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Entropy Analysis of Nano fluid in Open Cell Copper Metal Foam

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Abstract: ***Entropy analysis plays a crucial role in understanding the thermodynamic behavior and energy conversion processes in various thermal systems. Previous studies have explored various techniques, such as local and global entropy generation analysis and exergy analysis, to quantify entropy generation and identify optimization strategies. The research findings highlight the significance of entropy analysis in optimizing the performance of porous media-based systems in the presence of Nano fluids which enhance heat transfer.***
The study's findings show how entropy analysis might improve heat transfer by improving the functionality of systems based on porous media. With different pore densities (PPI = 10, 20, and 40), nanoparticle mass fractions (from 0.0 to 0.5 wt%), and Reynolds numbers (Re = 414-1119), the impact of metal foam on entropy formation was investigated. The total amount of nanofluids first decreases, then increases with an increase in mass fraction, and finally decreases with an increase in PPI. The least amount of total entropy is produced by nanofluids with = 0.3 wt% under PPI = 40.
It demonstrates that in this ideal scenario, the irreversible loss between the route and the working fluid may be reduced, actively reducing the system's entropy generation.
Keywords: Entropy generation, Nanofluids, heating section, metal foam, heat transfer.

I. INTRODUCTION

In recent years, there has been a growing interest in utilizing Nano fluids as a heat transfer medium in thermal systems. Nano fluids, which are colloidal suspensions of nanoparticles in a base fluid, have demonstrated enhanced thermal conductivity [1-3] and convective heat transfer properties compared to traditional fluids [9]. Many researchers have developed some empirical formulas of thermal conductivity [4-7]. The detailed review of the research on the preparation methods and thermal property parameters of nanofluids was presented in the literature [8]. Moreover, when these Nano fluids flow through porous media, such as porous structures, their heat transfer characteristics further improve due to increased surface area and interaction with the porous matrix [10]. Further, the analysis of entropy in thermal systems is of utmost importance in various engineering applications, as it provides insights into the system's efficiency, irreversibility, and overall performance [11].

Understanding and quantifying the entropy generation and transfer mechanisms in thermal systems with Nano fluids flowing through porous media are crucial for optimizing the system's performance and identifying potential areas for improvement. Entropy analysis provides a comprehensive approach to assess the irreversibilities and energy losses within the system, allowing engineers to design more efficient and sustainable systems [12]. After the ground-breaking work of Bejan [11] many scholars re-examined porous systems from the second law perspective. Cong Qi, et al [13] investigated the effects of metal foams with pore densities (20, 30, 40 PPI) on the exergy and entropy of TiO_2-water Nano fluids in a heat sink and experimentally studied it. Nano fluids with concentration of 0.3 wt% exhibited the highest exergy efficiency, and the metal foam with PPI = 40 showed the smallest entropy generation. M. Sheikholeslami, et al [14] numerically investigated the entropy behavior of Fe_3O_4-H_2O flowing within a porous media under a magnetic force impact considering non-darcy model. The outputs of the simulations showed that increasing permeability makes Bejan number. to decline, boundary layer thickness enhances with a rise of Lorentz force. They also suggested formulas for the estimation of the Bejan number and average Nusselt number. A numerical study of mixed convective flow in porous cavity with Al_2O_3 Nano fluid in an inclined channel (inclination angle = 0º to 360º) was presented by S. Hussain, et al [15]. The average values of Nusselt number, Bejan number, total entropy generation, entropy generation due to fluid friction and heat transfer showed enhancement with an increase in the inclination angle and had a maximum values at 135º. The entropy generation analysis of three different nanofluids copper, alumina and titania in porous asymmetric micro channel was done by S. Noreen, et al [16]. The copper–water nanofluid and Al_2O_3 nanofluid showed same enhancement for total entropy generation and Bejan number (Be) while, total entropy generation and Be number of TiO_2 nanofluid was lower than copper–water nanofluid and Al_2O_3 water nanofluid.

Although the carbon based nanoparticles have been used very rarely, Noreen S Akbar, et al [17] analyzed single-wall carbon nanotubes (SWCNT) nanoparticles with water as a base fluid through a ciliated porous medium by preparing mathematical model. An enhancement in Entropy generation was observed with rising values of both Brinkman number and Darcy number and was greater for SWCNT-nanofluids. Numerical investigation of Entropy generation due to conjugate natural convection–conduction heat transfer in a square domain was performed under steady-state condition [18]. The domain composed of square porous cavity heated by a triangular solid wall and saturated with a CuO–water nanofluid. It was found that the addition of nanoparticles increases the entropy generation, also the largest solid thickness and the lower wall thermal conductivity ratio manifest better thermal performance.

The various applications of graphene in different types of heat exchangers, electronic devices challenges and opportunities, by highlighting the advantages of using graphene was described by K. Natesan, et al [19]. An experimental investigation had been conducted for studying the effects of graphene nanofluids by M. Fares, et al [20] on the convective heat transfer in a vertical shell and tube heat exchanger. A maximum increase in the heat transfer coefficient of 29% was observed using 0.2% graphene/water nanofluids. Furthermore, the mean thermal efficiency of the heat exchanger was enhanced by 13.7%. To analyze thermo-physical properties of aqueous Graphene Nanoplatelet (GNP) at various mass concentrations of GNPs, an experimental investigation was performed within a microchannel at various heat flux and Reynolds number by M.M. Sarafraz et al [21]. The enhancement in the thermal performance of the system was attributed to the thermophoresis effect, Brownian motion and the enhancement in the thermal conductivity of the nanofluid due to the presence of the GNP nanoplatelets. These transport phenomenons (thermophoresis effect, Brownian motion) are well described by S. Belorkar, et al [22].

II. SPECIFICATIONS

Table I Specifications

Sr. No.	Material and instruments	Characteristics
1	Metal Foam	Size: 150*100*20 mm PPI : 10, 20 ppi Porosity: 95%
2	Thermocouple	Model: K Type Measuring range: 0-400 ºC Probe Size: 1 x 150mm/0.04" x 6"(d*l)
3	Heating pad	Heating Temperature: 120-150°C Size: 50 x 100mm (total 3 in number) Power: 15W Voltage: DC 12V
4	Differential pressure transmitter	Measuring range: 0 to 250 Psi Power supply: 24V DC
5	Data Acquisition system	Model: USC-2010 Supply voltage: 230V AC
6	Pump	Operating Voltage - 12 Volts DC Operation: Centrifugal
7	DC battery	Voltage: 12 V Capacity: 7 Ah

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III. EXPERIMENTAL SETUP

The four basic components of an experimental setup are a heating section, a flow section, a heat exchanger, and a data collection device. A heating section with the following outside measurements: 165*120*40 mm is made out of a fiber sheet that contains open-cell copper-porous metal foam.

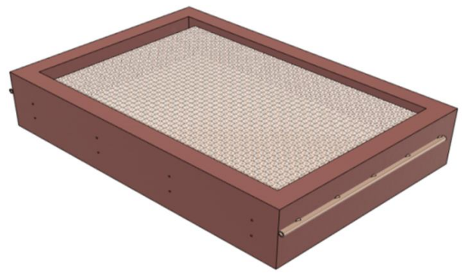


Fig 1. CAD Design for the heating section

Fig 2. Actual heating section

By laying this copper metal foam on a thin copper plate with a 2 mm thickness that is being heated by a silicon heat pad, heat is removed from the area. There is a 45 W total heat input. Along the length of the heating section, there is an inlet and outlet. A header of four 6 mm diameter copper tubes is installed at the heating section's inlet and outflow to guarantee that the nanofluid is distributed uniformly throughout. The copper tubes of the input and outlet header are spaced uniformly apart by 25 mm.

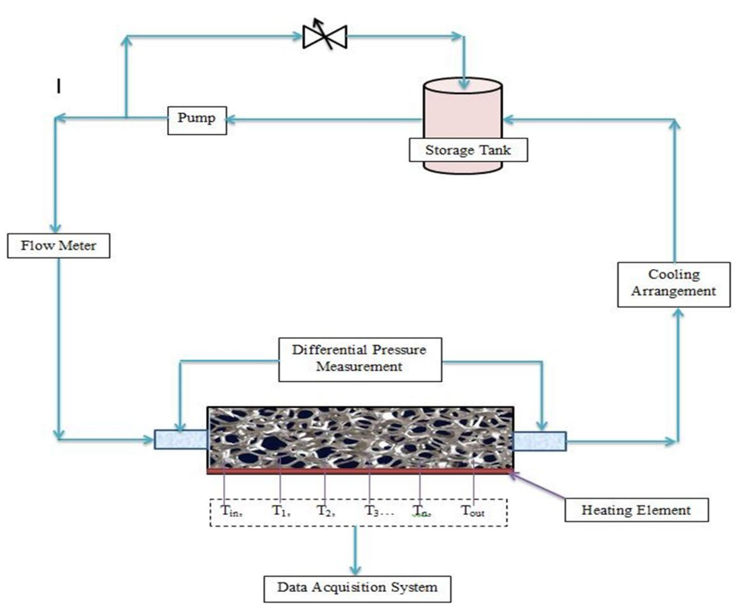


Fig 3. Schematic Diagram of Experimental Setup

For investigation, copper metal foam with dimensions of 150*100*20 mm and porosities of 10, 20, and 40% is employed. The electrical circuit contains parallel connections between these heating pads. A battery with a capacity of 7 Ah (12V DC) is utilized to supply the heating pads with DC power. Eight k-type thermocouples that are evenly distributed along the length of the heating section are used to measure temperature differences in the copper metal foam and along the length of the heating section. Additionally, two additional k-type thermocouples are available for measuring the temperatures of the nanofluid's input and outflow. A differential pressure transmitter measures the pressure difference between the intake and outlet. Temperature and differential pressure readings are captured using the USC-2010 Data Acquisition System (230V AC). Through the ATC-820 (RS-485 USB interface convertor), the recorded data of readings is sent to the computer's DPM Data logger software and saved there.

These experiments make use of the Copper Oxide-water nanofluid (CuO-H2O) in various concentrations. For this investigation, the concentrations were 0.1 wt%, 0.2 wt%, 0.3 wt%, 0.4 wt%, and 0.5 wt%, respectively. The schematic diagram of the experimental apparatus is shown in Figure 1. $CuO\text{-}H_2O$ nanofluid with a 0.1% concentration is passed through a specific metal foam, let's say 10 PPI, at varied flow rates. By-pass valves that bypass excessive amounts of nanofluid are used to manage this flow rate. This nanofluid absorbs heat from a copper plate to flow through the metal foam's pores.

A heat exchanger that uses water as a cooling fluid passes this heated nanofluid across it. Heat is lost, and it returns to the storage tank. The heat exchanger is composed of a copper cooling coil with a 6 mm diameter and four complete turns measuring 11 cm in diameter. After that, the heat exchanger's cool nanofluid is kept in a storage tank. The heating part receives nanofluid from the storage tank through a 12V DC pump. PVC tubing with a 6 mm diameter is employed in the experimental setup, and a flow meter is used to measure the flow of the nanofluid.

IV. ANALYSIS

The following relationships are employed in this research because the main focus of this experimental investigation is on entropy generation for convective heat transfer of Nano fluid in porous metal foam. The experimental research of Ping Li, et al[23] is represented by the relations used in the current work.

A. *Thermal Entropy Generation (S'_t)*

Numerous factors affect the thermal entropy generation in thermal systems using porous metal foam and nanofluid. The overall entropy generation is significantly influenced by the porosity, geometry, and size of the metal foam, as well as the concentration, type, and size of the nanoparticles in the nanofluid. Convective heat transmission is additionally influenced by the flow rate, temperature gradients, and fluid characteristics, which has an impact on entropy generation. The relationship for the generation of thermal entropy is given as

$$S't = \frac{q''^2 \pi D^2}{kT^2\, Nu}$$

Where,

q'' = surface heat flux rate, w/m^2

D = hydraulic diameter, m

k = thermal conductivity of Nano fluid, w/m k

T = temperatures, k

Nu = Nusselt number

B. *Frictional Entropy Generation (S'_f)*

As a result of the added resistance that the nanofluid and porous metal foam add to the fluid flow, the system experiences more frictional effects. The complex shape of the porous metal foam and the nanoparticles suspended in the nanofluid cause extra interfacial interactions and flow disruptions, increasing energy loss and entropy production. These frictional effects produce heat and irreversibilities, which help the system produce entropy overall. The frictional entropy generation relation is given as

$$S'f = \frac{32m^3}{\pi^2\rho^2 T}\frac{f}{D^5}$$

Where,

m = mass flow rate, kg/s

ρ = density of nanoparticles and fluids, kg/m^3

T = temperatures, k

f = frictional resistance coefficient of fluids

D = hydraulic diameter, m

C. Total Entropy Generation (S'_{Total})

As a key indicator of irreversibility, entropy generation (S'Total) is divided into two sections: frictional entropy generation (S'F) and thermal entropy generation (S'T)

$$S'_{Total} = \frac{q''^2 \pi D^2}{k T^2\, Nu} + \frac{32 m^3}{\pi^2 \rho^2 T}\frac{f}{D^5} = S'_T + S'_F$$

V. RESULT AND DISCUSSION

According to numerous studies, the entropy generation analysis can be used to optimize the geometric sizes of the heat exchange system. Entropy generation study offers important insights into the irreversibilities and energy losses taking place within the system. This chapter provides a thorough analysis of the mechanisms that produce entropy, their dependency on numerous factors like the metal foam PPI and nanoparticle mass fraction, and their effects on the overall efficiency of nanofluid flow in metal foam porous media**.**

A. Thermal Entropy Generation

Fig 4 illustrates the impact of various metal foam PPIs (10, 20 and 40) on the formation of thermal entropy at various nanoparticle mass fractions (0.0 wt%, 0.1 wt%, 0.2 wt%, 0.3 wt%, 0.4 wt%, and 0.5 0.0 wt%). The structure of metal foam with enhanced heat transmission properties determines that PPI = 40 produces less thermal entropy than PPI = 10 and PPI = 20. In metal foam, as the PPI value rises, the number of pores increases, pore width shrinks, and the heat transmission area grows. The increase in heat transport is facilitated by the pore density.

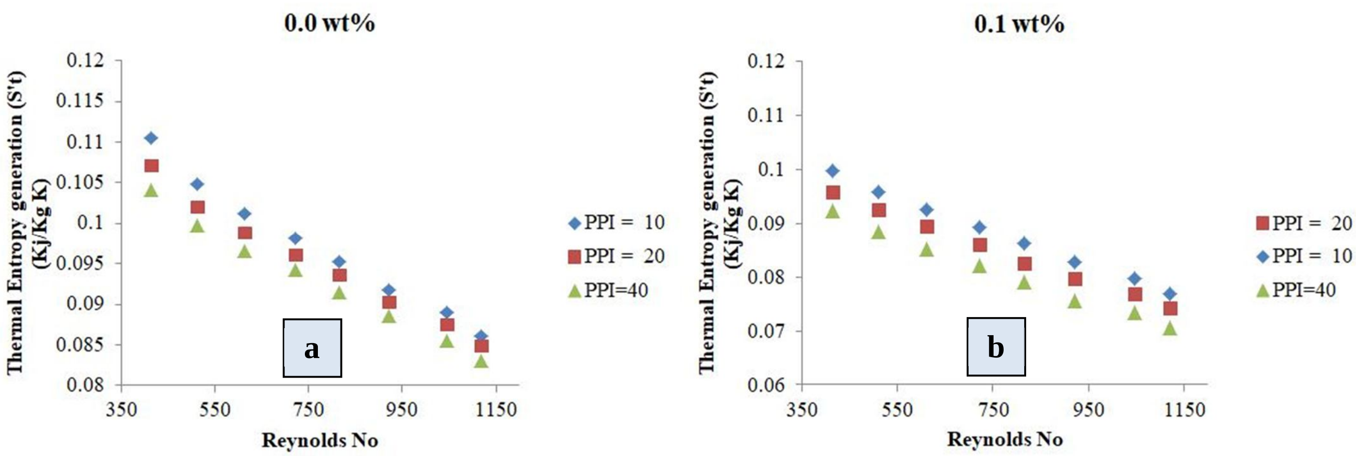
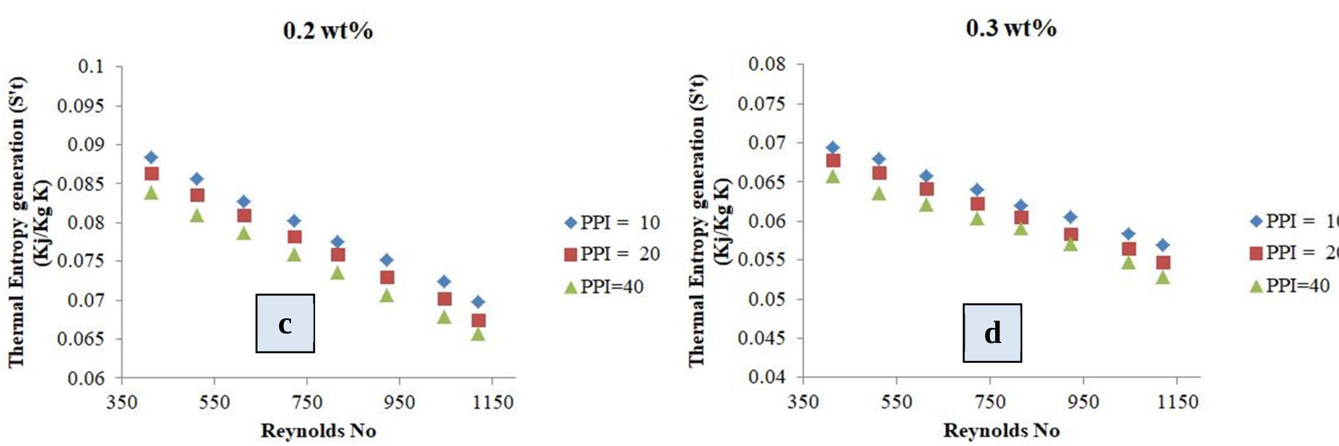


Fig 4. Thermal Entropy Generation, a (β = 0.0 wt %) (Water), b (β = 0.1 wt %)

Additionally, from the standpoint of the thermal entropy generation formula, the convection heat transfer coefficient can be enhanced with the use of nanofluids, which also embodies enhanced heat transfer of nanofluids by increasing the product of the Nusselt number and the thermal conductivity in the denominator of the thermal entropy formula.



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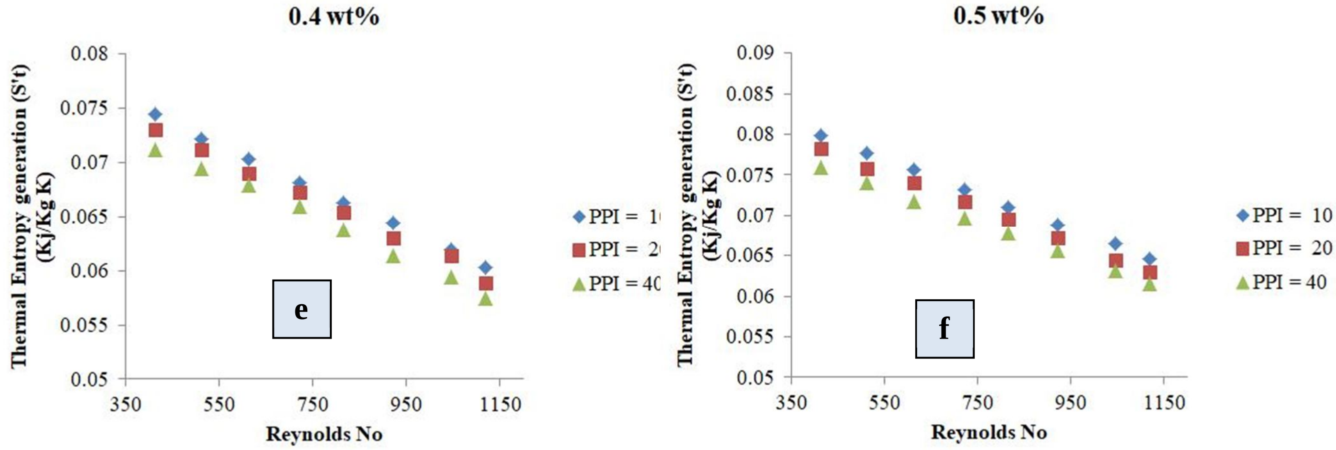

Fig 4. Thermal Entropy Generation, c (β = 0.2 wt %), d (β = 0.3 wt %), e (β = 0.4 wt %), f (β = 0.5 wt %)

Thermal entropy generation is reduced as a result of the combined effects of the two components, and comparable trends are observed for nanofluid concentrations of 0.1, 0.2, 0.3, 0.4, and 0.5 wt%. For metal foam with varied PPI (10, 20 and 40), the smallest thermal entropy generation is discovered at a nanoparticle mass fraction of 0.3 wt%, and its value is calculated to be 0.052 KJ/Kg-K.

A. Frictional Entropy Generation

In Fig 5, the frictional entropy generation at constant nanoparticle mass fractions (0.0 wt%, 0.1 wt%, 0.2 wt%, 0.3 wt%, 0.4 wt%, and 0.5 0.0 wt%) is demonstrated to be affected by varying metal foam PPI (10, 20 and 40). According to the figure, the frictional entropy generation at PPI = 40 is higher than at PPI = 10 and PPI = 20, which is a result of the metal foam's structural characteristics.

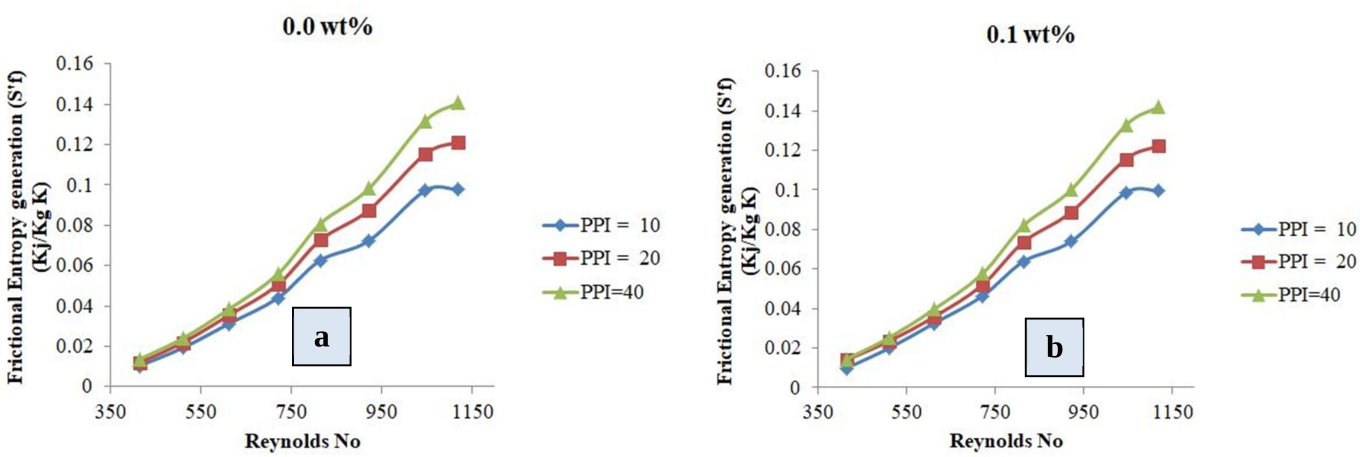

Fig 5. Frictional Entropy Generation, a (β = 0.0 wt %) (Water), b (β = 0.1 wt %)

As the metal foam's PPI value rises, the pore diameter and permeability all decrease, and the flow resistance of fluid increases. From the frictional entropy generation formula, it can be deduced that frictional entropy generation is proportional to working fluid density and to the third power of working fluid mass flow rate, which is the primary cause of the noticeably large increase in frictional entropy generation value. The increase in viscosity may be caused by the mass fraction. The frictional entropy generation of nanofluids increases with the addition of mass fraction and Reynolds number under the combined action of both components.

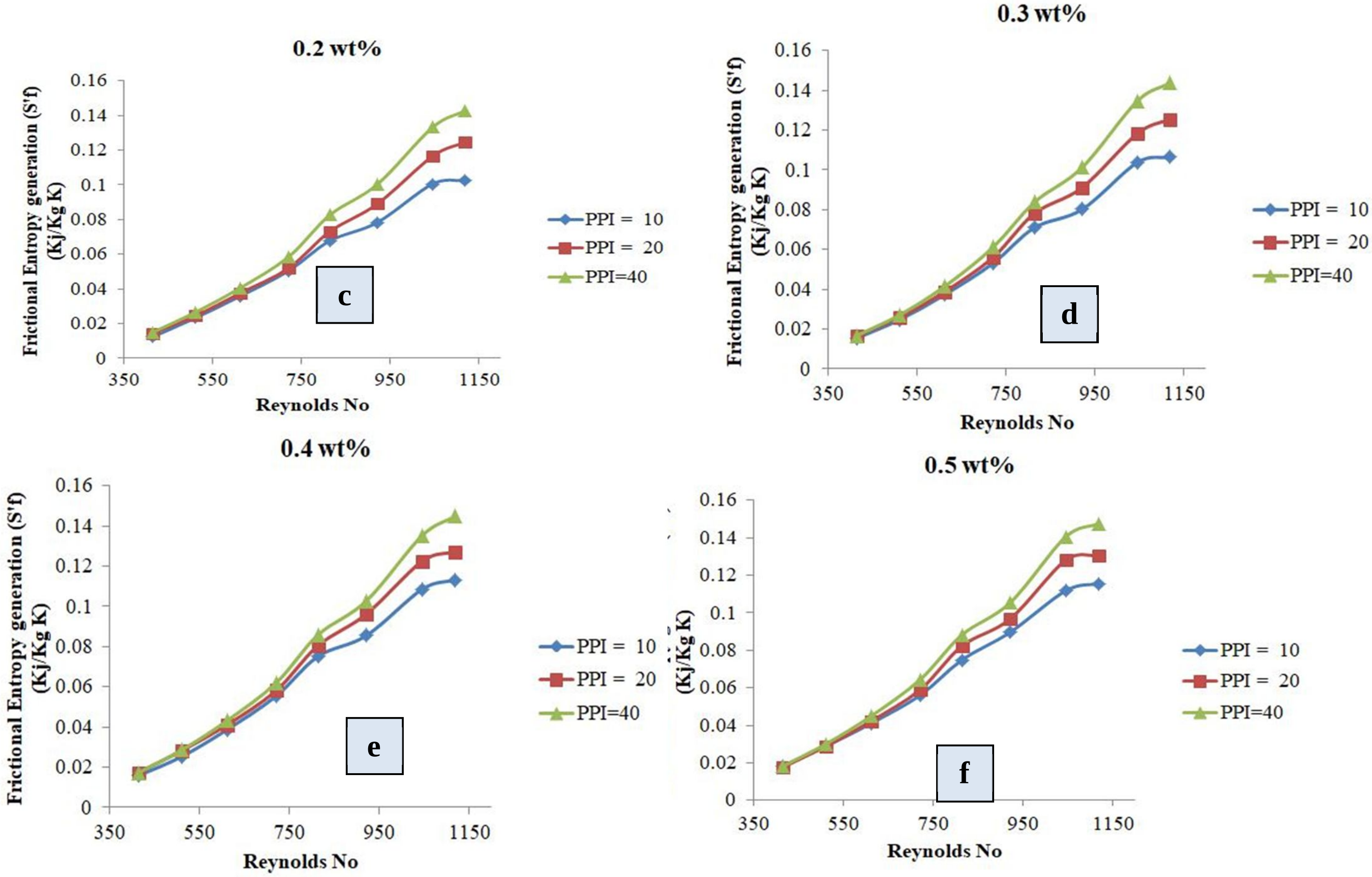

Fig 5. Frictional Entropy Generation, e (β = 0.4 wt %), f (β = 0.5 wt %)

At water with metal foam of varied PPI (10, 20 and 40), the smallest frictional entropy generation is discovered at a nanoparticle mass fraction of 0.0 wt%, and its value comes out to be 0.0987 Kj/KgK at the largest value of Reynolds number.

B. *Total Entropy Generation*

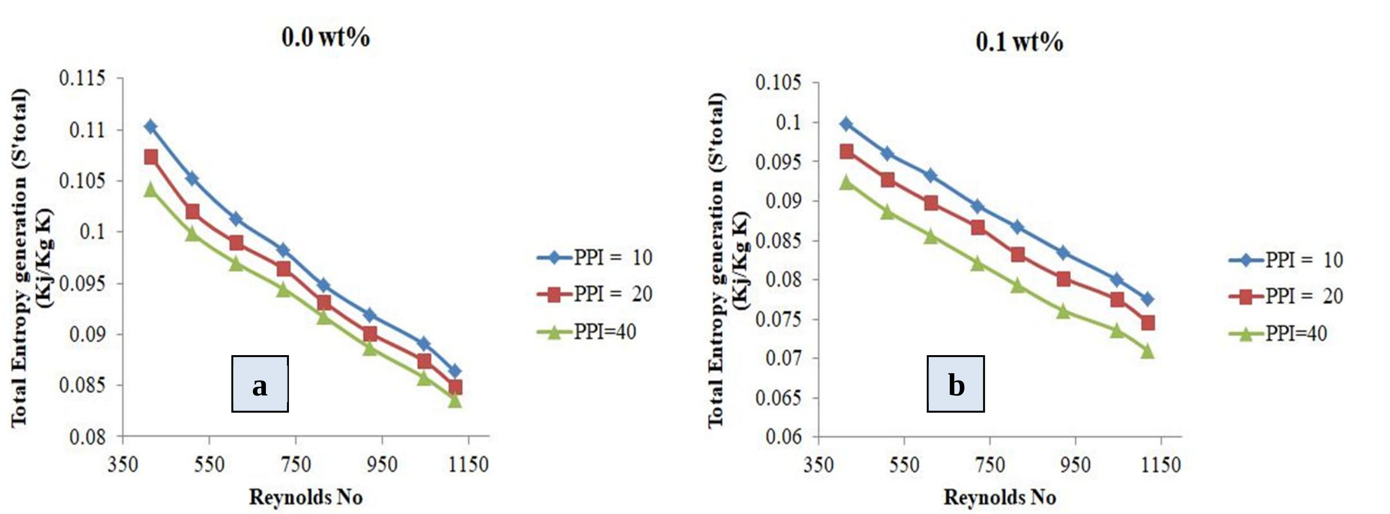

Fig 6. Total Entropy Generation, a (β = 0.0 wt %) (Water), b (β = 0.1 wt %)

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On total entropy generation at constant nanoparticle mass fractions (0.0 wt%, 0.1 wt%, 0.2 wt%, 0.3 wt%, 0.4 wt%, and 0.5 0.0 wt %), the effects of varied metal foam PPI (10, 20 and 40) are shown in Figure 3. PPI = 10 generates more overall entropy than PPI = 20 and PPI = 40 combined.

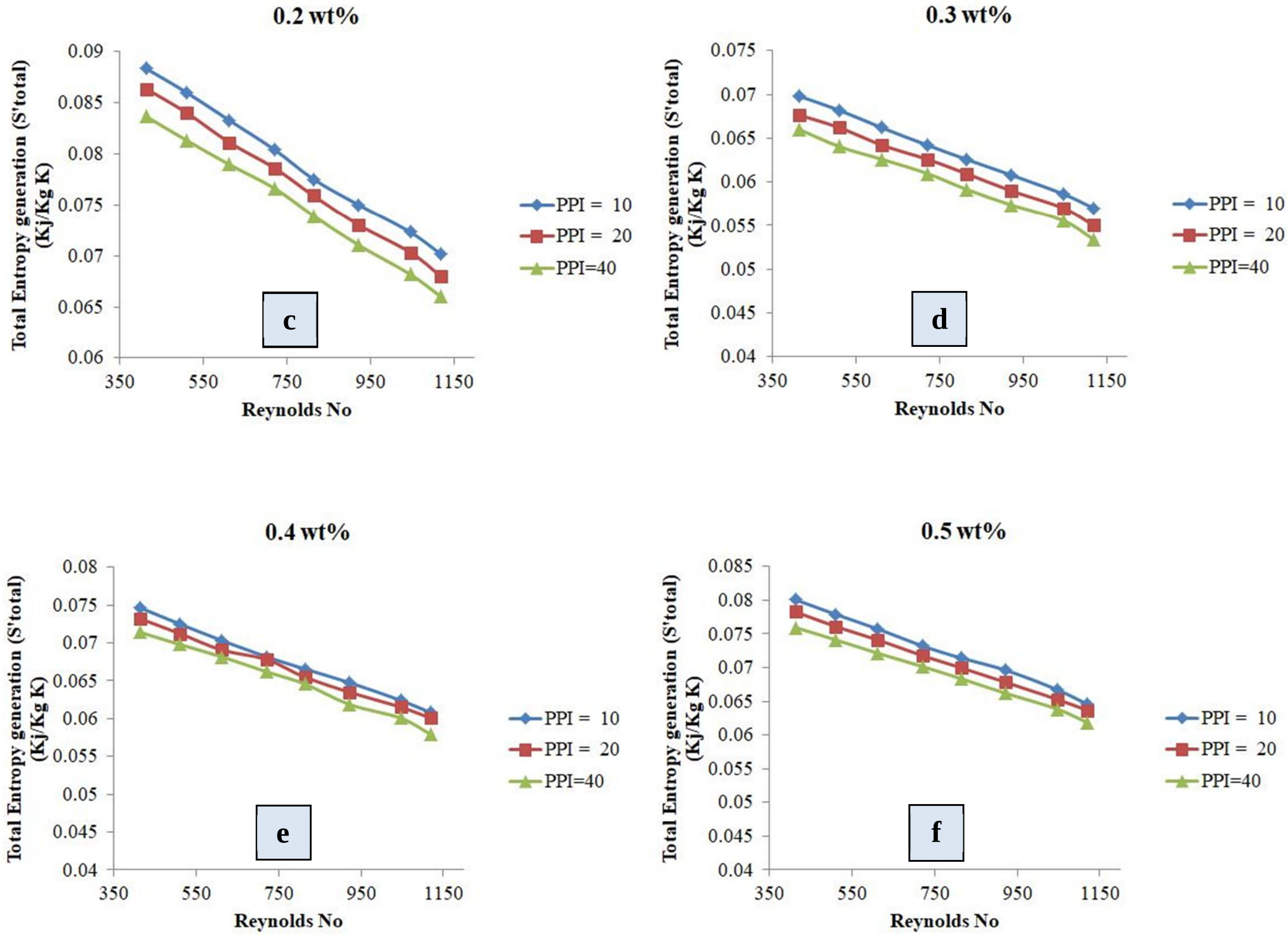

Fig 6. Total Entropy Generation, c (β = 0.2 wt %), d (β = 0.3 wt %) e (β = 0.4 wt %), f (β = 0.5 wt %)

The graph shows that frictional entropy generation makes up the least amount of total entropy generation, while thermal entropy generation makes up the majority. The particular causes have already been explained in the previous section on thermal and frictional entropy creation, but the change rules for total entropy generation keep pace with those for thermal entropy generation. The overall entropy generation of metal foam PPI = 40 is lowest when the concentration is = 0.3 wt%. It shows that under this ideal circumstance, the irreversible loss between the channel and the working fluid can be decreased, which actively contributes to lowering the system's entropy creation.

VI. CONCLUSION

Experimental investigation is being done on the entropy generation in thermal systems with copper metal foam that has a range of pore densities (PPI = 10, 20, and 40) and nanoparticle mass fractions (0.0 wt%, 0.1 wt%, 0.2 wt%, 0.3 wt%, 0.4 wt%, and 0.5 0.0 wt%).

The following are some important conclusions:

1) According to the graph, frictional entropy generation in nanofluids is significantly higher than in pure water and grows with proportion. The formation of frictional entropy is greatly influenced by the Reynolds number.
2) The total amount of nanofluids first declines, then increases with an increase in mass fraction and decreases with an increase in PPI. The least amount of total entropy is produced by nanofluids with = 0.3 wt% under PPI = 40.

3) The frictional entropy generation of nanofluids increases with the increase of mass fraction and Reynolds number under the combined action of working fluid density and mass flow rate.
4) It shows that under this ideal circumstance, the irreversible loss between the channel and the working fluid can be decreased, which actively contributes to lowering the system's entropy creation.
5) According to the thermal entropy generation formula, the use of nanofluids can increase the convection heat transfer coefficient of the channel. This is because the thermal conductivity and Nusselt number product, which is also a manifestation of improved heat transport of nanofluids, can be raised in the denominator of the thermal entropy formula.
6) While increasing pressure drop, metal foam has a greater potential for heat transfer.
7) The following tasks entail examining the impact of the local metal foam filling and different rotation angles on the heat sink.

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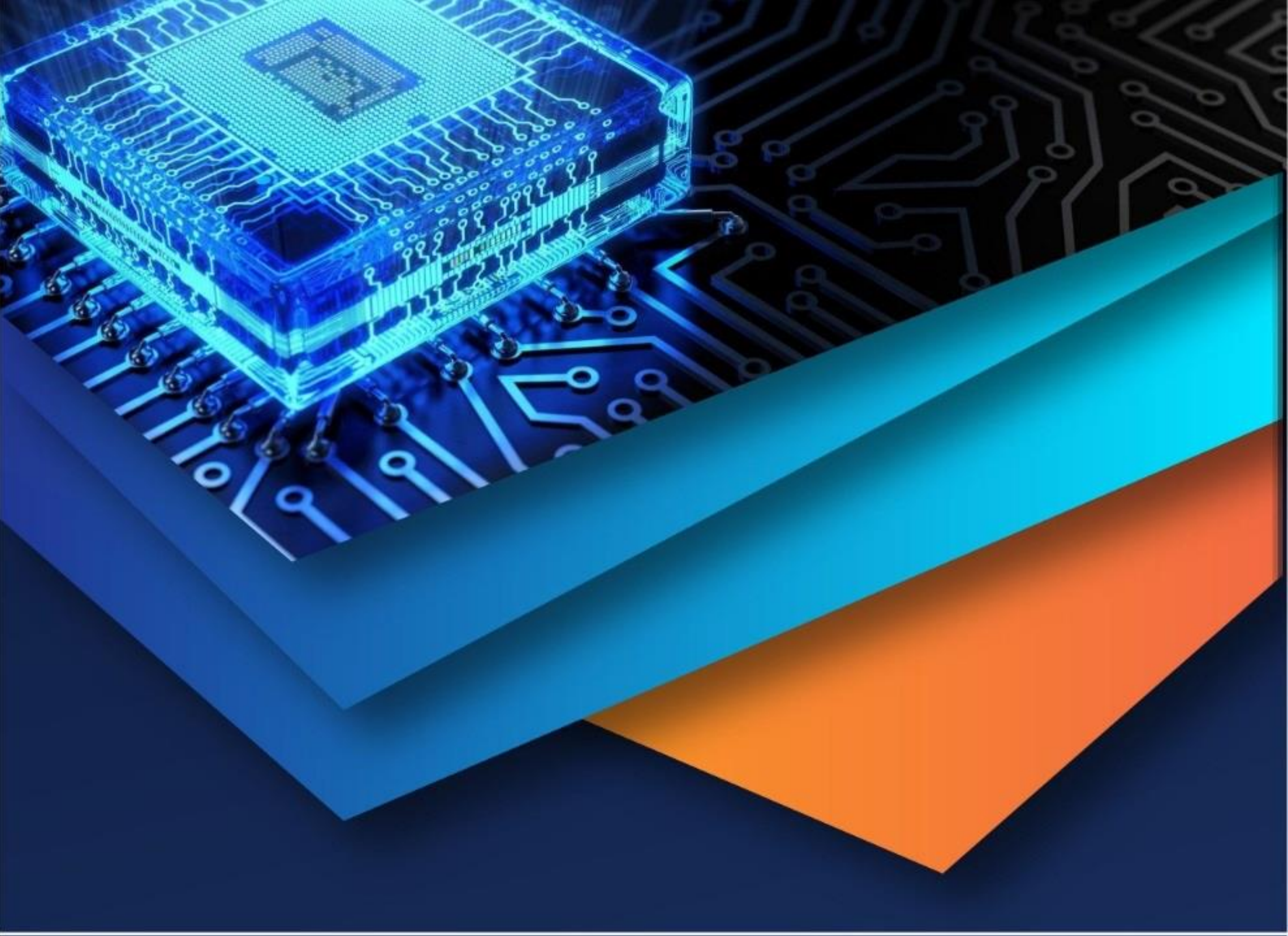

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