Avrupa Bilim ve Teknoloji Dergisi
Özel Sayı 24, S. 398-404, Nisan 2021

Araştırma Makalesi

www.ejosat.com ISSN:2148-2683

European Journal of Science and Technology
Special Issue 24, pp. 398-404, April 2021

Research Article

Entropy Generation Analysis of a Heat Exchanger Tube with Graphene-Iron Oxide Hybrid Nanofluid

Orhan Keklikcioglu[1*]

[1*] Erciyes Üniversitesi, Mühendislik Fakültesi, Makine Mühendisliği Bölümü, Kayseri, Türkiye, (ORCID: 0000-0002-6227-3130), keklikcioglu@erciyes.edu.tr

(2nd International Conference on Access to Recent Advances in Engineering and Digitalization (ARACONF)-10–12 March 2021)

(**DOI:** 10.31590/ejosat.898765)

ATIF/REFERENCE: Keklikcioglu, O. (2021). Entropy Generation Analysis of a Heat Exchanger Tube with Graphene-Iron Oxide Hybrid Nanofluid. *European Journal of Science and Technology*, (24), 398-404.

Abstract

In this study, the entropy generation analysis of the Graphene-Iron Oxide-Water hybrid nanofluid with six different volumetric fractions in the range of 0.5-1% in a heat exchanger tube under turbulent flow conditions was numerically investigated. The constant surface heat flux was applied to the tube and the Reynolds number was obtained in the range of 10000-50000. The $k-\varepsilon$ RNG solver method was selected for the turbulence method and grid independence was checked. According to the results examining the dimensionless entropy production, entropy production showed a descending trend with the increment of hybrid nanofluid volume fraction. For the dimensionless entropy generation number, which increased with the increasing Reynolds number, configurations above unity were found at the volumetric fractions of 0.5, 0.6, 0.7 and 0.8 %, in addition, all values for entropy generation number with the volume fractions of 0.9 and 1 % were realized below unity up to the Reynolds number of 40000. This result showed that the use Graphene-Iron oxide of hybrid nanofluid in heat exchangers provides great advantages in terms of thermodynamics.

Keywords: Nanofluids, Entropy generation, Heat transfer.

Grafen-Demir Oksit Hibrit Nanoakışkanı Kullanılan Bir Isı Değiştirici Borusunun Entropi Üretim Analizi

Öz

Bu çalışmada, türbülanslı akış koşullarında bir ısı değiştirici borusunda % 0.5-1 aralığında altı farklı hacimsel karışım oranına sahip Grafen-Demir Oksit-Su hibrit nanoyakışkanın entropi üretim analizi sayısal olarak incelenmiştir. Boru üzerine sabir ısı akısı sınır şartı uygulanmış ve Reynolds sayısı çalışma aralığı 10000-50000 olarak belirlenmiştir. Sayısal analizde $k-\varepsilon$ RNG çözüm metodu seçilmiş ve ağ bağımsızlığı çalışması gerçekleştirilmiştir. Boyutsuz entropi üretimini incelendiği sonuçlara göre, entropi üretimi, hibrit nanoakışkan hacimsel karışım oranının artmasıyla düşen bir eğilim göstermiştir. Artan Reynolds sayısı ile artış gösteren boyutsuz entropi üretim sayısı 0,5, 0,6, 0,7 ve 0,8 % hacimsel karışım oranında birim değer üzerinde daha fazla konfigürasyonda gerçekleşirken, 0,9 ve 1 % hacimsel karışım oranlasında entropi üretim sayısı için tüm değerler 40000 Reynolds sayısına kadar birim değerin altında gerçekleşmiştir. Bu sonuç, hibrit nanoakışkanın Grafen-Demir oksitinin ısı değiştiricilerde kullanılmasının termodinamik açıdan büyük avantajlar sağladığını göstermiştir.

Anahtar Kelimeler: Nanoakışkanlar, Entropi üretimi, Isı transferi.

[*] Corresponding Author: keklikcioglu@erciyes.edu.tr

1. Introduction

Heat control in complex engineering systems not only increases the efficient availability of energy, but also extends the life of the whole of these systems or a part in the system, as well as providing operational stabilization. Increasing the performance of heat exchangers, one of the most frequently used engineering systems to provide heat control in thermal systems. For this reason, researchers carry out various studies in order to increase the heat transfer capabilities of heat exchangers. These studies are mostly focused on the techniques known as passive method, which are easy to install, do not require any external energy input, and are used in designing higher efficiency heat exchangers. In addition to passive methods, the use of nanofluids in heat exchangers has been rapidly increasing in recent years. It draws attention to use fluids containing nanoparticles instead of fluids such as water, mono ethylene glycol, propylene glycol, oil, which are the base heat transfer fluids.

The primary goal of the application of nanoparticles in base fluid types is to increase the average heat transfer coefficient by adding nanoparticles with high thermal conductivity coefficient into the fluid. In connection with this goal, removing of the extra thermal load in the systems, increasing the cooling performance and providing heat recovery are secondary goals. In addition to increasing the thermal conductivity of the fluid to which they are added, nanoparticles support turbulence by dispersing in the fluid and contribute positively to heat transfer by increasing the flow surface area (Ozerinc, 2010). Following the favorable results of many studies on the mono use of nanoparticles in base fluids, studies on the use of hybrid nanofluids have also gained importance in recent years. It is aimed to provide a nanofluid model considering the superior thermal and hydraulic properties, and balance the cost caused by nanoparticles that do not have common production but have relatively superior properties. In this study, the Graphene nanoparticle with more extraordinary thermophysical properties and the Iron Oxide nanoparticle with relatively poor thermophysical properties and cost were selected, and a more stable nanofluid model was created in terms of both thermohydraulic performance and cost.

The hybrid nanofluids are the newest type of heat transfer fluids that used to control the heat in thermal systems. Since the hybrid nanofluids very up-to-date, it is very limited in studies on the entropy generation of using the hybrid nanofluids. Ahammed et al. (2016) carried out a study on entropy generation in a minichannel with using Alumina-Graphene hybrid nanofluids in a laminar flow region. It was concluded that the total entropy generation decreased with the increment of Reynolds number and using hybrid nanofluid approximately 20 %. Hussain et al. (2017) conducted a numerical study on entropy generation of Al2O3 – Cu/water in a horizontal channel. It was reported that the increase in loading ratio of nanoparticle in the base fluid caused an increment of total entropy generation. Rahimi et al. (2018) used the SiO2-TiO2/Water-Ethylene glycol (60:40) nanofluid in a square channel. The results showed that the total entropy generation showed a descending trend with the increment of nanofluid volume fraction. A similar study also carried out by Kasaeipoor et al. (2007) on entropy generation of a cavity with refrigerant solid body using MWCNT-MgO/water hybrid nanofluid. The numerical results showed that the volume fraction was one of the effective parameter on total entropy generation. Total entropy generation showed a descending trend with increasing of hybrid nanofluid volume fraction. In another study, Mehrali et al. (2017) experimentally investigated the entropy generation of Graphene-Fe3O4/water hybrid nanofluid in a tube. It was achieved that the total entropy generation reduced up to 40% with using hybrid nanofluid. In another study, Askari et al. (2017) used Fe3O4/Graphene nanoparticles as a hybrid nanofluid with 0.1, 0.2, and 1.0% weight ratios and an enhancement in the thermal conductivity in the range of 14-32% was obtained compared to the water. Shahsavar et al. (2017) numerically investigated the effect of CNTs-Fe3O4 hybrid nanofluid on entropy generation in a counter flow double pipe heat exchanger. It was found that the entropy generation increased with the increment of particle loading. In other study of Shahsavar et al. (2018), the effect of Mn-Zn hybrid nanofluids on entropy generation also investigated witg usin parallel plates. Bahiraei and Heshmatian (2018) used the Graphene-Silver hybrid nanofluids to investigate the cooling performance of electronic processors. It was concluded that the cooling performance was enhanced due to the unique thermophysical properties of Graphene-Silver hybrid nanofluids. Bahiraei and Mazaheri (2018) numerically studied the characteristics of entropy generation of Graphene-Platinum hybrid nanofluids inside a chaotic twisted microchannel. The results indicated that using hybrid nanofluid enhanced the frictional entropy generation, conversely, reduced the thermal entropy generation.

From the literature cited above, several hybrid nanofluid types have been applied in thermal systems to investigate the entropy generation rate. On the other hand, no study has been presented on entropy generation analysis for a heat exchanger tube with Graphene-Iron Oxide with various volume fractions in turbulence flow region in the range of Reynolds number from 10000-50000. Graphene nanoparticle is the first particle used in this study because of its high thermal conductivity (approximately 3000W / mK (Potenza, 2017)) compared to other metal oxide and metal nanoparticles and its higher stabilization ability compared to other nanoparticles (Manikandan, 2019). The Iron Oxide nanoparticle, which is used as a hybrid with the Graphene nanoparticle, is the second preferred metal-oxide nanoparticle, since it is compatible with the Graphene nanoparticle (Yongsheng, 2012).

2. Material and Method

2.1. Numerical method

In this study, a solution was obtained by applying finite volume method in ANSYS Fluent 18 for numerical analysis. The single-phase flow condition has been defined and the k - ε RNG (Re-Normalization Group) model was chosen as the turbulence model, the SIMPLE algorithm was used to evaluate the relationship between pressure and velocity, and the QUICK scheme was used to evaluate convection. The convergence criterion for continuity, velocity, energy, k and ε values is evaluated as $1\text{x}10^{-5}$. The k - ε RNG model, which can provide precise solutions between turbulence models, basically uses three governing equations and these are given in Eqs. 1, 2 and 3, respectively (Fluent, 2016).

Conservation of mass:

$$\nabla(\rho\vec{V}) = 0 \tag{1}$$

Conservation of momentum:

$$\nabla(\rho\vec{V}\vec{V}) = -\nabla P + \nabla(\mu\nabla\vec{V}) \tag{2}$$

Conservation of energy:

$$\nabla\left(\rho c_p \vec{V} T\right) = \nabla(k \nabla T) \quad (3)$$

The transport equations k and ε for RNG solution method is given in Eqs. 4 and 5 for, respectively.

$$\frac{\partial}{\partial t}(\rho k) + \frac{\partial}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}\left(\alpha_k \mu_{eff} \frac{\partial k}{\partial x_j}\right) + G_k + G_b - \rho\epsilon - Y_m + S_k \quad (4)$$

$$\frac{\partial}{\partial t}(\rho\epsilon) + \frac{\partial}{\partial x_i}(\rho\epsilon u_i) = \frac{\partial}{\partial x_j}\left(\alpha_\epsilon \mu_{eff} \frac{\partial \epsilon}{\partial x_j}\right) + C_{1\epsilon}\frac{\epsilon}{k}(G_k + C_{3\epsilon} G_b) - C_{2\epsilon}\rho\frac{\epsilon^2}{k} - R_\epsilon + S_\epsilon \quad (5)$$

The boundary values for the turbulent quantities near the wall are specified with the enhanced wall treatment method. $C_\mu = 0.0845$; $C_{1\varepsilon} = 1.42$; $C_{2\varepsilon} = 1.68$; $\beta = 0.012$; $\eta_0 = 4.38$ constants in the turbulence transport ss (Fluent, 2016).

2.2. Numerical model and boundary conditions

In this study, analyzes were made using the Computational Fluid Dynamics method for the 3-dimensional pipe given in Figure 1. The geometric model consists of a circular pipe consisting of three main parts, the hydrodynamic development section in order to develop the flow in the pipe hydrodynamically, the test section on which constant heat flux is applied, and the exit section to prevent the effects of back flows that will occur at the fluid outlet.

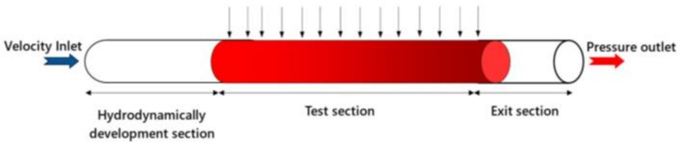

Figure 1. Numerical model

The numerical model given in Figure 1 is designed such that the pipe diameter (D) is 10 mm, the development zone, test zone and exit zone lengths are 100mm (10D), 1000mm and 50mm (5D), respectively. A constant heat flux of 20 kW / m^2 was applied on the test zone and the Reynolds number range was selected as 10000-50000 in order to ensure turbulent flow conditions and to be suitable for the fluid velocity values used in the applications. Graphene-Iron Oxide-Water hybrid nanofluid volume fractions were selected as 0.5, 0.6, 0.7, 0.8, 0.9 and 1, with 50% Graphene and 50% Iron Oxide.

2.3. Grid independence

In order to evaluate the accuracy of the results of the studies involving numerical analysis, the grid independence for the numerical model should be examined. In this study, the grid structure and cell size were examined for the flow region given in Figure 2. It was obtained that the Nusselt number was affected less than 2% in the grid structure where the cell size was less than 0.57. Therefore, the grid model, shown in Figure 2, with a cell size of 0.57 mm and a cell number of 1.18 million, was created for all analyzes.

In order to provide a faster and more precise solution for the grid structure, a polyhedra grid model was applied. The y^+ value, which is a parameter that should be controlled in grid model, was realized as $y^+ \approx 2$ by providing the $y^+ < 5$ (Salim, 2009) condition as it should be in the boundary layer region.

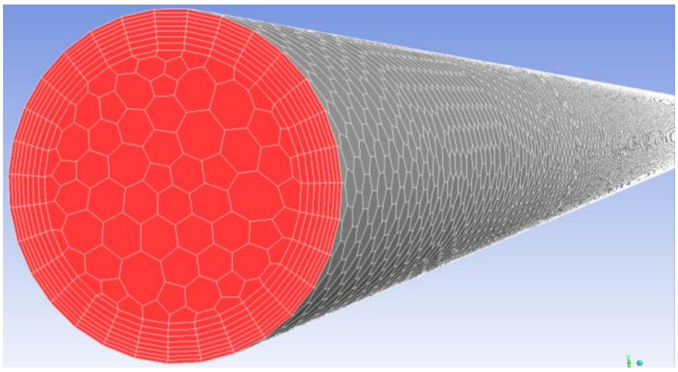

Figure 2. Grid structure

2.4. Thermophysical properties of nanofluids

The density, specific heat, thermal conductivity and dynamic viscosity equations given by Anjali and Suriya (2016) are used for the calculation of thermophysical properties of hybrid nanofluids and that are given in the Eqs. 6, 7, 8 and 9 respectively.

$$\rho_{hnf} = \left[(1-\phi_2)\left\{(1-\phi_1)\rho_f + \phi_1\rho_{s1}\right\} + \phi_2\rho_{s2}\right] \quad (6)$$

$$(\rho Cp)_{hnf} = \left[(1-\phi_2)\left[(1-\phi_1)(\rho Cp)_f + \phi_1(\rho Cp)_{s1}\right] + \phi_2(\rho Cp)_{s2}\right] \quad (7)$$

$$\frac{K_{hnf}}{K_{bf}} = \frac{K_{s2} + (n-1)K_{bf} - (n-1)\phi_2(K_{bf} - K_{s2})}{K_{s2} + (n-1)K_{bf} + \phi_2(K_{bf} - K_{s2})} \quad (8)$$

$$\mu_{hnf} = \frac{\mu_f}{(1-\emptyset_1)^{2.5}(1-\emptyset_2)^{2.5}} \quad (9)$$

The thermophysical properties of the nanoparticles and the base fluid used in the calculation of the thermophysical properties of hybrid nanofluids are given in Table 1.

2.4. Calculation method

After calculating the thermophysical properties of hybrid nanofluids, these properties were defined in ANSYS Fluent 18 program and analyzes were carried out. According to the data obtained as a result of the analysis, Reynolds number, Nusselt number, friction factor and dimensionless entropy generation number and the Bejan number were calculated according to the following equations.

The Reynolds number was calculated as given in Equation 10.

$$\boldsymbol{Re} = \frac{\rho D V}{\mu} \quad (10)$$

In the Eq. 10 ρ and μ respectively represent the hybrid nanofluid density and dynamic viscosity, D diameter and V the mean fluid velocity.

The heat transfer coefficient is calculated as given in Eq. 11, q' represents the heat flux applied over the flow region, while ΔT represents the difference between the surface temperature and the fluid mean temperature.

$$\boldsymbol{h} = \frac{q'}{\Delta T} \quad (11)$$

After calculating the heat transfer coefficient, the Nusselt number was calculated as given in Eq. 12, k symbolizes the thermal conductivity of the hybrid nanofluid.

$$\boldsymbol{Nu} = \frac{\boldsymbol{hD}}{\boldsymbol{k}} \quad (12)$$

The friction coefficient was calculated according to Eq. 13.

$$\boldsymbol{f} = \frac{\boldsymbol{\Delta P}}{\frac{1}{2}\boldsymbol{\rho V^2 \frac{L}{D}}} \quad (13)$$

ΔP, given in Eq. 13, represents the fluid differential pressure at the entrance and exit of the test section, and L represents the length of the test zone.

Entropy generation in a tube using heat transfer improvement technique can be calculated in Eq. 14.

$$\dot{\boldsymbol{S}}'_{\boldsymbol{gen}} = \frac{\boldsymbol{q'^2}}{\boldsymbol{\pi T^2 k Nu}} + \frac{\boldsymbol{32\dot{m}^3 f}}{\boldsymbol{\pi^2 \rho^2 T D^5}} \quad (14)$$

In the Eq. 14, T and ρ bulk properties. The Eq. 14 derived for for a straight tube and can be applied tube with nanofluids. The first term of the equation is the contribution made by heat transfer, while the second term is the contribution due to fluid friction:

$$\boldsymbol{S}'_{\mathrm{gen}} = \boldsymbol{S}'_{\mathrm{gen},\boldsymbol{\Delta T}} + \boldsymbol{S}'_{\mathrm{gen},\boldsymbol{\Delta P}} \quad (15)$$

The entropy generation number (Ns) is defined as the proportion of entropy generation rate by tube with nanofluid to the entropy generation rate in smooth tube with base fluid.

$$\boldsymbol{N_s} = \boldsymbol{S}'_{\mathrm{gen},\boldsymbol{n}} / \boldsymbol{S}'_{\mathrm{gen},\boldsymbol{s}} \quad (16)$$

Heat transfer augmentation techniques with N_s <1 are thermodynamically advantageous, because these techniques both enhance the heat transfer rate and reduce the degree of irreversibility of the unit's performance (Ventsislav, 1994).

Another dimensionless number in which entropy generation is considered in terms of evaluating the performance of the thermal system is known as the Bejan number (Haddad, 2004) as given in Eq. 17 and is defined as the ratio of irreversibilities caused by heat transfer to total irreversibility.

$$\boldsymbol{Be} = \frac{\dot{\boldsymbol{S}}'_{\boldsymbol{gen,\Delta T}}}{\dot{\boldsymbol{S}}'_{\boldsymbol{gen,\Delta T}} + \dot{\boldsymbol{S}}'_{\boldsymbol{gen,\Delta P}}} \quad (17)$$

The Bejan number can take values ranging from 0-1. It is stated that the irreversibilities due to heat transfer are greater than the irreversibilities due to total fluid friction when the Bejan number approaches 1.

Table 1. Thermophysical properties of nanoparticle

Properties	Graphene(Keklikcioglu,2020)	Iron Oxide(Krishna,2017)	Water
Specific heat (J/kgK)	790	104	4182
Density (kg/m³)	2250	5180	998.2
Dynamic viscosity (kg/ms)	-	-	1.003E-03
Thermal conductivity (W/mK)	3000	17.65	0.6

3. Results and Discussion

3.1. Validation of numerical study

In numerical studies, the results obtained according to the variable parameters should be compared with the well konown correlations and the validation process of the study should be done. In this study, analysis results using only base fluid water were compared with the Gnielinski and Blasius (Keklikcioglu, 2020) equations given in Eqs. 18 and 19 for Nusselt number and friction factor, respectively.

$$Nu_D = \frac{(f/8)(\mathrm{Re}_D - 1000)\mathrm{Pr}}{1.07 + 12.7(f/8)^{1/2}(\mathrm{Pr}^{2/3} - 1)} \quad (18)$$

$$f = 0.316 Re^{-0.25} \quad (19)$$

As seen in Figs. 3 and 4, both the Nusselt number and the friction factor were compared with the well known correlations in the literature. It was obtained that the numerical study results at different Reynolds numbers and the values obtained from the well known correlations coincide with each other, and they provide approximately the same trend. The highest deviation between the numerical results and the values obtained from the correlations were 9.2% and 5.6% for the Nusselt number and the friction factor, respectively.

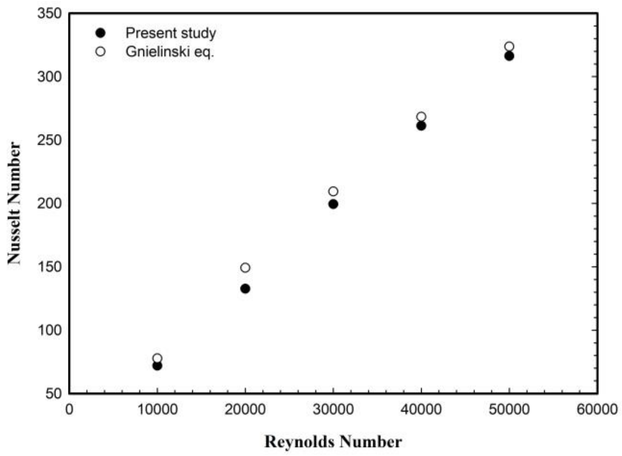

Figure 3. Validation of Nusselt number

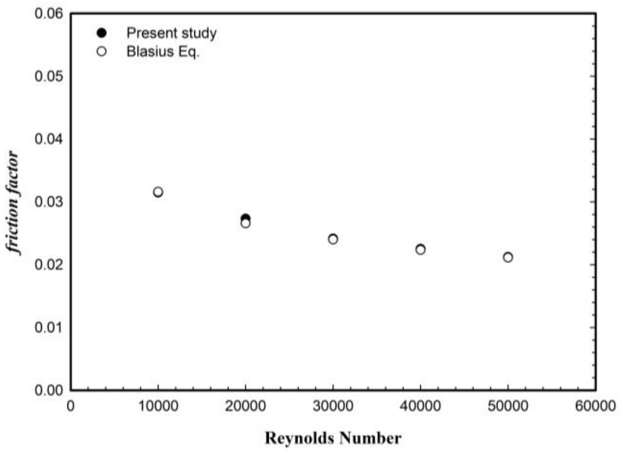

Figure 4. Validation of friction factor

3.2. Entropy generation analysis

Heat transfer and pressure drop analyzes can be analyzed in heat exchangers using different fluids, but in order to examine the actual effect of the fluid used on the thermodynamic performance of thermal system, the entropy generation value of the system should be compared with the value before and after the application of enhancement technique. In this study the results for a tube heat exchanger tube with nanofluids evaluated in terms of entropy generation theorem.

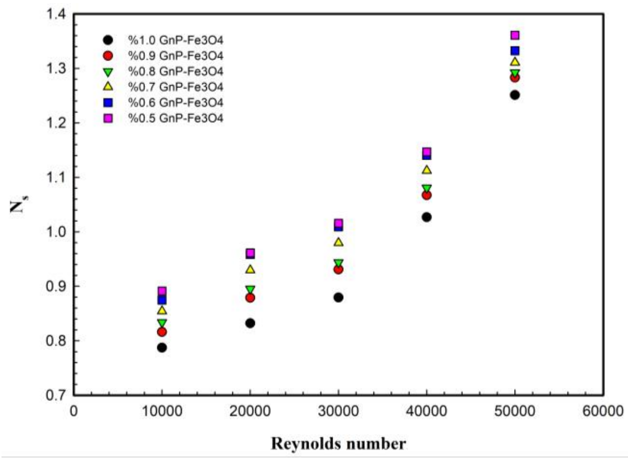

Figure 5. Variation of dimensionless entropy generation number versus Reynolds number

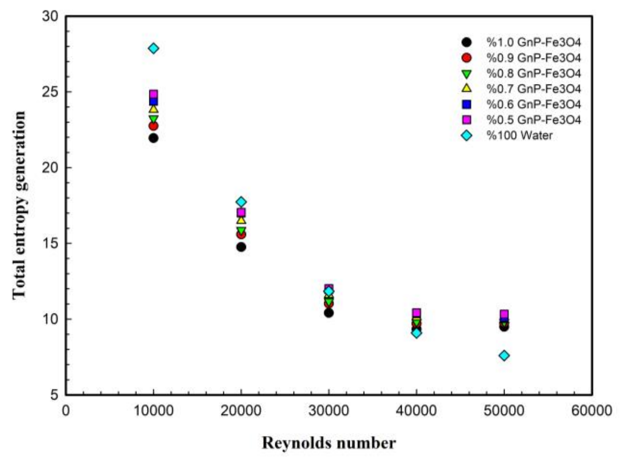

Figure 6. Variation of total entropy generation versus Reynolds number

Fig. 5 represents the entropy generation number for the various Reynolds number for different volume fractions of Graphene-Iron Oxide hybrid nanofluids. As in Fig. 5 entropy generation number increase with increasing Reynolds number and volume fraction of hybrid nanofluid. Particle loading at higher rates increases the system performance and reduces the dimensionless entropy generation number. Due to the frictional irreversibility show ascending trend at higher velocity values, the dimensionless entropy generation increases with the increment of Reynolds number. As shown in Fig. 5, the dimensionless entropy generation number with the volume fractions of 0.9 and 1 % were realized below unity up to the Reynolds number of 40000. All of the configurations were thermodynamically advantages up to the Reynolds number of 30000 since the entropy generation number remained under unity. The lowest entropy generation number was achieved as 0.78 with using 1% Graphene-Iron Oxide water nanofluid at lowest Reynolds number of 10000.

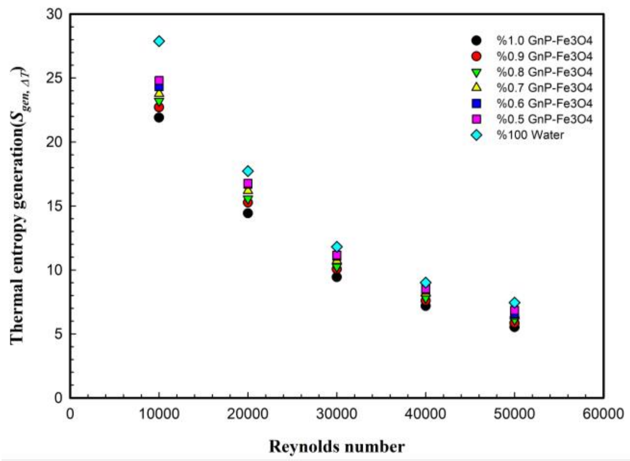

Figure 7. Variation of thermal entropy generation versus Reynolds number

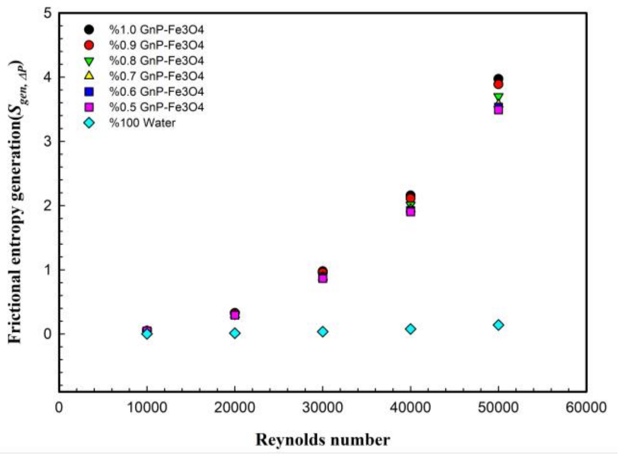

Figure 8. Variation of frictional entropy generation versus Reynolds number

Fig. 6 shows the total entropy generation versus Reynolds number for the case of using hybrid nanofluids and base fluid water. As shown in Fig. 6, using Graphene-Iron Oxide hybrid nanofluids in the heat exchanger tube dramatically reduces the total entropy generation up to the 40000 Reynolds number. The total entropy generation rate increases with the decreasing of volume fraction. As can be understand in Fig. 6, irreversibility arising from heat transfer are overcomed by using a higher hybrid nanofluid volume fraction. As in Fig. 7 the thermal entropy generation number decreases with the increasing hybrid nanofluid volume fraction. This demonstrates that the heat transfer process is enhanced with using hybrid nanofluids. The use of hybrid nanofluids achieve the h,gher heat transfer rate in the thermal system and reduce the entropy generation over the smooth tube with base fluid. Fig. 8 proves the hybrid nanofluids increase the entropy generation rate due to the fluid friction contrarily to thermal entropy generation.

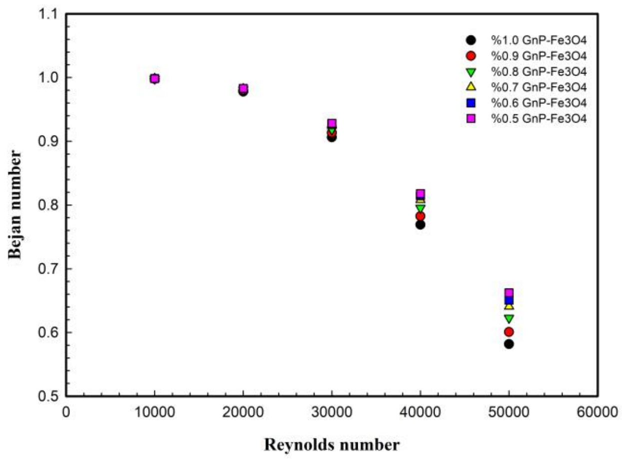

Figure 9. Variation of dimensionless Bejan number versus Reynolds number

The Bejan number another dimensionless number to consider entropy generation in thermal systems. As given in Fig. 9 the Bejan number increased with the decreasing hybrid nanofluid volume fraction. At high Reynolds numbers the frictional irreversibility overcomed the irreversibility caused the heat transfer. Particle loading also decreased the total irreversibility as given in Fig. 9.

4. Conclusions and Recommendations

As a result of the study, the important findings listed below were obtained.

- The use of Graphene-Iron Oxide-Water nanofluid in heating and cooling systems is a heat transfer enhancement technique with a thermodynamic advantage. In addition, Graphene-Iron Oxide-Water hybrid nanofluid was not used in a heat exchanger tube under the physical conditions and boundary conditions used in this study, and the importance of this technique was revealed with this study.
- In this study, it has been shown that by using the Graphene nanoparticle with high thermal conductivity coefficient and high cost and the Iron Oxide nanoparticle with relatively low thermal conductivity and cost as a hybrid nanofluids, a balance can be achieved in terms of both thermophysical properties and cost, and lower entropy generation rates can be achieved.
- The dimensionless entropy generation number was below the unity for all configurations up to the Reynolds number of 30000. This demonstrated that the used method thermodynamically advantages especially high particle loading rates.
- The total entropy generation and the Bejan number also effected with using hybrid nanofluid. The increasing volume fraction cause a reduction both total entropy generation and Bejan number. This result indicated that irreversibility were reduced in heat exchanger tube with using hybrid nanofluid.
- Choosing hybrid nanofluids as heat transfer fluid is important in terms of providing thermodynamic advantage in applications. As can be seen from the results of this study, Graphene-Iron Oxide-Water nanofluid obtains as an effective heat transfer fluid due to its unique thermophysical properties, it has the potential to be evaluated as an economical model compared to mono use.

5. Acknowledge

Orhan Keklikcioglu would like to thank Prof. Dr. Veysel Ozceyhan and Erciyes University for contribution to this study.

References

1. Ozerinç, S., Kakaç, S., Yazıcıoğlu, A.G. (2010). Enhanced Thermal Conductivity of Nano-Fluids: A State-of-the-Art Review. Microfluid Nanofluid, 8(2), 145-170.
2. Ahammed, N., Asirvatham, L.G., Wongwises, S. (2016). Entropy generation analysis of graphene–alumina hybrid nanofluid in multiport minichannel heat exchanger coupled with thermoelectric cooler. Int. J. Heat Mass Transf., 103, 1084–1097.
3. Hussain, S., Ahmed, S.E., Akbar, T. (2017). Entropy generation analysis in MHD mixed convection of hybrid nanofluid in an open cavity with a horizontal channel containing an adiabatic obstacle, Int. J. Heat Mass Transf., 114, 1054–1066.
4. Rahimi, A., Sepehr, M., Lariche, M.J., Mesbah, M., Kasaeipoor, A., Malekshah, E.H. (2018). Analysis of natural convection in nanofluid-filled H-shaped cavity by entropy generation and heatline visualization using lattice Boltzmann method, Physica E: LowDimensional Systems and Nanostructures. 97, 347–362.
5. Kasaeipoor, A., Malekshah, E.H., Kolsi, L. (2017). Free convection heat transfer and entropy generation analysis of MWCNT-MgO (15% −85%)/water nanofluid using lattice Boltzmann method in cavity with refrigerant solid body-experimental thermophysical properties, Powder Technol., 322,9–23.
6. Mehrali, M., Sadeghinezhad, E., Akhiani, A.R., Latibari, S.T., Metselaar, H.S.C., Kherbeet, A.S., Mehrali, M. (2017). Heat transfer and entropy generation analysis of hybrid graphene/Fe3O4 ferro-nanofluid flow under the influence of a magnetic field, Powder Technol., 308, 149–157.
7. Askari, S., Koolivand, H., Pourkhalil, M., Lotfi, R., Rashidi, A. (2017). Investigation of Fe3O4/Graphene nanohybrid heat transfer properties: Experimental approach. International Communications in Heat and Mass Transfer, 87, 30-39.
8. Shahsavar, A., Rahimi, Z., Bahiraei, M. (2017). Optimization of irreversibility and thermal characteristics of a mini heat exchanger operated with a new hybrid nanofluid containing carbon nanotubes decorated with magnetic nanoparticles, Energy Convers. Manag., 150, 37–47.

9. Shahsavar, A., Ansarian, R., Bahiraei, M. (2018). Effect of line dipole magnetic field on entropy generation of Mn-Zn ferrite ferrofluid flowing through a minichannel using twophase mixture model, Powder Technol., 340, 370–379.
10. Bahiraei, M., Heshmatian, S. (2018). Thermal performance and second law characteristics of two new microchannel heat sinks operated with hybrid nanofluid containing graphene–silver nanoparticles, Energy Convers. Manag., 168, 357–370.
11. Bahiraei, M., Mazaheri, N. (2018). Second law analysis for flow of a nanofluid containing graphene–platinum nanoparticles in a minichannel enhanced with chaotic twisted perturbations, Chem. Eng. Res. Des., 136, 230–241.
12. Potenza, M., Cataldo, A., Bovesecchi, G., Corasaniti, S., Coppa, P., Bellucci, S. (2017). Graphene nanoplatelets: Thermal diffusivity and thermal conductivity by the flash method. AIP Advances, 7, 1-15.
13. Manikandan, S. P., Baskar, R. (2018). Assessment of the Influence of Graphene Nanoparticles on Thermal Conductivity of Graphene/Water Nanofluids Using Factorial Design of Experiments. Periodica Polytechnica Chemical Engineering, 62(3), 317-322.
14. Yongsheng, F., Haiqun, C., Xiaoqiang, S., Xin, W., (2012). Combination of cobalt ferrite and graphene: High-performance and recyclable visible-light photocatalysis. Applied Catalysis B: Environmental, 111, 280–287.
15. Fluent (2016). ANSYS Fluent V.17.0 User Guide, Fluent Corporation, Lebanon, New Hampshire.
16. Keklikcioglu, O., (2020). İçerisinde Grafen katkılı nanoakışkan ve konik iç eleman kullanılan boruda termohidrolik performans ve entropi üretiminin incelenmesi. Erciyes Üniversitesi, Fen Bilimleri Enstitüsü, Doktora Tezi, 191s, Kayseri.
17. Krishna V., K.P.V., Kishore, P.S., Durga Prasad, P.V., (2017). Enhancement of Heat Transfer Using Fe3O4 / Water Nanofluid with Varying Cut-Radius Twisted Tape Inserts. International Journal of Applied Engineering Research, 12, 7088-7095.
18. Salim, S.M., Cheah, S.C. (2009). Wall y+ Strategy for Dealing with Wall-bounded Turbulent Flows. International MultiConference of Engineers and Computer Scientists, 18-20 Mart, Hong Kong, 2165-2170.
19. Anjali Devi, S.P., Suriya U.D.S. (2016). Numerical investigation of hydromagnetic hybrid Cu–Al2O3/water nanofluid flow over a permeable stretching sheet with suction. International Journal of Nonlinear Sciences and Numerical Simulation, 17, 249–257.
20. Bejan, A., (2001). Thermodynamic optimization of geometry in engineering flow systems, Exergy, An International Journal, 1(4), 269 – 277.
21. Ventsislav D. Zimparov, Nikolai L. Vulchanov, (1994). Performance evaluation criteria for enhanced heat transfer surfaces, International Journal of Heat and Mass Transfer, 37, 1807-1816.
22. Haddad, O., Abuzaid, M., ve Al-Nimr, M. (2004). Entropy generation due to laminar incompressible forced convection flow through parallel-plates microchannel, Entropy, 6, 413–426.