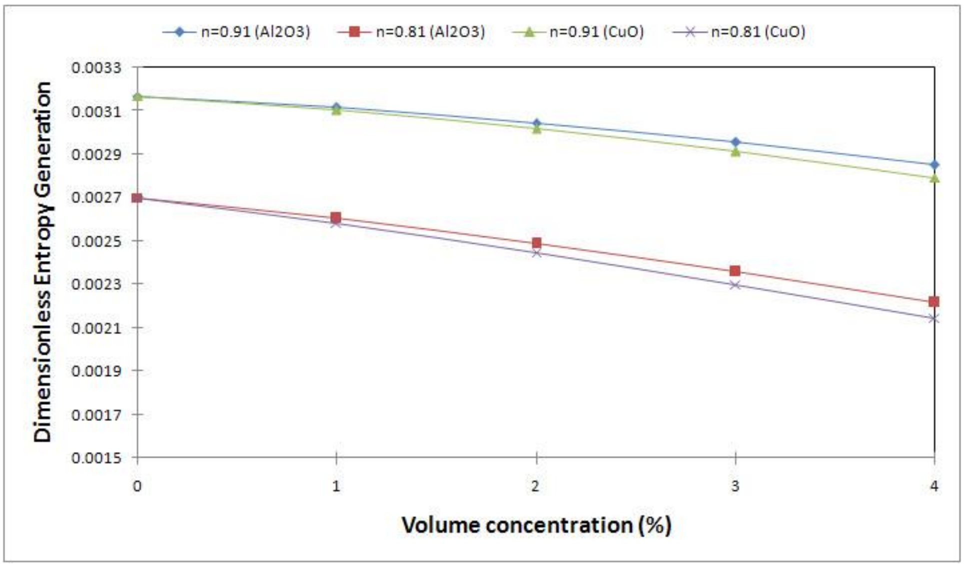

Figure 6. The effect of Power law number and volume concentration of Al2O3 and CuO on dimensionless entropy generation (Re=500, θ=0.08)

Figure 7 shows the effect of length of duct and nanoparticles types on dimensionless entropy generation for fixed volume concentration of nanoparticles. It can be seen that dimensionless entropy generation increases with the increase of duct length for each type of nanoparticles, because by increasing of length of duct thermal irreversibility increases.

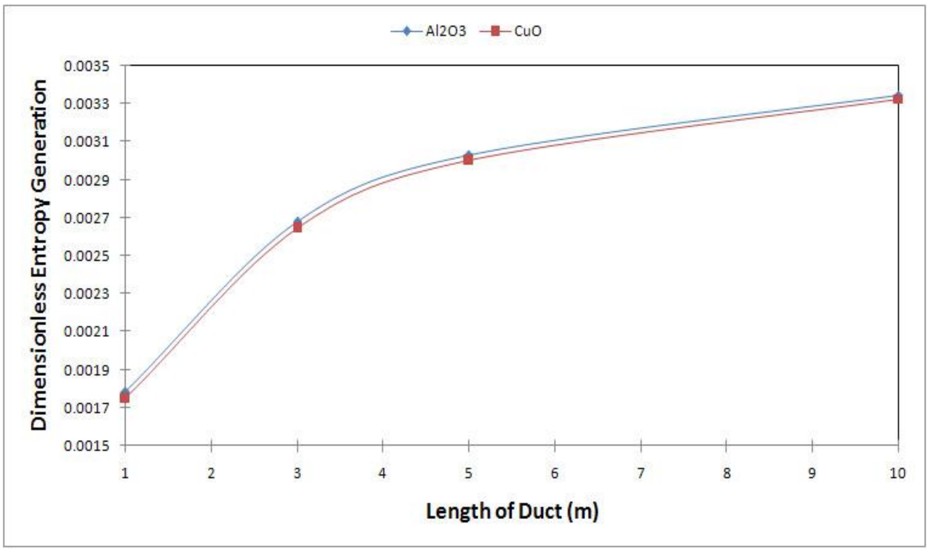

Figure 7. The effect of length of duct and nanoparticles types on dimensionless entropy generation (n=0.85, θ=0.08, φ=2% and Re=500)

4.0 CONCLUSIONS

In this study second law analysis of laminar flow of pseudo-plastic non-Newtonian nanofluids has been obtained for circular duct under uniform wall temperature thermal boundary. Some conclusions can be given as follows:

- Dimensionless entropy generation decreases with increasing of volume concentration of nanoparticles and Reynolds number.
- As the Power-law Number decreased, dimensionless entropy generation decreases for each volume concentration of nanoparticles.
- Dimensionless entropy generation increases with the increase of dimensionless temperature and increase of duct length for each type of nanoparticles.
- Dimensionless entropy generation of CuO /CMC-Water nanofluids is lower than the Al_2O_3/CMC-Water nanofluids.
- Dimensionless entropy generation increases with the increase of duct length for each type of nanoparticles.

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NOMENCLATURE

C_P	specific heat , *kJ/kg K*
d	diameter, *m*
f	friction factor
G	mass flow rate, *kg/s*
h	heat transfer coefficient, $W/m^2 K$
k	thermal conductivity of the fluid, *W/m K*
L	length of coiled tube, *m*
m	Power law consistency
n	Power law index
Nu	Nusselt number
N_L	Dimensionless length
Pr	Prandtl number
Re	Reynolds number
S	specific entropy, *kJ/kg K*
T	temperature, K
x	local position along the flow direction, *m*

Greek symbols

μ	viscosity of the fluid, *Pa.s*
ρ	density, kg/m^3
φ	nanoparticles volume fraction
θ	dimensionless temperature

subscripts

bf	base fluid
nf	Nanofluid
p	particles
w	Wall