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# Exergy Destruction of Forced Convective (Ethylene Glycol+Alumina) Nanofluid Through a Duct with Constant Wall Temperature in Contrast to (Ethylene Glycol) Fluid

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**Abstract:** In the present study, the exergy transfer characteristics of (Ethylene glycol+ Alumina) nanofluid and Ethylene glycol fluid flow through a circular duct with constant wall temperature for hydrodynamic and thermally fully developed laminar flow have been considered. To examine the exergy transfer rate, the nanofluid is assumed to be single phase and the effects of nanoparticles enter in the physical characteristics of base fluid. The basis of single phase model is the fact that solid particles in nanofluid are ultra fine(less than 100 nm) and are easily fluidized. In this manner, nanofluid can be treated as a pure fluid. Volume fraction of nanoparticle assumed to be 0.1 in nanofluid and zero in pure fluid. The Results show that exergy destruction in nanofluid is higher than base fluid. But there is a maximum point of exergy loss along the duct and after that, exergy destruction, decreases.

**Key words:** Nanofluid, exergy transfer, force convection, exergy destruction, ethylene glycol+alumina

## INTRODUCTION

Recent investigations on nanofluids indicate that nanoparticles change the base fluid characteristics. Nanofluids are produced by dispersing nanometer particles in base fluids, such as water, Ethylene glycol and etc.

Alumina and copper oxide are the most common and inexpensive nanoparticles used in experimental investigations.

Lee *et al.* (1999) suspended CuO and $AL_2O_3$ (18.6 and 23.6, 24.4 and 38.4 nm) with two different base fluids, water and ethylene glycol (EG) and obtained four combinations of nanofluids. Results showed that nanofluids have substantially higher thermal conductivities than the base fluids. Maiga *et al.* (2004) investigated the thermal characteristics of nanofluids flowing through a heated duct. Results showed that (ethylene glycol+alumina) provided higher heat transfer enhancement than (water+alumina).

Wang *et al.* (1999) measured the relative viscosity of (ethylene glycol+alumina) nanofluid. Results showed that relative viscosity increase with increasing solid volume fraction. Das *et al.* (2003) considered the effect of temperature on thermal conductivity of nanofluids containing Alumina (38.4 nm) nanoparticles. He changed the temperature from 21 to 52°C and observed that the ratio of the thermal conductivity increasing is 2 to 4.

Li and Peterson (2006) investigated the effects of variations in the temperature and volume fraction on (water+alumina) thermal conductivity. Results demonstrated that diameter, volume fraction and temperature variation, have large effect on nanofluid thermal conductivity. Heris *et al.* (2006) investigated the (water+Alumina) nanofluids flow through a duct with constant wall temperature. Results showed that with increasing volume fraction of nanoparticles, heat transfer coefficient increases.

Pulm *et al.* (2006) considered the laminar forced convection flow of metallic nanofluids between two coaxial and parallel disks. Their results indicate that considerable heat transfer benefits are possible with the use of fluid-solid particle mixtures.

Anoop *et al.* (2009) investigated the convective heat transfer characteristics of (water+alumina)nanofluids with two various particle sizes. It was observed that both nanofluids showed higher heat transfer characteristics than the base fluid and the nanofluid with 45 nm particles showed higher heat transfer coefficient than that with 150 nm particles.

Khoddamrezaee *et al.* (2010) studied the characteristics of ($EG+AL_2O_3$) nanofluid and (EG) fluid which cross a rectangular arrangement of tubes in a shell and tubes heat exchanger. Results show that by using of nanofluid, the stagnation and separation points of flow were postponed and the amount of heat transfer coefficient increases.

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Since, all nanofluids studies is about heat transfer and physical properties, in this article the exergy transfer characteristics of (ethylene glycol+alumina) as a well known nanofluid has been considered and compared with the base fluid (Ethylene glycol).

Exergy is a thermodynamic concept which enables us to articulate what is consumed by working system. In other words, Exergy is the energy that is available to be used. After the system and surroundings reach equilibrium, the exergy transfer is zero. Assume a cooling system as a control volume under the thermally steady state. According to the law of energy conservation, the amounts of energy flowing in and out are equal but the amounts of exergy flowing out is smaller than flowing in and the output entropy increase. So, in the energy transfer processes like heat transfer, a part of the exergy is consumed. The amount of decreased exergy is proportional to entropy generation and ambient temperature. Exergy consumed is the product of entropy generated and environmental temperature.

Exergy is the one of important parameters to increase the system efficiency. Numerous studies on the energy and exergy analysis of thermal systems have been done by some researchers. But, to the best of our knowledge, there is no information on the exergy analysis of nanofluid as a working fluid in a duct.

The purpose of this research is study the effect of alumina nanoparticle in the energy and exergy characteristics of Ethylene glycol in a duct with constant wall temperature.

## PHYSICAL MODELING

Force convective flow of (ethylene glycol+alumina) nanofluid in a constant cross-sectional circular duct, have been considered. The wall temperature $T_w$ keeps constant. As shown schematically in Fig. 1, $T_{fi}$ is the inlet bulk temperature and the outlet bulk temperature is $T_{fo}$. The inner diameter is $d_i$ and tube length is L. To consider the exergy transformation due a duct, assume a differential element like in Fig. 1 with inlet exergy ($E_X$) and outlet exergy ($E_{X+dX}$).

**Physical properties of nanofluid:** The general Equation of two-phase mixture is used to calculate the density and specific heat transfer coefficient.

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

$$Cp_{(nf)} = (1-\phi)Cp_{(bf)} + \phi.Cp_{(p)} \tag{2}$$

where, $\phi$ is defined as volume fraction of nanoparticles in base fluid. (nf) index refers to nanofluid and (bf) to base fluid.

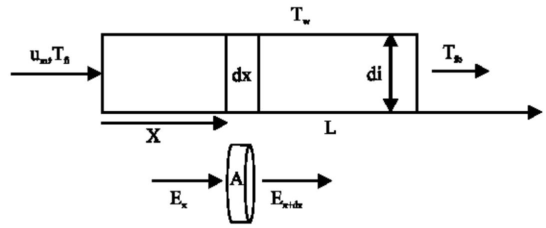


Fig. 1: Tube schematic and inlet flow

In this study base fluid is Ethylene glycol and nanofluid is ($EG+AL_2O_3$).

The dynamic viscosity of nanofluid has been proposed by Batchelor (1977). He considered the effect of Brownian motion of spherical particles on the dynamic viscosity.

$$\mu_{(nf)} = [6.5\phi^2 + 2.5\phi + 1]\mu_{(bf)} \tag{3}$$

Conduction heat transfer coefficient has been obtained by using model:

$$K_{(nf)} = [\frac{K_P + 2K_b + 2(K_P - K_b)\phi}{K_P + 2K_b - (K_P - K_b)\phi}]K_{(bf)} \tag{4}$$

## SOLUTION METHODOLOGY

Two approaches have been used in the literature to simulate nanofluids. The first approach assumes that the continuum assumption is still valid for fluids with suspended nano size particles. The other approach uses two-phase model for better description of both the fluid and the solid phases. In this study, Due to the very small size of particles, it may be reasonable that such a mixture can be easily fluidized and therefore the slip velocity between the phases is negligible. Also, by considering the local thermal equilibrium, the tow-phase mixture may be considered as a conventional single-phase fluid with modified physical properties.

The exergy transfer equations of convective heat transfer may be written as follows on the basis of the linear non-equilibrium thermodynamics theory:

$$E = h_{e(nf)}.A.\Delta T_{(nf)} \tag{5}$$

$$e = \frac{E}{A} = h_{e(nf)}.\Delta T_{(nf)} \tag{6}$$

where, E is defined as exergy transfer rate, A is peripheral area of element. e is exergy flux, $h_{e(nf)}$ is conventional exergy transfer rate coefficient of nanofluid and $\Delta T_{nf}$ is defined as:

$$\Delta T_{(nf)} = \frac{T_{fo} - T_{fi}}{\ln(\frac{T_w - T_{fi}}{T_w - T_{fo}})} \quad (7)$$

The bulk temperature variation of the fluid along the duct can be obtained as:

$$T_{fx(nf)} = T_w - \Delta T_i.\exp(-4St_{(nf)}.\frac{x}{d_i}) \quad (8)$$

Where:

$$\Delta T_i = T_w - T_{fi} \quad \text{and} \quad St_{(nf)} = \frac{h_{(nf)}}{\rho_{(nf)}.Cp_{(nf)}} \quad (9)$$

From Eq. 8 for nanofluid outlet temperature we have:

$$T_{(fo)} = T_w - \Delta T_i.\exp(-4St_{(nf)}.L), \quad L = \frac{1}{d_i} \quad (10)$$

Substitute Eq. 10 into the Eq. 7:

$$\Delta T_{(nf)} = \frac{\Delta T_i(1 - \exp(-4St_{(nf)}.L)}{4St_{(nf)}.L} \quad (11)$$

The exergy transfer rate over a differential element of length dx is given by Wu *et al*. (2007):

$$dE_{nf} = h_{ex(nf)}.dA.\Delta T_{x(nf)} \quad (12)$$

$$dA = \pi d_i dx$$

Using the specific exergy transfer rate definition:

$$de'_{nf} = dh_{nf} - T_0.ds_{nf} \quad (13)$$

and from thermodynamic equation:

$$Tds_{nf} = dh_{nf} - \nu.dp_{nf} \quad (14)$$

rearranging Eq. 13 by 14 one obtains:

$$de'_{nf} = (dh(1 - \frac{T_0}{T_f}) - \nu\frac{T_0}{T_f}dp)_{nf} \quad (15)$$

$$de'_{nf} = C_{p(nf)}(1 - \frac{T_0}{T_f})dT + \frac{\nu}{T_f}T_0 dp \quad (16)$$

Thus, exergy transfer rate of nanofluid over the element is:

$$dE_{nf} = G[C_p(1 - \frac{T_0}{T_f})dT + \frac{\nu}{T_f}T_0 dp]_{nf} \quad (17)$$

From Eq. 12 and 17:

$$h_{ex(nf)} = GC_{p(nf)}.\frac{1}{(T_w - T_{fx})\pi d_i}(1 - \frac{T_0}{T_f}) .\frac{dT_f}{dx} + G\frac{\nu}{T_{fx}}\frac{1}{(T_w - T_{fx})\pi d_i}T_0\frac{dp}{dx} \quad (18)$$

Where:

$$\frac{dp}{dx} = -\frac{f.u_m^2}{2d_i}\rho_{nf} \quad (19)$$

$$f = 64/(Re_{nf}) \quad (20)$$

Putting Eq. 8 and 19 into Eq. 18 gives:

$$h_{ex(nf)} = h_{(nf)}(1 - \frac{T_0}{T_w - \Delta T_i.\exp(-4St_{(nf)}.\frac{x}{d_i})} - \frac{fU^3}{8}\frac{T_0}{\Delta T_i.T_w}.\frac{1}{\exp(-4St_{(nf)}.\frac{x}{d_i})}.\frac{1}{1 - (\frac{\Delta T_i}{T_w})\exp(-4St_{nf}.\frac{x}{d_i})} \quad (21)$$

Combining Eq. 6 and 21, the local exergy flux becomes:

$$h_{ex(nf)} = h_{(nf)}(1 - \frac{T_0}{T_w - \Delta T_i.\exp(-4St_{(nf)}.\frac{x}{d_i})} - \frac{fU^3}{8}\frac{T_0}{\Delta T_i.T_w}.\frac{1}{\exp(-4St_{(nf)}.\frac{x}{d_i})}.\frac{1}{1 - (\frac{\Delta T_i}{T_w})\exp(-4St_{nf}.\frac{x}{d_i})} \quad (22)$$

## HEAT TRANSFER ANALYSIS OF FORCED CONVECTIVE NANOFLUID

The local and mean heat fluxes of flow pass through a duct with constant wall temperature condition are:

$$q_x = h.\Delta T_x = h_{nf}(T_w - T_{f(nf)}) = h_{nf}\Delta T_i \exp(-4St_{nf}.\frac{x}{d_i}) \quad (23)$$

$$q = \frac{1}{l}\int_0^l h_{nf}(T_w - T_{f(nf)})dx = \frac{T_0 K_{nf}}{L}\frac{Re_{nf}Pr_{nf}}{4}\frac{\Delta T_i}{T_0}(1 - \exp(-4St_{nf}L) \quad (24)$$

## BOUNDARY CONDITION

All conditions for (Ethylene glycol+Alumina) and (Ethylene glycol) flow are equal. The length and inner diameter of duct are 3 and 0.02 m. The inlet temperature of fluid and nanofluid is 303 K and the surrounding temperature is 298 K. Volume fraction of Alumina in Ethylene glycol is 0.1 and the diameter of nanoparticles is $10^{-9}$ m. Note that there is no limitation for compressible or incompressible flow. Also the flow is steady and laminar.

$$K_{EG} = 0.252(W/m^2.k),\ Cp_{EG} = 2415(J/kg.k),\ \rho_{EG} = 1111.4(kg/m^3)$$
$$\mu_{EG} = 0.0157(kg/m.s),\ K_{AL2O3} = 46(W/m^2.k),\ Cp_{AL2O3} = 765(J/kg.k)$$
$$\rho_{AL2O3} = 3970(kg/m^3),\ \phi = 0.1$$

## RESULTS AND DISCUSSION

Exergy and energy transfer characteristics of (Ethylene glycol+ Alumina) nanofluid and Ethylene glycol laminar fluid flow through a circular duct with constant wall temperature have been considered in equal boundary condition. Figure 2 and 3 show the variation of exergy and heat transfer rate with volume fraction of alumina nanoparticle in Ethylene glycol. Results show that by increasing the volume fraction of particles, the values of both of heat and exergy transfer, increase. The inclines of curves reduce and fix by increasing in volume fraction. It means that the quantity of heat and exergy transfer increasing is higher in fewer volume fractions. The exergy transfer of a system in the stable surrounding temperature is proportional with the antropy conversion. So, results show that by increasing in volume fraction of nanoparticles, the entropy variation of system increases. Figure 4 and 5 compare the variation of exergy flux with X and Re for pure fluid and nanofluid. In both charts amount of exergy waste increase first and then decrease. Thus there is an optimum value for the pipe length. After the maximum point the value of exergy loss decreases and thermal design is done in this area. Also, by increasing the Reynolds number in both of nanofluid and pure fluid, length of maximum exergy loss is increased. As figures show, although the exergy loss in nanofluid is higher than base fluid but in the shorter length exergy loss reaches to maximum point and then decreases. However in general exergy loss rate in nanofluid is higher than base fluid but due to high heat transfer rate, higher exergy loss is neglected.

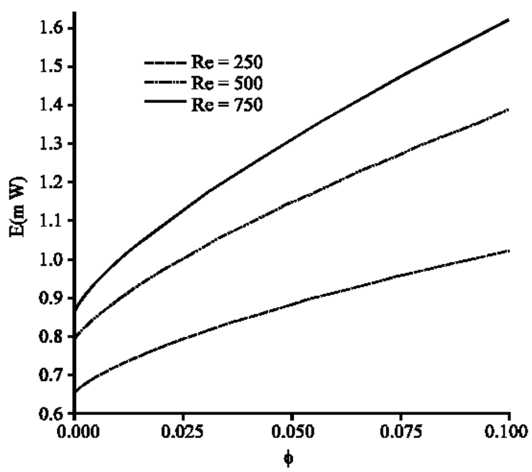


Fig. 2: Variation of Exergy and heat transfer with volume fraction ($\phi$) and Reynolds number for (Ethylene glycol+ Alumina)

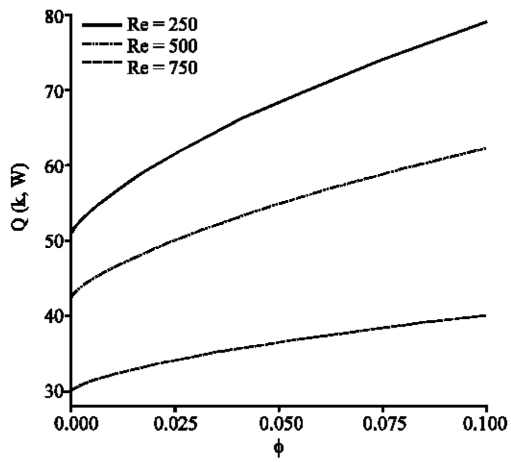


Fig. 3: Variation of heat transfer with volume fraction ($\phi$) and reynolds number for (ethylene glycol+ alumina)

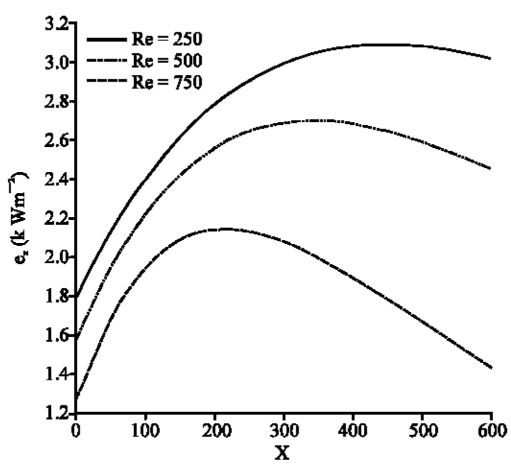


Fig. 4: Variation of Exergy flux and tube length with Reynolds number for (Ethylene glycol)

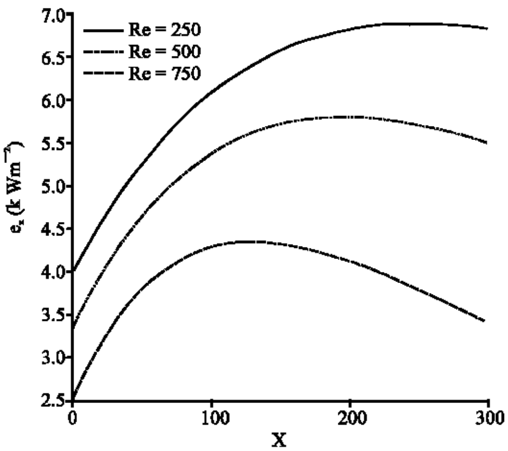


Fig. 5: Variation of energy flux and tube length with Reynolds No. for (ethylene glycol+ alumina)

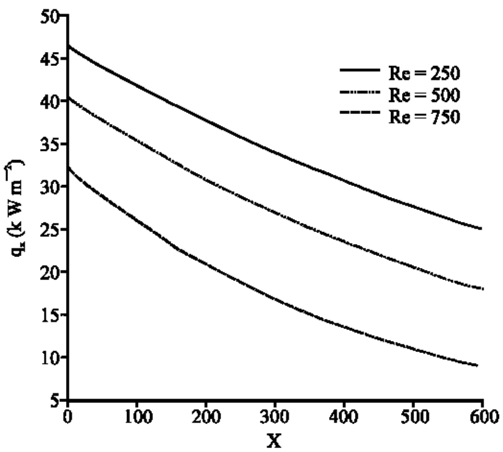


Fig. 6: Variation of heat flux and tube length with Reynolds number for (Ethylene glycol)

Figure 6 and 7 compare the value of nanofluid and base fluid heat transfer. As results show nanofluid rate of heat transfer increased more than 2 times.

Figure 8 show the ethylene glycol Exergy transfer with various wall temperatures. Comparing it with Fig. 9 shows that by using higher wall temperature, exergy loss increases in both nanofluid and pure fluid cases.

But the effect of wall temperature in nanofluid is more than base fluid. In both cases, the value of exergy losses can be reducing with increasing duct length.

The variation of exergy flux versus Reynolds number is shown in Fig. 10 and 11 for base fluid and nanofluid. Results indicate that by increasing in Reynolds number, the value of exergy loss increases too.

Figure 12 and 13 shows that nanofluid heat flux is higher than pure fluid more than 2 times and confirm the results of other researchers.

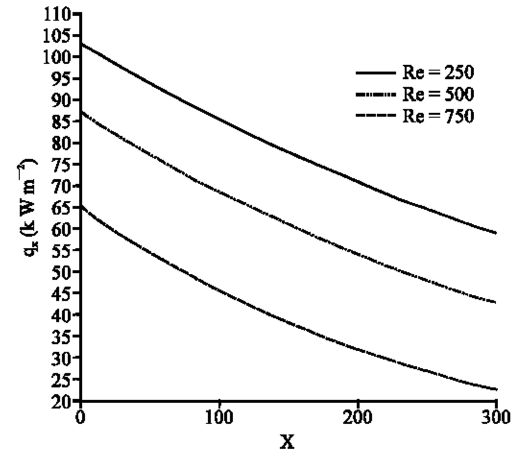


Fig. 7: Variation of heat flux and tube length with Reynolds number for (Ethylene glycol +alumina)

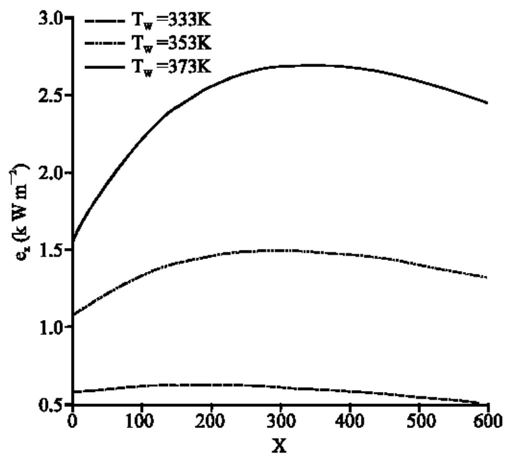


Fig. 8: Variation of exergy flux and tube length with wall temperature for (Ethylene glycol)

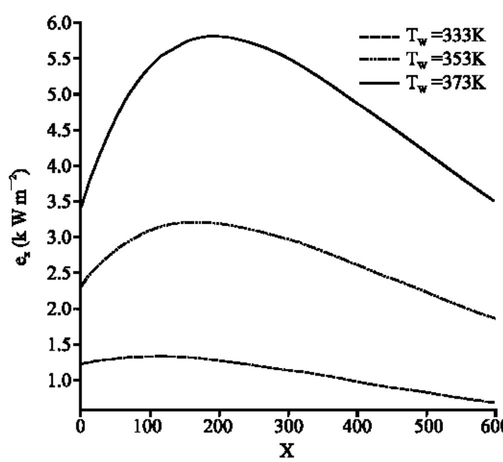


Fig. 9: Variation of exergy flux and tube length with wall temperature for (Ethylene glycol +Alumina)

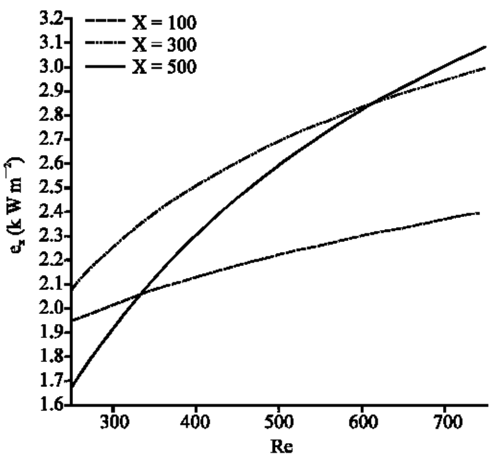


Fig. 10: Variation of exergy flux and Reynolds number with tube length for (Ethylene glycol)

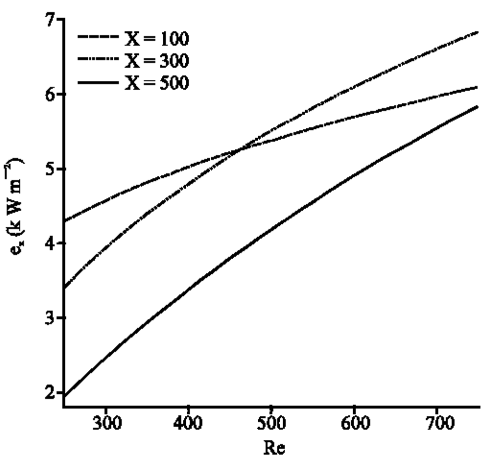


Fig. 11: Variation of exergy flux and Reynolds number with tube length for (Ethylene glycol +Alumina)

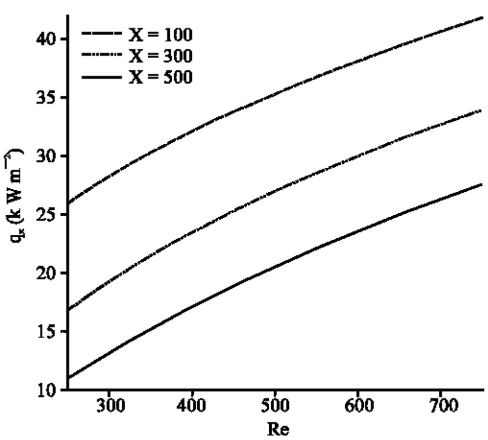


Fig. 12: Variation of heat flux and Reynolds number with tube length for (Ethylene glycol)

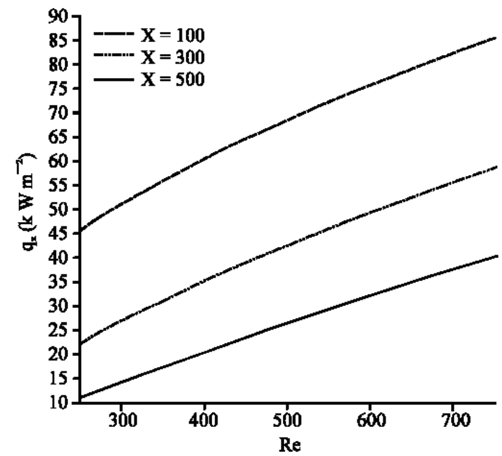


Fig. 13: Variation of heat flux and Reynolds number with tube length for (Ethylene glycol +Alumina)

## CONCLUSION

In this study energy and exergy analysis carried out on (ethylene glycol+alumina) nanofluid and (ethylene glycol) fluid, based on mathematical modeling. The results show that in spite of high heat transfer of nanofluid in compare to pure fluid, the exergy destruction in nanofluid is higher than base fluid. The exergy analysis depicts that exergy destruction increases with increasing Reynolds number and wall temperature in both of nanofluid and base fluid. But along duct, there is a maximum point of exergy loss and after this point, exergy destruction decreases.

## NOMENCLATURE

A = Peripheral area (m$^2$)
Cp = Specific heat capacity (J/ kg K)
$d_i$ = Inner diameter of duct (m)
$d_n$ = $10^{-9}$ m (nanoparticles diameter)
e = Exergy flux (W m$^{-2}$)
e' = Specific exergy (J kg$^{-1}$)
E = Exergy transfer rate (w)
f = Friction factor
G = Mass rate (kg sec$^{-1}$)
h = Convective heat transfer coefficient (W/m$^2$K)
$h_{ex}$ = Local exergy transfer coefficient (W/m$^2$K)
k = Thermal conductivity (W/mK)
L = Duct length (cm)
$Pe_d$ = $\rho_{nf}\, u\, d_n\, Cp_{nf} / k_{nf}$
Pr = Prandtl number
q = Heat flux (W m$^{-2}$)
Re = Reynolds No.
s = Specific entropy (J/kg K)

St = Stanton No.
$T_{fi}$ = Inlet bulk temperature (K)
$T_{fo}$ = Outlet bulk temperature (K)
$T_0$ = Surrounding temperature
$T_w$ = Tube wall temperature
$U_m$ = Average fluid velocity (m $sec^{-1}$)
V = Specific volume ($m^3$ $kg^{-1}$)

**Subscripts:**
bf = Basefluid
nf = Nanofluid
I = Inlet
o = Outlet

**Greek letters:**
$\rho$ = Fluid density (kg $m^{-3}$)
$\mu$ = Dynamic viscosity (kg m $sec^{-1}$)
$\varphi$ = Nanoparticle volume fraction

## REFERENCES


Anoop, K.B., T. Sundararajan and S.K. Das, 2009. Effect of particle size on the convective heat transfer in nanofluid in the developing region. Int. J. Heat Mass Transfer, 52: 2189-2195.

Batchelor, G.K., 1977. The effect of Brownian motion on the bulk stress in a suspension of spherical particles. J. Fluid Mech., 83: 97-117.

Das, S.K., N. Putta, P. Thiesen and W. Roetzel, 2003. Temperature dependence of thermal conductivity enhancement for nanofluids. ASME Trans. J. Heat Transfer, 125: 567-574.

Heris, S.Z., S.G. Etemad and M.N. Esfahany, 2006. Experimental investigation of oxide nanofluids laminar flow convective heat transfer. Int. Commun. Heat Mass Transfer, 33: 529-535.

Khoddamrezaee, F., R. Motallebzadeh and D. Jajali Vahid, 2010. Simulation of (EG+$Al_2O_3$) nanofluid through the shell and tube heat exchanger with rectangular arrangement of tubes and constant heat flux. J. Applied Sci., 10: 500-505.

Lee, S., S.U.S. Choi, S. Li and J.A. Eastman, 1999. Measuring thermal conductivity of fluids containing oxide nanoparticles. J. Heat Transfer, 121: 280-289.

Li, C.H. and G.P. Peterson, 2006. Experimental investigation of temperature and volume fraction variations on the effective thermal conductivity of nanoparticle suspensions. J. Applied Phys., 99: 084314-084322.

Maiga, S.E.B., C.T. Nguyen, N. Galanis and G. Roy, 2004. Hydrodynamic and thermal behaviors of a nanofluid in a uniformly heated tube. Computat. Stud., 5: 453-462.

Pulm, S.J., G. Roy and C.T. Nguyen, 2006. Heat transfer enhancement with the use of nanofluids in radial flow cooling systems considering temperature-dependent properties. J. Applied Thermal Eng., 26: 2209-2218.

Wang, X., X. Xu and S.U.S. Choi, 1999. Thermal conductivity of nanoparticle-fluid mixture. J. Thermophys. Heat Transfer, 13: 474-480.

Wu, S.Y., Y.R. Rong, Y. Chen and L. Xiao, 2007. Exergy transfer characteristics of forced convective heat transfer through a duct with constant wall temperature. Int. J. Energy, 32: 2385-2395.