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EXPERIMENTAL STUDIES ON FE_3O_4 NANOFLUID FLOWING THROUGH A CIRCULAR TUBE

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Abstract: *This study deals with an experimental investigation 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 of nanofluid for different particle volume concentrations varying from 1 % to 6 % and also for the different Reynolds numbers. Measured data from the experimentation is taken as input to calculate the thermal entropy and frictional entropy generation. Finally total entropy generation and Bejan number are calculated and analyzed. Experimentally it is proved that the changes in the thermal and frictional entropy generations are opposite, such a way that, as particle concentration increases thermal entropy generation decreases whereas frictional entropy generation 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.*

Keywords: Nanofluid, Experimental, Entropy generation, Bejan number, Heat transfer.

1. Introduction

Exponential growth in the electronics industry leads to the higher heat generation rates from different electronic devices and demands for safer and more efficient cooling systems. Due to the limitations over heat transfer characteristics, air-cooling and liquid-cooling with conventional fluid as working fluid reaches the saturation limit. Because of favorable thermal characteristics, nanofluids are proven as alternative coolant in various thermal management systems (Godson et al. 2009, Ahammed et al. 2016). However, nanofluids possess high viscosity compared to that of the base fluid. This higher viscosity leads to the more pressure drop there by increases the pumping power requirement. So, always there exists a trade-off between higher heat transfer characteristics and higher pumping power. Thermodynamic second law analysis is an effective tool to find the suitability of the nanofluid in any thermal management system. It is to be noted that, with nanofluids, entropy generation due to the heat transfer decreases where as entropy generation due to the friction increases.

In this study, a customized test rig is developed to represent different flow conditions (different Reynolds numbers) and different heat fluxes. Due to its vast usage in electronic cooling systems, Fe_3O_4-water nanofluid is chosen for the 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 datais used to calculate entropy generation and Bejan number.

2. Methodology

2.1. Nanofluid thermo physical properties

Inorder to determine the entropy generation, precise information on the thermophysical properties of the working fluid is necessary. The thermophysical properties of nanofluid strongly depends on the quantity of nanoparticles added to the base fluid.

Density of nanofluid is estimated based on the principle of the mixture rule and can be calculated by using following equation proposed by Pak et al. (1999).

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

Thermal conductivity is one of the vital property, which governs the heat transfer characteristics of the nanofluid, and it can be estimated by using Maxwell correlation (1883).

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

Heat Capacity can be calculated by the correlation proposed by Pak et al. (1999).

$$C_{p,nf} = (\emptyset\, \rho_{np}C_{p,np} + (1-\emptyset)\rho_{bf}C_{p,bf})/\rho_{nf} \quad (3)$$

Viscosity can be calculated by the correlation proposed by Batchelor (1977)

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

Nomenclature		***Greek Letters***	
k	Thermal conductivity [W/mK]	ρ	Density [kg/m^3]
C_p	Specific heat [kJ/kg K]	*Φ*	Particle concentration
$E_{g,f}$	Frictional entropy generation [W/K]	μ	Viscosity [kg/m s)]
$E_{g,T}$	Thermal entropy generation [W/K]	***Subscripts***	
E_g	Total entropy generation	np	Nano particle
d	Diameter of the tube [m]	bf	Base fluid
m	Mass flow rate [kg/s]	av	Average
q	Heat flux [W/m^2]	nf	Nanofluid
Dimensionless numbers		i	Inlet
Re	Reynolds number	o	Outlet
Nu	Nusselt number		
Pr	Prandtl number		
Be	Bejan number		

2.2. Experimental set up

A detailed schematic of the experimental facility used in this investigation is shown in Fig. 1. Photograph of the test rig is shown in Fig. 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.

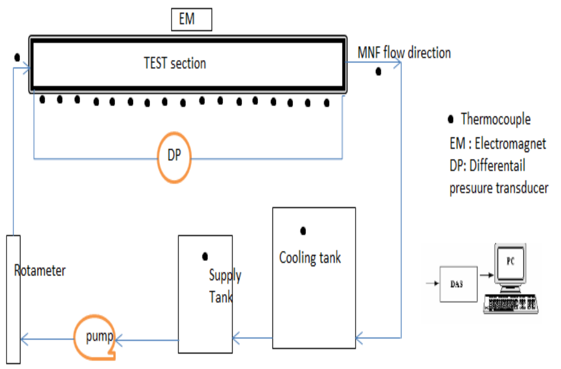

Fig. 1: Schematic of the test facility.

Fig. 2: Photograph of test facility.

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

Mass flow rate and surface temperature are taken from the experimental data. Whereas, 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 Nu and Pr are calculated.

The entropy generation due to friction can be expressed as (Bejan, 1982) $E_{g,f} = \frac{32 m^3 fL}{\rho_{nf}{}^2 \pi^2 d^2 T_{av}}$.

The entropy generation due to heat transfer can be expressed as (Bejan, 1982) $E_{g,T} = \frac{\pi d^2 L q^2}{k_{nf} Nu T_{av}}$.

The total entropy generation can be given by $E_g = E_{g,T} + E_{g,f}$.

To find the relative influence of thermal and frictional entropy generations on the total entropy generation, a non-dimensional number, i.e. Bejan number can be used $Be = \frac{E_{g,T}}{E_g}$.

3. Results and Discussion

It is well known that, heat transfer characteristics are favorable with nanofluid as working fluid when compared with that of the base fluid. This is due to the enhancement of some thermo-physical properties such as thermal conductivity. However, due to the increased viscosity, frictional resistance also increases. In order to find the optimum particle concentration for the given Reynolds (Re) number, experiments are conducted and results are presented in the present section. Bejan (1982) derived closed form solutions to calculate the entropy generation per unit length of the circular tube section and the corresponding formulae are presented in the preceding section. Data collected from the experimentation is used to calculate the entropy generation.

3.1. Effect of nano particle concentration

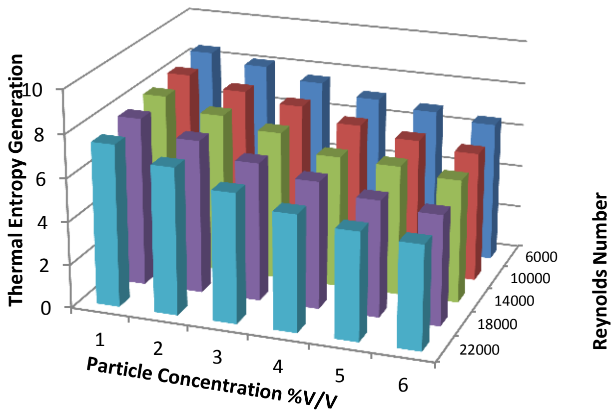

Fig. 3: Variation of thermal entropy generation.

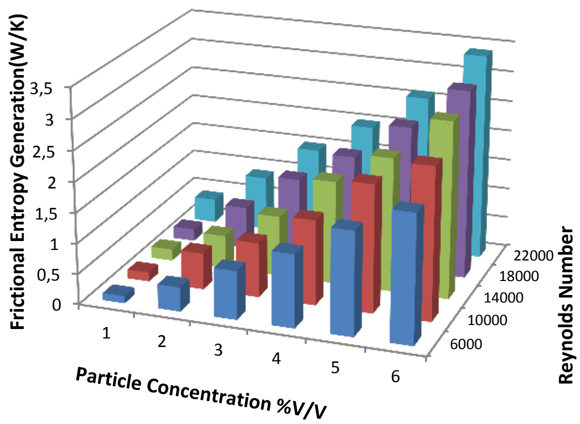

Fig. 4: Variation of frictional entropy generation.

Fig. 3 and Fig. 4, respectively, show the affect of particle concentration on the thermal and frictional entropy generations. It is to be noted that, Reynolds number is varied from 6000 to 22000 for all the particle concentrations. Heat flux is kept constant for all the cases. It is evident from Figs. 3 and 4 that the thermal entropy generation is dominant compared with the frictional entropy generation in all the cases within the range of study. Furthermore, with the increase in concentration of nanoparticles, the thermal and frictional entropy generations have opposing trends of variation. From equations it is clearly evident that the effective thermal conductivity and Nusselt number increases with increase of particle concentration which is responsible for the decreasingtrend of entropy generation. However, the frictional entropy generation, increases withparticle concentration since the effective viscosity increases. Although with the increase of nanoparticleconcentration both the viscosity and density of nanofluid increases, the increase of viscosity dominates the increase of density which leads to an increase of the shear stress.

3.2. Effect of Reynolds Number

From Figs. 3 and 4, it can be witnessed that thermal entropy generation decreases with the increase of the Reynolds number, where as the frictional entropy generation increases. This may be attributed to the increase in Nusslet number with Reynolds number. It is further noticed that the variation in 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. Fig. 5 shows the variation of total entropy generation with concentration and Reynolds number. The same result may be detected by examining the trend of Bejen number, in Fig. 6, which shows that at the higher Reynolds number and particles concentration, frictional entropy generation dominates. So from these results it can be concluded that there exists an optimum particle concentration for the given Reynolds number. Depending on the flow, irreversibilities due to heat transfer and irreversiblities due to frictional resistance may dominate each other.

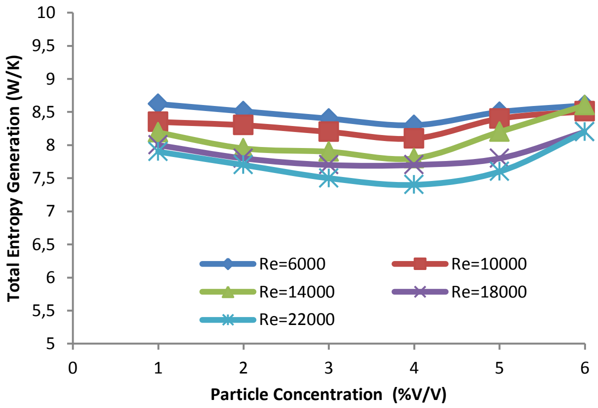

Fig. 5: Variation of total entropy generation.

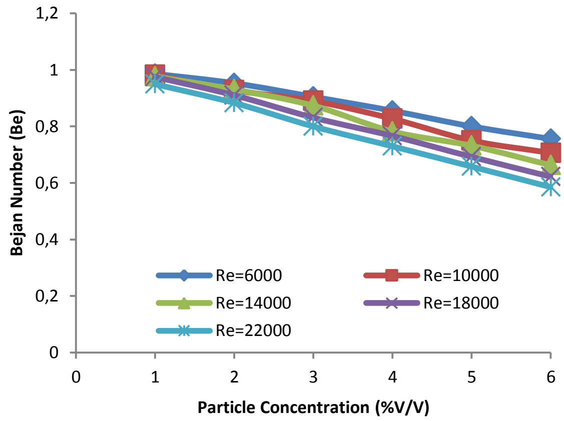

Fig. 6: Variation of Bejan number.

3. Conclusions

In this paper, analysis of entropy generation is presented in order to investigate the optimum value of particle concentration for the given Reynolds number in the turbulent region. Experiments are conducted and results are analyzed. The following conclusions are drawn from the present study:

1. With increase in nanoparticle volume concentration the entropy generation due to heat transfer decrease, whereas entropy generation due to fluid friction increases.
2. The reverse trend is observed with increase in Reynolds number.
3. There exists an optimum value of concentration for the given Reynolds number where the total entropy generation is found minimum.

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