Thermodynamic Analysis of Fe_3O_4Nanofluid Flowing Through A Circular Tube

Praveena Devi N, Ch. Srinivasa Rao, K Kiran Kumar

Abstract: Present work is an experimental study of entropy generation of Fe_3O_4-water nanofluid flowing through a circular tube. Flow is maintained in the turbulent region and tube is exposed to constant heat flux along the length. Experiments are conducted to study the entropy generation rate for different conditions such as particle volume concentrations varying from 1% to 6% and also for the different Reynolds numbers varying from 6000 to 22000. Measured data from experimentation is taken as input to calculate thermal entropy and frictional entropy generation separately. Based on these thermal entropy and frictional entropy generation total entropy generation and Bejan number are calculated and results are analyzed. Experimentally, it is proved that the changes in the thermal and frictional entropy generations are converse, such a way that, as particle concentration increases entropy generation due to heat transfer decreases whereas entropy generation due to friction increases. Finally experimental results reveal that there exits an optimum particle volume concentration where the total entropy generation is minimal. The same result has also appended by calculating the Bejan number.

Index Terms: Bejan number, entropy generation due to heat transfer, entropy generation due to friction, Heat transfer, Nanofluid.

I. INTRODUCTION

Exponential growth in the electronics industry leads to the higher heat generation rates from electronic devices and demands for safer and more efficient cooling systems. Due to the limitations over their heat transfer characteristics, air-cooling and liquid-cooling with conventional fluid as working fluid reaches its saturation limit. Because of favorable thermal characteristics, Nanofluids are proven as alternative coolant in various thermal management systems [1]. Uniform dispersion of nano-meter sized nanoparticles (metallic or non-metallic) into the conventional fluid (water, Ethylene Glycol etc.) is termed as nanofluid [2]. It has been proven by many researchers that important thermo-physical property such as higher thermal conductivity favors nanofluid to use in many thermal management systems. However, nanofluids possess high viscosity compared to that of conventional fluids. This higher viscosity leads to more pressure drop there by increases the pumping power. So, always there exists a trade-off between higher heat transfer characteristics and higher pumping power. Thermodynamic second law analysis is an efficient tool to find the suitability of the nanofluid in any thermal management system. It is to be observed that, with nanofluids, thermal entropy generation decreases whereas frictional entropy increases [3]. Bianco et al. [4] reported that at higher Reynolds number for minimum entropy generation, the most favorable nanoparticles concentration is low. Mahian et al.[5] in their studies on two co-rotating cylinders showed the possibility of minimizing the entropy generation in the nanofluid with respect to the nanoparticles concentration .

A customized experimental test rig is fabricated which represent different flow conditions (different Reynolds numbers) and different heat fluxes. Fe_3O_4-water nanofluid is chosen for experimentation. Some researchers studied the effect of magnetic field on magnetite nanofluid (Fe_3O_4-water) [6]. Due to its vast usage in electronic cooling systems, Fe_3O_4-water nanofluid is chosen for the present study. Particle volume concentrations are varied from 1% to 6% V/V. Circular tube section is considered for the study. Experiments are conducted by varying Reynolds number and volume fraction. Experimental data is used to calculate entropy generation and Bejan number.

Revised Manuscript Received on August 25, 2019.

Praveena Devi N, Assistant Professor at department of Mechanical engineering, S R Engineering College, Warangal, Telangana, India.

Ch Srinivasa Rao, Professor at department of Mechanical Engineering, Andhra University, Visakhapatnam, Andhra Pradesh, India.

K Kiran Kumar, Associate Professor at department of Mechanical engineering, NIT Warangal,Warangal,Telangana,India.

II. METHODOLOGY

Thermo-physical properties of nanofluid:

In order to determine the entropy generation, precise information on the thermo-physical properties of the nanofluid is necessary. The thermo-physical properties of nanofluid strongly depend on nanoparticle concentration.

Pak and cho (1999) suggested a correlation to calculate density of nanofluid.

$$\rho_{nf} = (1-\phi)\rho_{bf} + \phi\rho_{np} \quad (1)$$

Maxwell (1883) suggested a correlation to calculate thermal conductivity

$$k_{nf} = k_{bf}\left\{\frac{\left[k_{np} + 2k_{bf} - 2\phi(k_{bf} - k_{np}\right]}{\left[k_{np} + 2k_{bf} + \phi(k_{bf} - k_{np}\right]}\right\} \quad (2)$$

Heat Capacity can be calculated by the correlation proposed by Pak and cho (1999) proposed a correlation to calculate specific heat

$$C_{p.nf} = \frac{(\phi\rho_{np}C_{p,np} + (1-\phi)\rho_{bf}C_{p,bf})}{\rho_{nf}} \quad (3)$$

Batchelor (1977) proposed a correlation to calculate viscosity of nanofluid

$$\mu_{nf} = (1 + 2.5\phi + 6.2\phi^2)\mu_{bf} \quad (4)$$

III. EXPERIMENTAL SET UP

A detailed sketch of the test facility used in analysis is shown in Fig 1. Photograph of test rig is shown in figure 2. All the thermocouples, mass flow meters and differential pressure gauges are well calibrated and calibration errors are taken into account while doing the data reduction. A detailed sketch of the test facility used in analysis is shown in Fig 1. Photograph of test rig is shown in figure 2. All the thermocouples, mass flow meters and differential pressure gauges are well calibrated and calibration errors are taken into account while doing the data reduction.

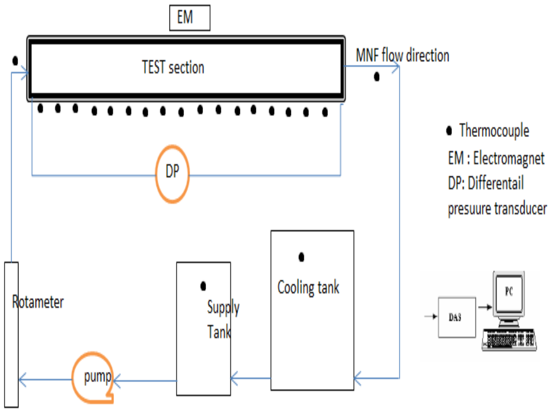

Fig. 1. Sketch of test facility

Fig. 2: Photograph of test rig

Data Reduction:

K-type thermo-couples are used to log the temperature data. Average temperature of the fluid is calculated by using Equation given as

$$T_{av} = \frac{T_i - T_o}{\ln\left(\frac{T_i}{T_o}\right)}$$

Mass flow rate and surface temperature are taken from the experimental data where as other thermo-physical properties are calculated from the correlations given in the previous section. Based on these experimental and calculated values, dimensionless parameters such as Nusselt number (Nu) and Prandtl number (Pr) are calculated.

The entropy generation due to friction can be estimated from equation 5 (Bejan, 1982),

$$E_{g,f} = \frac{32m^3 fL}{\rho_{nf}{}^2 \pi^2 d^5 T_{av}} \quad (5)$$

The entropy generation due to heat transfer can be be estimated from equation 6(Bejan, 1982),

$$E_{g,T} = \frac{\pi d^2 L q^2}{k_{nf} Nu T_{av}} \quad (6)$$

The addition of equation 5 and 6 gives total entropy generation,

$$E_g = E_{g,T} + E_{g,f}$$

Bejan number, $Be = \frac{E_{g,T}}{E_g}$

IV. RESULTS AND DISCUSSION

Effects of %V/V and Reynolds number on entropy generation due to heat transfer, entropy generation due to friction, total entropy generation and Bejan number are analyzed in this section. Fe_3O_4-water nanofluid is considered for the analysis. When compared with conventional fluids, nanofluid heat transfer characteristics are favorable because of enhancement of thermo-physical properties like thermal conductivity. However, due to the increased viscosity, frictional resistance also increases. In order to identify the optimum %V/V for the given Re number, experiments are conducted and results are presented in the present section. Bejan (1982) derived closed form solutions to calculate the entropy generation and the corresponding formulae are presented in the preceding section. Data collected from the experimentation is used to calculate the entropy generation.

Effect of nanoparticle concentration:

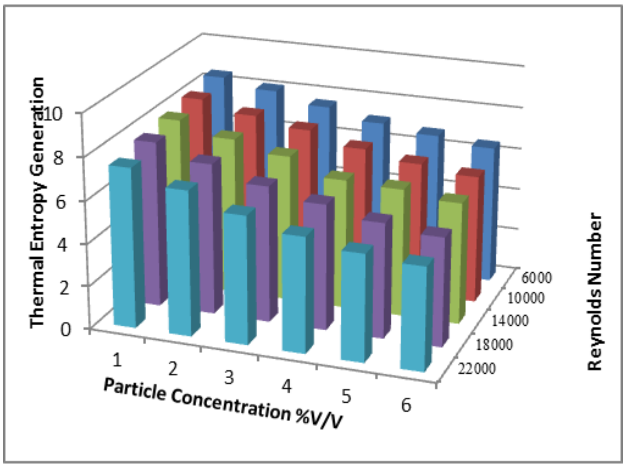

Fig. 3: Effect of %V/V and Re on thermal entropy generation

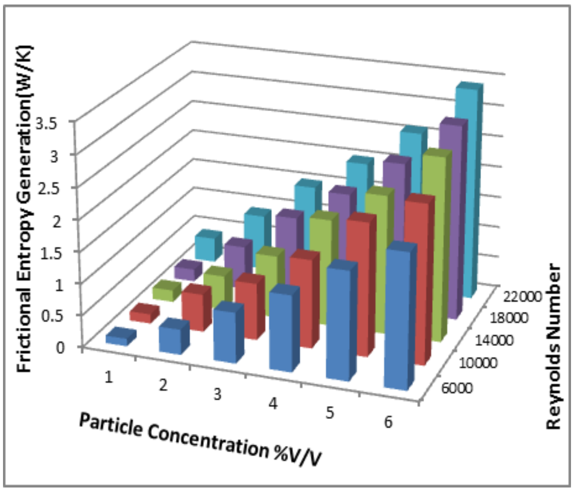

Fig. 4: Effect of %V/V and Re on frictional entropy generation

Figure 3 shows the effect of %V/V and Re on thermal entropy generation. To find the nanofluid concentration effect, %V/V has been varied from 1 to 6. For all the concentrations Reynolds number has been varied from 6000 to 22000 with the step size of 4000. Similarly for the similar independent variables i.e.,nanofluid concentration from 1%V/V to 6%V/V and Reynolds number from 6000 to 22000,change in the entropy generation due to friction has been plotted in figure 4. It is to be noted that heat flux is kept constant for all the cases. It is evident from figure 3& 4 that the entropy generation due to heat transfer is dominant compared with the entropy generation due to friction in all cases within the range of study. Furthermore, with the increase in %V/V, the entropy generations due to friction and heat transfer have differing trends of variation. From above equations it is clearly evident that the effective thermal conductivity and Nusselt number increases with increase of %V/V which is responsible for the decreasing trend of entropy generation. However, entropy generation due to friction increases with %V/V due to increase in effective viscosity. Shear stress increases as the viscosity of nanofluid increases.

Effect of Reynolds Number:

From figures 3 &4, it can be witnessed that entropy generation due to heat transfer decreases with the increase of the Re number, where as the entropy generation due to friction increases. This may be attributed to the increase in Nusselt number with Reynolds number. It is observed that variation of frictional entropy generation is low at lower concentrations (up to 3%) and there after it is predominant.

Because of the decreasing and increasing trends of thermal and frictional entropy generations, the total entropy generation exhibits an optimum condition with minimum entropy generation. Figure 5 represents the effect of %V/V and Re number on total entropy generation. To know the nanofluid concentration effect, %V/V has been varied from 1 to 6. Reynolds number has been varied from 6000 to 22000 with the step size of 4000. For Re=22000 and 3%V/V, the total entropy generation is 7.5 W/K for 3%V/V and 7.2 W/K for 4%V/V.For the same Re number and 6%V/V, the total entropy generation is 8.25 W/K. It is clear that there is decrement in the total entropy generation up to 4%V/V and there after it is predominant for different Re values. Similarly for the similar independent variables i.e.,nanofluid concentration from 1%V/V to 6%V/V and Reynolds number from 6000 to 22000,the trend of Bejan number has been plotted in figure 6. With increase in %V/V for a fixed Re value, there is decrement in Bejan number because of increment in frictional entropy generation. For Re=22000, Bejan number is 0.95 for 1%V/V and 0.6 for 6%V/V respectively. It can be concluded that at high Re values and %V/V, frictional entropy generation dominates thermal entropy generation. So from these results it can be concluded that an optimum %V/V exists for the given Revalue. Depending on the condition of flow, irreversibility due to frictional resistance and heat transfer may dominate each other.

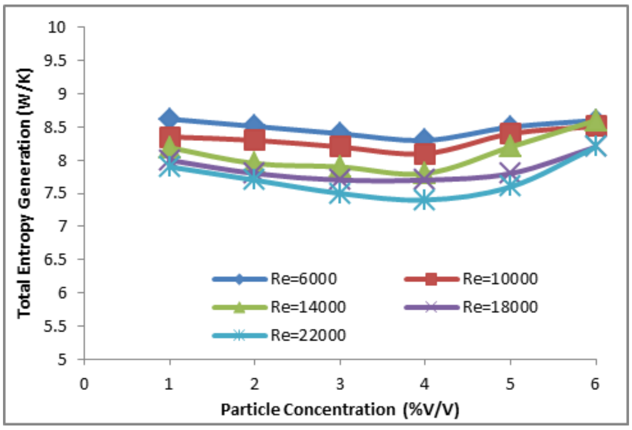

Fig. 5: Effect of %V/V and Re on total entropy generation

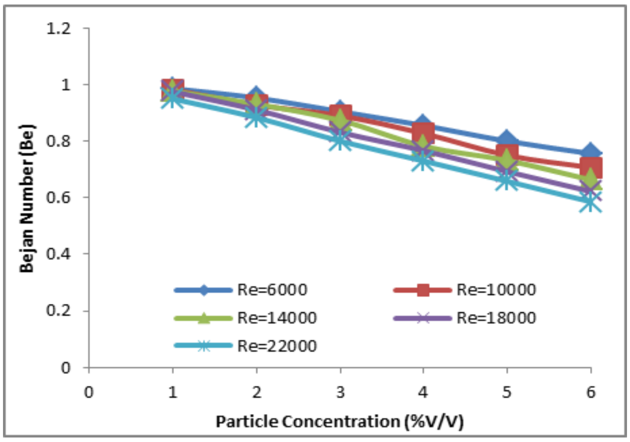

Fig. 6: Effect of %V/V and Re on Be

V. CONCLUSIONS

In this paper, effects of %V/V and Reynolds number on entropy generation due to heat transfer, entropy generation due to friction, total entropy generation and Bejan number are analysed in order to investigate the optimum value of %V/V for the given Reynolds number in the turbulent region. Experiments are conducted and results are analyzed. The following points are observed from the present study:

1. With increase in nanoparticle volume concentration, the entropy generation due to heat transfer decreases, whereas entropy generation due to fluid friction increases.

2. Reverse trend is observed with increase in Reynolds number.
3. There exists an optimum value of concentration for the given Re number where the total entropy generation is minimum.

Nomenclature

k	Thermal Conductivity (W/m K)
C_p	Specific Heat (kJ/kg K)
$E_{g,f}$	Entropy generation due to friction (W/K)
$E_{g,T}$	Entropy generation due to heat transfer (W/K)
E_g	Total Entropy Generation
np	Nano particle
d	Diameter of tube (m)
bf	Base fluid
m	Mass flow rate (kg/s)
av	Average
q	Heat flux (W/m^2)
nf	Nanofluid
Dimensionless	*Number*
Be	Bejan Number
Greek Letters	
ρ	mass density (kg/m^3)
%V/V	Particle Concentration
μ	Viscosity (kg/m s)
Subscripts	
np	Nano particle
bf	Base fluid
av	Average
nf	Nanofluid
i	Inlet
o	Outlet

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AUTHORS PROFILE

Praveena Devi is working as Assistant Professor in Mechanical Engineering department, S R Engineering College,Warangal,India.She had 10 years of teachnig and research experience.Her research interests are nanofluids and heat transfer.

Dr. Ch Srinivasa Rao is working as Professor in Mechanical Engineering department, Andhra University, Visakhapatnam, India. He published more than 100 research papers in reputed journals and conferences.

Dr.K.Kiran Kumar is working as Associate Professor in mechanical Engineering department, NIT Warangal,India. His area of research is nanofluids and two phase flow boiling.