International Information and Engineering Technology Association
Advancing the World of Information and Engineering

International Journal of Heat and Technology
Vol. 42, No. 3, June, 2024, pp. 1037-1057
Journal homepage: http://iieta.org/journals/ijht

A Review Study of Different Effects on the Performance of Natural Convection Within Enclosures

Younus Janabi[1*], Tudor Prisecaru[1], Valentin Apostol[1], Qusay Rasheed Al-Amir[2]

[1] Department of Thermotechnics, Thermal Machines and Refrigeration Systems, Polytechnic University of Bucharest UPB, Bucharest 060042, Romania
[2] Air Conditioning and Refrigeration Techniques Engineering Department, Al-Mustaqbal University, Babylon 51001, Iraq

Corresponding Author Email: younus.janabi90@gmail.com

https://doi.org/10.18280/ijht.420331

Received: 8 March 2024
Revised: 20 May 2024
Accepted: 3 June 2024
Available online: 27 June 2024

Keywords:
natural convection, MHD, nanofluid, porous media, FEM, cavities, heat transfer

ABSTRACT

The concept behind this article is an extensive analysis of the most recent findings about free convection thermal flow in an enclosure or cavity, as well as the methods employed to enhance heat transfer (HT). There are different heat transfer enhancers such as (a) nanofluids, (b) porous media, (c) large particle suspensions, (d) phase-change devices, (e) flexible seals, (g) fins and microfins, and (h) ultra high thermal conductivity composite materials. The majority of heat transfer enhancement techniques that use porous media, fins, and nanofluids are reviewed in the literature. In this review, both experiments and theoretical studies on different cavities are highlighted through investigating the subsequent parameters: impacts of the configuration of the cavities, effect of the type of nanoparticles, significance of cavities in nanofluids, effects of the cavities' tilt angle, wave amplitude, the magnetic field's (MF) influence in cavities, and cooler and heater impacts. Through a review of the literature, it was found that the use of nanofluid in all forms of cavities increases its thermal performance. The most used cavity is square, which has many applications. The results obtained from previous studies can be used to improve the design and heat refinement of the geometry applied in diverse energy systems. Additionally, as the Hartmann number rises, there is a rising tendency observed in the average Nusselt number. Furthermore, as the concentration of nanofluid particles and Rayleigh numbers rise, so does the rate of heat transfer. The heat transfer within the cavity is improved by the hybrid nanoparticles. The amount of the augmentation would, however, decrease as the concentration of nanoparticles increased. The lowest volume fraction of nanoparticles, $\varnothing$ = 0.2 vol.%, showed the greatest increase. Also, the inner wave affects the flow pattern when the wave amplitude rises but the flow strength stays constant. The most important findings showed that the heterogeneous porous medium transfers heat more effectively than the homogeneous porous medium in different enclosures.

1. INTRODUCTION

For decades, the topic of improving the heat transfer properties of the liquids has been an important matter for researchers to enhance the quality of thermal transfer in diverse system types. A different technique has been used by researchers to achieve this aim. Generally, heat transfer techniques play an effective role in reducing thermal resistance by creating turbulence as means of force convection or by rising the effect of HT area. These techniques need to increase the pumping power required when implemented in systems, and this leads to higher systems costs. Because of this circumstance, researchers are searching for other methods that are more affordable and feasible. one of the techniques to refine thermal transfer is to change the thermal properties of the base fluids. Through previous studies, microparticles were used to obtain an improvement in the properties of the based fluids in terms of thermal transfer improvement. While it has achieved some successes, there are problems with the system requirements. The most important of these problems are the size of the microparticles, which is considered relatively large, and this in turn causes blockage during operations. The ability of a microparticle to improve heat transfer requires more work due to a drop in fluid pressure [1]. New techniques emerged that are more advanced in material technology and are characterized by their small size compared to microparticles, and researchers have begun to be able to employ them in processes, and they are known as nanoparticles.

The past few years, Authors have concentrated on improving heat transfer in industrial applications. The majority of the applications use pure fluid, like Oil, EG, and water as liquid cooling, which does not have a high heat conductivity, which restricts the improvement in the rate of thermal transfer [2]. Using novel fluids, like nano-fluids, improves thermal efficiency. Nano-fluid defined as mixture of based fluid and dispersed nanometer size, which is presented for first time by Choi and Eastman [3] the purpose of this mixing to develop thermal Transport fluids with significant conductivities. The heat conductivities of the conventional foundation fluid can be essentially improved through incorporating metallic nanoparticles to the foundation fluid and enhancing the HT of these fluids. Nanofluids are widely used because of substantial amount of engineering uses and Industrial implementations such as Air conditioning, refrigeration, processor of mobile computers, etc.

Heating or cooling obtained from convective HT is considered among the finest desirable HT methods in heat engineering processes because of the advantages it possesses in terms of economy and simplicity. There are numerous uses for natural convection in numerous technological domains when it takes on different geometric configurations, such as heat storage systems, aerospace engineering, the automotive industry, microelectronic device design, textile engineering etc. However, scientists are continuously searching for ways to modify the system's or the working fluid's geometry in order to accomplish more effective thermal transfer modes [4-6]. The study of free convection HT in a cavity/ enclosure saturated with nanofluids and porous media has acquired significant interest, such as the storing grains of food under fumigation, Thermal control of electronic devices, the cooling of aluminum billets, solar collector, etc. The fluid motion and convection HT within the enclosure filled with porous media and nanofluid has been widely examined for various conditions and scenarios across numerous fields work [7]. Azzouz and Hamida [8] studied a numerical study in 2D to determine the extent to which HT is impacted by four heating cylinders in a circular shell under a MF. Using Fine element approach to solve the mathematical model. The FEM basis COMSOL Multiphysics has been utilised to solve the mathematical model equations. It was discovered that the small value of Rayleigh number in the present of the Hartmann number has no impact on the Nusselt number. Meanwhile, a high value of the Rayleigh number changes the heat transfer from conduction to convection because the buoyancy force increases. It was also observed that the Nusselt number decreases in in present of Ha number at high Rayleigh number. Pal et al. [9] performed how HT is influenced with two cylinders heater inside a cavity and applied magnetic field. The fluid assumed Newtonian and incompressible. The key equations are solved applying FEM numerical solver. At lower value Ra, the outcome revealed that the thermal transfer did not affect by imposed to MF, while for high Ra, there was a complex interaction between thermophysical properties and magnetic field to determine the HT rate. With rise the dimensionless spacing between the cylinders (S) from 0.1-0.2 the Nu decrease initially at higher Ra, then slightly increase with Yuan et al. [10] investigated the effect of the Ha, Ra, magnetic field tilt on the entropy generation and average Nusselt number of semicircular cavities saturated with CuO-H_2O nanofluid and placed the thermal sources in the core of the enclosure. The results showed that when Ra was increased, there was a noticeable improvement in the entropy generation and thermal transfer performance. The total generation of entropy reduced with increased in Hartmann number. The MF inclination has a greater impact as the Hartmann number rises. On the whole, the thermal transfer of nano-fluid was negatively affected when an external MF was applied. A change in the angle of the MF is crucial in regulating the heat transfer productivity of nanofluid to a certain extent, the average Nusselt number reaches a greater value at angle of =30.

Numerical simulation of free thermal flow in rectangular enclosure have been carried out by Begum et al. [11] to look into how unstable free convection flow is affected by volumetric generation and viscous dissipation. Assumed to be Newtonian fluid and incompressible. The left wall was cooled, and the right wall was hot, Whereas the other walls were adiabatic. A numerical method based on iterative successive over relaxation together with Finite different scheme technique and implicit finite different technique, have been employed to solve the key equations numerically. It has obviously been observed that there is a decrease in local and average Nu with rise Eckert number. As aspect ratio elevates the thermal transfer of average and local Nu decrease along with heated vertical wall. As rises the Pr from 0.7 to 15 the Average and local Nu elevate, also the Nu increase significantly with rises Ra, whereas Nu reduces with increase the viscous energy loss and heat generation within the systems. Berrahi et al. [12] used free convection in a laterally enclosure filled with an electroconductive fluid in the present of a thermal source and an external magnetic field. The SIMPLER algorithm with FVM was employed to solve the model of governing equations MHD flow. A magnetic field was used in two directions to obtain the best control of the flow. When the MF was horizontally applied, the strongest stability of the flow is obtained with internal thermal generation. It was observed that the Nu increase with increasing Pr with the presence of a thermal source and the influence of the MF on the Nusselt number is decreased at cold side and increased at hot wall and this is because of the presence of internal heating ($S_{Q.}$). The average Nu increases with the elevate in Gr and A with a presence of high value of internal heat source.

Numerical simulation of MHD free convection was carried out by Saha et al. [13], to examine the heat flux inside rectangular cavity is saturated with tri-hybrid nanofluid (Graphene, carbon Nanotube, Al_2O_3, and water). It was imposed to a uniform internal generation within the system and magnetic field. The research also has investigated the influence of MF direction and strength on the free convection flow. The key equations were solved by the applying of the FEM. The outcome showed that rising the volume fraction of nanoparticles led to an increase in the average Nu. It was noticed that the Nu decreased with an increase in Ha and this impact became more noticeable at greater numbers of Ra. A two-dimensional numerical investigation of natural convection was conducted by Bilal et al. [14] to investigate the natural convection flow of an MWCNT-water in a star shaped enclosure and containing a hot rectangular baffle. Along the x direction a regular MF is employed to exhibitor convective flow created by differences in density. The finite element approach base software COMSOL-muti-physics was employed to solve the dimensionless mathematical formulations numerically. Laminar, Incompressible, and steady were considered and assumed no-slip at all the boundaries. Increasing the spatial density ratio of the MWCNT-water increased the local Nu. The thermal flow rate decreases with a rise the magnitude of magnetic field.

Khelifa et al. [15] numerically modelled the three-dimensional flow and HT convection of a solar energy utilizing (Al_2O_3-water nanofluid and Air). Figure 1 shows a bi-hybrid fluid PVT module. Figure 2 depicted the absorber panel's placement, the tubes, and the shape of the solar panel. The employ different concentration of Al_2O_3-nanofluids PVT systems could be significantly enhanced their performance. It was found that in comparison to a traditional PV system, the use of a 1% condensation of (Al_2O_3–water) nanofluid increases the heating effectiveness of air by 4.92% and water by 41.19% respectively. This results in a total enhance in heat efficiency (blending air and water) of 35.72%. In the present work, a comprehensive review is conducted on the simultaneous application of nanofluids and porous media for heat transfer enhancement purposes in thermal systems with different geometries, cavity tilt angles, type of nanoparticles, and magnetic fields.

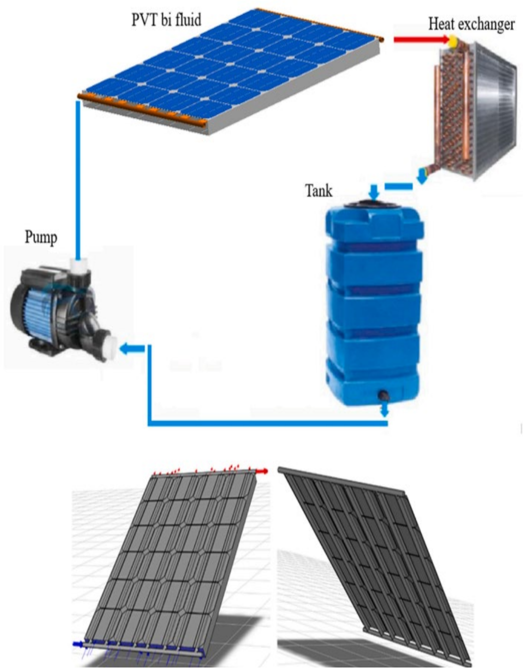


Figure 1. View of a bi-hybrid fluid PVT module [15]

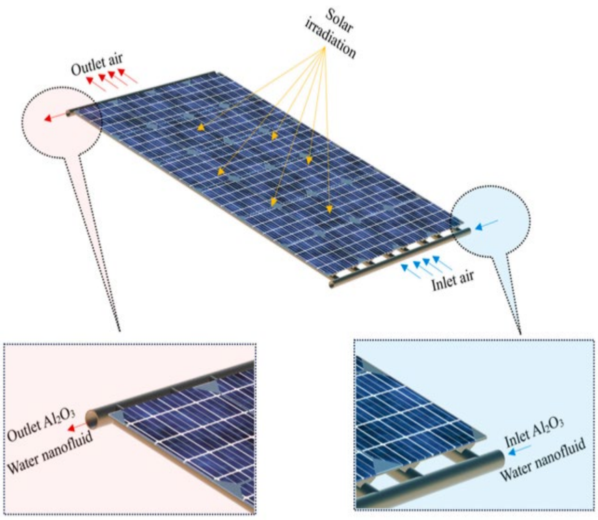


Figure 2. Image of the tubes that are beneath the absorber and solar panel [15]

2. THE EFFECT OF THE CAVITY GEOMETRY ON THE HT PERFORMANCE

The different geometries of enclosures have numerous advantages in several applications, e.g., open enclosures such as hexagonal, triangular, trapezoidal, and ellipsoidal were used in building cooling and heating, the cooling of the electronic equipment, and automotive applications. L-shaped cavities have been utilized in cooling processes of chemical reactors, nuclear and electronic elements [16].

The natural convection inside square cavities have attracted a lot of interest because of the numerous of uses and the significance of these enclosure. technology and Science have formed continuous entitlement and considerable developments in each portion of human activity such as pharmaceutical industries, manufacturing industries, biomedical applications, and cooling and heating electronics [17, 18]. computational simulation of free convection inside a square cavity consisting of eight types of nanofluids were examined to carry out the impact of various parameters (tilt angle, volume fraction of nanoparticles, Ha, and Ra by Nurul Huda et al. [19]. The results noted that the best nanofluid is cobalt kerosene, which has the extreme thermal flow rate compared with to seven other kinds of nanofluids. The result either indicated that when the magnetic field inclination is 90 and period number = 1, optimal thermal performance is achieved. computational analysis of natural convection of Titanium Oxide-water nanofluid within square enclosure was studied by Khan et al. [20]. The FM approach was applied to solve key equations numerically. This study has observed that the high value of Ra led to enhance the HT and improved the local Nu, simultaneously it revealed that the heat flow raised with increased the spatial density ratio of nanoparticles. Faraz et al. [21] numerically implemented a of free convection of Cu-water in hexagonal with fitted square enclosure was examined to investigate the fluid flow and HT. COMSOL direct solver and Newton method have been employed to solve discrete nonlinear processes. they were observed that the thermal flow elevated with raised the value of volume fraction of nanoparticles. It was either found that the Nu increased with increasing volume fraction and Ra. Rashid et al. [22] discussed the free convection inside square enclosure with fixed a circular barricade at the core and carry out the influence the nanoparticles shapes on the flow of nanofluids. Three types of nanoparticles (column, sphere, and lamina) were used to explain the enhancement of HT. They were found that the higher performance of nanoparticles in lamina shape in terms of heat transfer and temperature distribution. Saha et al. [23] examined two-dimensional numerical simulations of Magnetohydrodynamic free convection inside square wavy cavity saturated with Al_2O_3-H_2O nanofluid and A single heated fin was attached bottom vertically in the middle of the cavity. FE approach have implemented to solve the mathematical model. It was discovered that heat transfer increases by up to 3% when adding nanoparticle (Al_2O_3) to pure water. It was also found that the shape of the nanoparticles has significant impact on the heat transfer. The blade-shape of nanoparticles reaches up to 7.65% enhancement, while spherical shape nanoparticles reaches up to 2.86%.

2D numerical investigate of free convection flow inside a square enclosure saturated with Al_2O_3-Cu hybrid nanofluids and heated by two sources to generate thermal from the inside has been implemented by Hiki et al. [24]. The FV technique was manipulated to solve the key equations and thus executed in a computational code in the Fortan language base on SIMPLER algorithm. The temperature reduces by up to 18% when adding nanoparticles (Al_2O_3-Cu) to pure water. It was also found the temperature reduces further by up to 12% at Rayleigh number ($Ra \leq 10^5$)when installing fins on the blocks surfaces. Sreedevi and Reddy [25] implemented finite difference technique to study effect heat radiation and MF on free convection within a square enclosure saturated with TiO_2 as nanoparticles and (EG) as base fluid employing the Tiwari-Das nanofluid model. They were found that the high value of MF raised the temperature of EG-TiO_2 inside the cavity. A higher value of Ra can be resulted higher value of Nu [26-28]. Two-phase free convection within square enclosure saturated with Cu-water is carried out by applying method of Lattice Boltzmann to solve the key equations. Eqs. (1) and (2) can be applied to examine the heat conductivity and effective viscosity of the nanofluid after adding nanoparticles. It was observed that increasing the values of nanoparticles and Rayleigh number leads to a rise in the local Nusselt number along the cooler wall.

$$\mu_{nf} = \frac{\mu_f}{(1-\emptyset)^{2.5}} \tag{1}$$

$$\frac{k_{nf}}{k_f} = \frac{k_p + 2k_f + 2\varphi(k_f - k_p)}{k_p + 2k_f - \varphi(k_f - k_p)} \tag{2}$$

where, f is the base fluid and the subscripts n_f, ϕ, s denotes the nanofluid, nanoparticles volume fraction, and solid phase respectively. The heat expansion, heat capacity, and the density of the nanofluid were achieved by applying the volume average technique.

$$\beta_{nf} = (1-\varphi)\bar{\beta}_{(bf)} + \varphi\bar{\beta}_{(sp)} \tag{3}$$

$$(\rho c_p)_{(nf)} = (1-\varphi) * (\rho c_p)_{(bf)} + \varphi(\rho c_p)_{(sp)} \tag{4}$$

$$\rho\beta_{nf} = (1-\varphi) * (\rho\bar{\beta})_{(bf)} + \varphi(\rho\bar{\beta})_{(sp)} \tag{5}$$

where, β_{nf} is the heat expansion of nanofluid, ρc_p is the heat capacity of nanofluid, ϕ is the volumetric concentration of nanoparticles, ρ is the fluid density of nanofluid. The property of systems velocity is defined as.

$$u_c = \sqrt{g\beta(T-T)}L_x \tag{6}$$

where, β is the heat expansion, g is the gravitational acceleration, (T_h - T_c) are hot temperatures and cold temperatures respectively, Lx is cavity length [25].

$$\Pr = cp * \frac{\mu}{k},\ Ra = \rho^2\beta g(T_h - T_c)Lx * \frac{pr}{\mu^2} \tag{7}$$

Dey and Dash [29] experimentally studied free convection within square cavity to study the influence of the rotational MF on the process of HT. Two nanoparticles were used and found the optimal thermal transfer at volume concentration = 0.1% for both nanofluid. Bouamoud and Houa [30] conducted a 2D free convection inside square enclosure saturated with water-alumina nanofluid employing double population approach and the heat LBM. The results showed that the maximum value of the average Nusselt number is reached at Ra= 10^5 and a volume fraction of nanoparticles $\phi = 0.08$. Rahmati and Tahery [31] implemented the LB approach for studying the free convection on Water-TiO_2 nanofluid. The Nu_{av} on the cold walls was raised by fix Ra and increasing the volume fraction. The obstacles position has positively affected on Nusselt number when they are fixed in the half of cavity. Tasnim et al. [32] conjugated natural HT flow of nanofluid (TiO_2-water) inside a square enclosure having generating elements and two thermal-conducting has been studied computationally. A laminar flow is roughly considered. 2D, steady state, energy and Finite element techniques have been applied to solve the Navier-Stokes equations. Impacts of the title angle of the cavity, Hartmann number, placements of the solid heat-generating components, nanoparticle volume fraction, and Joule heating have been observed. TPC, higher entropy, and lower Nu were obtained at a constant Ha with higher Joule heating parameters. The mathematical model of the current issue consists of Momentum, energy and mass continuity equations as follows [32-34]:

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} = 0 \tag{8}$$

$$\rho(u\frac{\partial u}{\partial x} + v\frac{\partial u}{\partial y}) = -\frac{\partial p}{\partial x} + \mu_{nf}(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2}) + (\rho\beta)_{nf}\, g(T_{nf} - T_c)\sin\delta \tag{9}$$

$$(u\frac{\partial v}{\partial x} + v\frac{\partial v}{\partial y}) = -\frac{\partial p}{\partial y} + \mu_{nf}(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2}) + (\rho\beta)_{nf}\, g(T_{nf} - T_c)\,\mathrm{con}\delta - \sigma B^2 v, \tag{10}$$

$$(\rho cp)(u\frac{\partial T}{\partial x} + v\frac{\partial T}{\partial y}) = k_{nf}(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}) + \sigma B^2 v^2 \tag{11}$$

For solid domain:

$$K_s(\frac{\partial^2 T}{\partial x^2} + \frac{\partial^2 T}{\partial y^2}) + q_{gen} = 0 \tag{12}$$

where, the temperature and pressure are represented by T and P, the acceleration due to gravity is represented by g, and the velocity components are v and u. μ, C_p, ρ, β, k, and σ stand for the dynamic viscosity, particular thermal under continuous pressure, density, expansion of volumetric heat, thermal conductivity, and electrical conductivity [33, 34].

Natural convection of Fe_3O_4 nanofluid within square enclosure was carried out by Hasan et al. [35] to investigate fluid movement and thermal transmission in the presence of exothermic chemical reaction and hydromagnetic field governed by Arrhenius kinetics. The FEM is used to solve the mathematical model. It was revealed that the velocity rises with an elevate in the Ra, and this indicates that the fluid motion rise because of the high in the buoyant force. At Ra = 10^6, the Nu increased by 75.92% comparing with Ra = 10^4. Hinojosa et al. [36] numerically performed of 3D free convection in open tilted cubic enclosure. The mathematical formulations were solved by applying FEM and SIMPLEC algorithm. It was observed that the heat transfer of the enclosure rises within the inclination angle range from 0 to 90, while the heat transfer of the enclosure reduces within inclination angle range from 120 to 180. Esfe et al. [37] implemented numerical simulations to study 3D free convection flow inside cubical cavity saturated with Cuo-water nanofluid and equipped with porous fin. The results showed that increasing Rayleigh number from (Ra=10^3 to 10^5) changes the HT from conduction mode to convection due to rise in the buoyancy force against viscous. Meanwhile, the Nusselt number rises by adding nanoparticles to based fluid.

Most investigations that have been published have focused on free convective HT inside square or rectangular cavities. Free convection in a enclosure with differential heating is actually a prototype for many industrial uses. Because trapezoidal enclosures can be used in many different industries, they have drawn a lot of attention. The solar energy collector with modest concentration is a significant illustration of a trapezoidal shape. Because of the sloping walls, investigating free convective HT in a trapezoidal configuration is more challenging than in rectangular or square cavities. Generally speaking, the mesh nodes are not located along the tilt walls; as a result, the simulating and computing work needed to create the flow characteristic increases dramatically. Alsabery et al. [38] numerically carried out the free convection within trapezoidal enclosure filled with water-based nanofluid having Cu or TiO_2 or Ag or Al_2O_3 nanoparticles. It was observed that by addition phase deviation the rate of thermal transfer increased significantly. It was also found that the heat transfer is strongly impacted by a lower power law index, which leads to a rise in the local Nusselt number. Qi et al. [39] investigated the natural convection of Cu-water nanofluid in solar collector. It was found that the entropy generation and Nusselt number enhanced by 90.0% with aspect ratio A=2:1, while the total entropy generation and Nusselt number of Nanofluid in the solar enhanced by 86.2% with aspect ratio A=1:1. With same cross-sectional area, the parallelogram and trapezoid cavities have poorer heat transfer capacities than the rectangular. The Nusselt number of the fluids in the trapezoid is less than that in the parallelogram cavity by 14.4%. At aspect ratio A=2, the Nusselt number is enhanced by 93% in the rectangular cavity compared to aspect ratio A=1.

Guedri et al. [40] studied the natural convection within Trapezoid filled with nanofluid. It was found that at high value of Rayleigh number, increasing porosity of porous medium, Darcy number and solid volume fraction of nanoparticles lead to an enhancement in the Nusselt number by 17%, 26%, and 23.5% respectively, while increasing the undulation N and Hartmann number reduces the Nusselt number by 13%. Venkatadri et al. [41] provided a depth-examination of natural convection of nanofluid flow inside trapezoidal enclosure that is filled with a porous. To simulate the flow the Tiwari and Das nanofluid technique was used. The FDM was employed to conduct this analysis. They were observed that the average Nusselt number rises with increasing Rayleigh number, and the temperature distribution within the enclosure reduces as the Darcy declines. Sompong and Witayangkurn [42] provided the natural convection within trapezoidal cavity with top wavy wall and saturated with seawater. The FEM was applied to carry out the key equations numerically. The flow pattern is impacted by the inner wave when the wave amplitude increases from 0.9 to 1.1, but the flow strength remains unchanged. It was also found that there is less temperature distribution at Da=10^{-5} and Ra=10^{6} due to the weak flow intensity, while there is greater temperature distribution and excellent circulation at Da= 10^{-3} . Malkeson et al. [43] numerically implemented natural HT in trapezoidal cavity with power-law fluids. The governing equation is solved by applying the finite volume approach. It was shown that the amount of Nu increase with decreasing of Power law n (up 4.1% and 193% increase for Ra=10^3 and Ra=10^5 respectively, between n=0.6 and n=1.8). Job and Gunakala [44] considered natural convection and Joule dissipation effects in Al_2O_3-water nanofluid and SWCNT-water nanofluid inside a wavy trapezoidal cavity presence of MHD. It was found that as the wave amplitude bottom wall increases the HT rate rises. As the Ha rises in both nanofluids, the flow velocity decreases. In addition, compared to the alumina-water nanofluid, the SWCNT-water nanofluid exhibits superior heat transfer efficiency. 2D natural HT flow in a trapezoidal cavity was numerically analyzed to study the HT rate and fluid motion patterns by Venkatadr et al. [45]. The FDM was utilized to solve the dimensionless mathematical formulations. The Nu_{ave} rises significantly with rising Ra, regardless of Prandtl number. For low values of Pr, the local Nu shows non-linear improvement regardless of the Rayleigh number. Aghaei et al. [46] provided the impact of MF on the HT, turbulent fluid flow, and entropy creation of oil (Cuo-MWCNT)-hybrid nanofluid in trapezoidal cavity. The SIMPLER algorithm and finite volume technique were utilized to solve the key equations. It was observed that decreasing the average Nu will be more noticeable when the Ha is raised for smaller Ra values. As the volume concentration of nanoparticles rises, the total generated entropy increases for all examined Ra and Ha. Rahman et al. [47] considered the Darcy-Galerkin weighted formulation to examine the free convection inside trapezoidal enclosure. The FEM by using software COMSOL-Multiphysics utilized to solve the governing non-dimensional equations. Table 1 depicts the thermos-physics characteristics of for porous matrix and fluid. It turned out that the thermal transfer rate diminished with porosity, thermal stratification, and aspect ratio of cavity, while increasing with Rayleigh number.

Table 1. The thermos-physics properties of for porous matrix and fluid

Thermos-Physics	ρ $/kgm^{-3}$	C_p $/Jkg^{-1}k^{-1}$	k $/wm^{-1}k^{-1}$
Glass ball	2500	840	1.05
Kerosene	810	2090	0.145
Sandstone	920	2650	1.7
Engine oil	848	2160	0.137
Water	997.1	4179	0.613
Aluminum foam AF	2700	897	205

Alomari et al. [48] implemented computational simulation MHD of hybrid nanofluid (Mgo-Ag/water) inside trapezoidal enclosure. The authors studied the influences of applying the span of Ra (10^3 to 10^6), volumetric concentration of nanoparticles (0 to 0.02), and Hartmann number (0 to 60). It was found that the Nu_{Local} and Nu_{avg} are rise as the solid volume fraction of nanoparticles and Rayleigh number increase, but they are decrease as the Hartman number increases. It was also found that in increasing Ha increases the isotherms strength and decreases the circulation of the flow. Mustaf and Ghani [49] numerically investigated thermal transfer free convection in trapezoidal cavity. The outcome showed that when the source length rises, the average Nu does as well. Khan et al. [50] investigated computational techniques to study the effects of adiabatic undulating walls and variable permeability on free convection flow in a trapezoidal cavity. The finite element technique was utilized to solve the mathematical modeled numerically by using software COMSOL. Working flowchart of FEM shown in Figure 3. He was revealed that the Nu and kinetic energy increase by 3.49% and 69.13%, respectively, as the cylinder diameter changes from 0.1 to 0.2.

Due to its numerous engineering uses, like building insulation, electronic instrument cooling processes, nuclear reactor design, solar energy collectors etc., free convection HT in rectangular cavities is a well-researched topic. Many geometries of the cavities with divers boundary conditions and initial, radiative characteristics of medium and walls and heat source locations have been considered under the influences of various variables including the cavity inclination, Ra, thermal properties, surface emissivity, and Prandtl numbers. Figure 4 shows rectangular enclosure and measuring equipment. Over the past 50 years, numerous researchers have examined the thermal and mass transfer mechanism in the regime under investigation using analytical, computational, and experimental methods [51, 52].

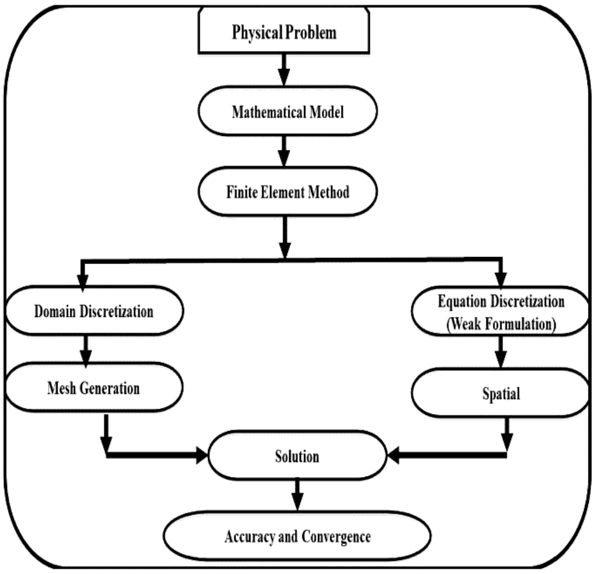


Figure 3. Working flowchart of FEM [50]

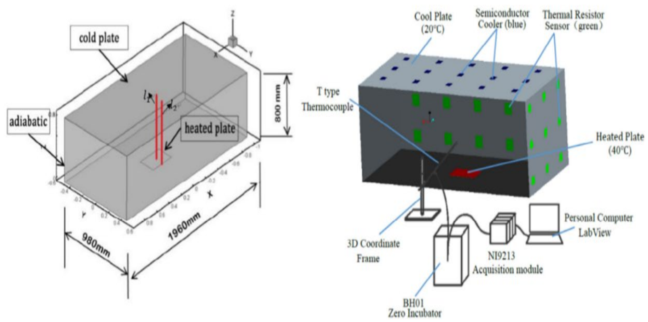


Figure 4. View of the rectangular enclosure and measuring equipment [52]

Abderrahmane et al. [53] carried out 3D free convection of Darcy porous rectangular wavy enclosure encompassing Fe_3O_4-water nanofluid in the presence of MF. The non-linear partial differential equation was solved by employed FE techniques of COMSOL Multiphysics numerically. The outcomes revealed that utilizing a MF to the cavity reduces the Nusselt number. Hartmann numbers have a negative impact on the rate of thermal transfer around 15%. It has also been observed that rising the Da and Ra leads to an elevate in the Nu.

The governing equations as following [54-57]:

Continuity:

$$\frac{\partial_u}{\partial_x}+\frac{\partial_v}{\partial_y}+\frac{\partial_w}{\partial_z}=0 \tag{13}$$

Momentum-X:

$$\frac{1}{\varepsilon^2}*\frac{\rho_{hf}}{\rho}\left(u\frac{\partial u}{\partial x}+v\frac{\partial u}{\partial y}+w\frac{\partial u}{\partial z}\right)=-\frac{\partial p}{\partial x}+\frac{1}{\varepsilon}\frac{v_h}{v_{fluid}}Pr\left(\frac{\partial^2 u}{\partial x^2}+\frac{\partial^2 u}{\partial y^2}+\frac{\partial^2 u}{\partial z^2}\right)-\frac{PrHa^2}{\varepsilon}U, \tag{14}$$

Momentum-y:

$$\frac{1}{\varepsilon^2}*\frac{\rho_{hf}}{\rho}\left(u\frac{\partial v}{\partial x}+v\frac{\partial v}{\partial y}+w\frac{\partial v}{\partial z}\right)=-\frac{\partial p}{\partial y}+\frac{1}{\varepsilon}\frac{v_h}{v_{fluid}}Pr\left(\frac{\partial^2 v}{\partial x^2}+\frac{\partial^2 v}{\partial y^2}+\frac{\partial^2 v}{\partial z^2}\right) \tag{15}$$

Momentum-z:

$$\frac{1}{\varepsilon^2}*\frac{\rho_{hf}}{\rho}\left(u\frac{\partial w}{\partial x}+v\frac{\partial w}{\partial y}+w\frac{\partial w}{\partial z}\right)=-\frac{\partial p}{\partial w}+\frac{1}{\varepsilon}\frac{v_h}{v_{fluid}}Pr\left(\frac{\partial^2 w}{\partial x^2}+\frac{\partial^2 w}{\partial y^2}+\frac{\partial^2 w}{\partial z^2}\right)-\frac{\beta_{hf}}{\beta_{hnf}}\Pr Ra\theta\frac{PrHa^2}{\varepsilon}w \tag{16}$$

Energy:

$$u\frac{\partial\theta}{\partial x}+v\frac{\partial\theta}{\partial y}+w\frac{\partial\theta}{\partial z}=\frac{\alpha_{hf}}{\alpha_{fluid}}\left(\frac{\partial^2\theta}{\partial x^2}+\frac{\partial^2\theta}{\partial y^2}+\frac{\partial^2\theta}{\partial z^2}\right), \tag{17}$$

Bilal and Kaddiri [58] examined the double diffusive free convection thermal transfer within rectangular enclosure saturated with nanofluid (water-Al_2O_3). The outcome showed that Ra has a considerable effect on heat and mass transfers, particularly for horizontal enclosures. The governing equation was solved employing the finite difference technique. Thirumalaisamy et al. [59] analyzed fluid movement and thermal transfer of nanofluid inside an inclination rectangular enclosure presence of magnetic field. The MAC technique was utilized to solve mathematical formulations. To investigate the properties of ternary nanofluids, the Tiwari-Das model is taken into consideration. It was found that the HT properties of the base fluids are significantly enhanced by a suitable combination of nanoparticles. It was also noticed that adding nanoparticles of MWCNT(45%)+Fe_3O_4(10%)+Cu(45%) to H_2O improved heat transfer by up to 8.95%, and it has better heat transfer than MWCNT(45%)+Fe_3O_4(45%)+Cu(10%) to H_2O. Vinodhini and Prasad [60] numerically studied convection heat transfer within rectangular cavity under incline magnetic field and with heat generation. FEM Harlow-Welch MAC method was used to solve the dimensionless non-linear formulations, Figure 5 depicted the flowchart of MAC method. It was observed that The Nu rises when there is a thermal sink (absorption), but it is suppressed when there is thermal generation.

Muhammad and Naveed [61] provied analytical study magnetohydrodynamic flow of the ethylene glycol based Al_2O_3 nanofluid in rectangular enclosure with expanding porous walls. Semi-analytical approach familiar as the technique of Moments was employed to solve nonlinear ODE governing the flow. It was noticed that the aggregation of Al_2O_3 nanoparticles impacts and sometimes inhibits the fluctuations brought on by other variables. Rehman et al. [62]

investigated the impact of MF on free convection flow in partially heated rectangular enclosure filled with nanofluid. FEM was utilized to solve the mathematical model. Corrugated hot bars are fixed on both the cavity's upper and bottom sides. The Nu at the top heated sinusoidal bar was found to exhibit a greater magnitude for increasing Hartmann numbers as compared to a lower heated corrugated rod. Li et al. [63] applied the open FOAM approach to investigate natural HT convection flow in rectangular cavity heated partially containing ferro-nanofluid presence of MF. It was discovered that the average Nusselt number reduces from 3.789 to 2.866 as Hartmann number rises from Ha=0 to Ha=10, while the Nusselt number rises from 0.888 to 3.319 as Rayleigh number rises from $10^3\ to 10^6$. Peiravi et al. [64] carried out 3D numerical simulations of thermal transfer inside rectangular saturated with multi-phase nanofluid. It was found that the height and arrangement of the baffles play a significant role in distributing the nanoparticles cross the entire compartment of the cavity under greater heat transfer situations.

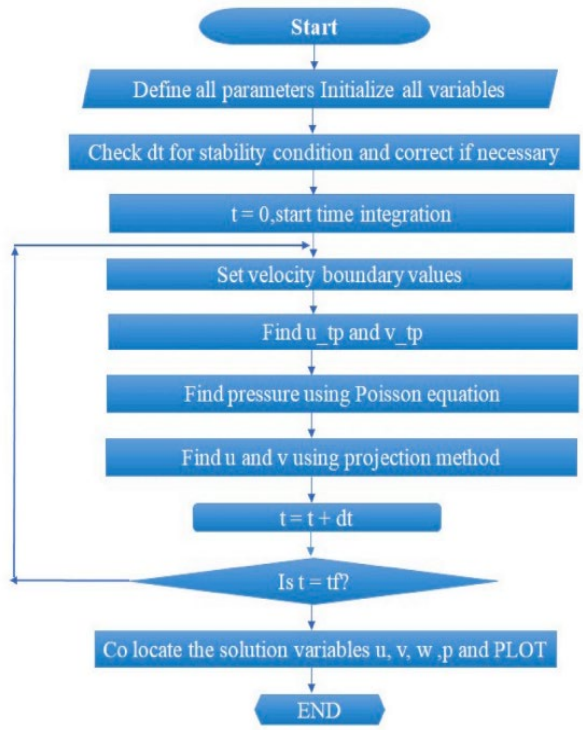


Figure 5. Flow chart of MAC model [60]

Several studies investigated how flow geometry affected natural convection. A variety of cavity shapes were examined, including prismatic [65], octagonal [66], rectangular [67], triangular [68], trapezoidal [69], sinusoidal [70], and annulus area [71]. The convective heat transfer inside the enclosure was subject to various boundary criteria, such as continuous thermal flux and constant wall temperature. There have been several investigations on the current thermal flow inside cavities filled with different types of nanofluids. Al-Zamily and Amin [72] numerically investigated entropy creation and HT in free convection flow in a Nanofluid-filled semicircular cavity. It was demonstrated that heat transfer is positively affected by increasing the Rayleigh number and the solid volume fraction of the nanoparticles. Alam et al. [73] enhanced free convection HT flow in nanofluid-saturated quarter-circular enclosure in existence of period MF. It is discovered that Co-Kerosene has a noticeably greater rate of thermal transfer than the other eight types of base fluid. it was also revealed that Cu-Eo has less heat transfer rate than Cu-kerosene. Jino et al. [74] numerically investigated HT convection in an annulus circular enclosure saturated with Cu-water nanofluid. GFEM method was utilized to solve non-linear differential formulations computationally. They were shown that the fluid flow pattern is significantly impacted by the MF. It was also found that with the decreasing Richardson number the average Nusselt increase. Bourantas et al. [75] performed thermal transfer flow in circular cavity. The problem was solved by using FEM and Arbitrary Lagrangian Eulerian (ALE). They found that Nusselt number reduces by 8.5% for angle of 90 compared to an angle of 30. It was also observed that average Nusselt number for location of thermal source and sink = -60 is up to 124.5% higher compared to location of thermal source and sink = 60. Aly [76] simulated free convection within circular enclosure filled with nanofluid porous media. It was demonstrated that the fluid flow and temperature distribution within the porous layer decrease with a lower value of Darcy number. It was also demonstrated that the velocity field and fluid penetration decrease with a rise in the porous layer radius.

The majority of the literature that is currently accessible states that dispersing nanoparticles effectively increases the augmentation of the HT rate. Thermally enhanced liquids can be created by mixing several kinds of nanoparticles with basic fluids. Bilal et al. [77] enhanced natural convection of 2D enclosure filled with MWCNT-water nanofluid. FEM base software COMSOL was employed to solve the numerical simulations. The results showed that Lorentz force is generated with a high magnitude of magnetic field, which leads to a reduction in the velocity field of the fluid. On the other hand, adding (MWCNT) nanoparticle to pure water improves the thermophysical properties, which leads to enhanced heat transfer and increase in the average Nusselt number at $\phi = 0.05$. Ali et al. [78] implemented the influence of thermophoresis, solar radiation, buoyancy pressure and Brownian motion on turbulent nanoparticles with the Darcy-Forchheimer relation. Sketched in Figure 6 radiation flow on all the vertical porous rod. It was observed that the importance of temperature alteration rises as thermophoresis, Brownian movement, and solar radiation increase. It was also observed that mass and thermal transfer improve as Modified buoyant force and Darcy Forchheimer increase.

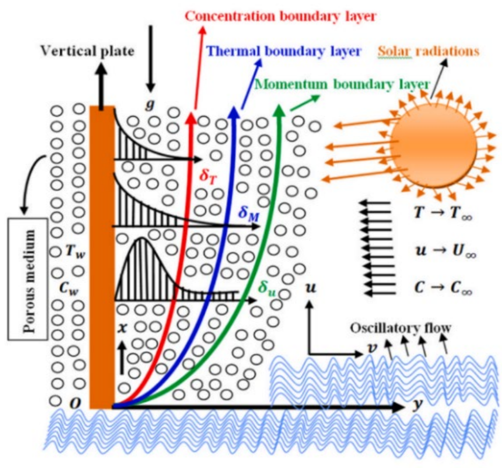


Figure 6. Solar radiation with Darcy-Forchheimer relation [79]

Jahan et al. [79] simulated HT free convection in inverted T-shape enclosure saturated with hybrid-nanofluid with localized heater. It was found that increasing the heater length from ϵ = 1/5 to ϵ = 4/5, Ra = 10^6, Bn = 1, and, ϕ = 0.02, the average Nusselt number rises by 170.25% and speed up the velocity. However, increasing Bingham number reduces the average Nusselt number and the velocity. Zehba et al. [80] analyzed HT free convection in V-shape saturated with porous and nanofluid using incompressible smoothed particle hydrodynamic ISPH. The main results observed that the heterogeneous porous medium has higher heat transfer than the homogeneous porous medium for V-shaped cavity. Al-Amir et al. [81] studied natural HT and entropy generation in corrugated Z-shape enclosure saturated with TiO_2-water nanofluid and porous medium. The results showed that average Nusselt number rises by 80% with increasing Rayleigh number from (Ra=10^3 to Ra=10^6), while it reduces by 30% with a rise in the heat generation from $\lambda = 0$ to $\lambda = 5$. Islam et al. [82], numerically investigated natural convection of MHD using TiO_2-Cu water hybrid-nanofluid in a 2D non-uniform close enclosure. It was shown that HT and velocity distribution are negatively influenced by the presence MF to the enclosure. Reddy et al. [83] examined MHD convection HT in a tilt annulus saturated with hybrid nonliquid and porous medium. It has been observed that rising the Da drives to an improvement in the average Nusselt number. Asha and Molla [84] carried out computation simulation free convection of MHD in C-shape enclosure saturated with nanofluid. The outcome revealed that while Bn and Ha increase, the average Nusselt number reduce. Muhammad et al. [85] observed that increasing values of Prandtl number (Pr) reduces the temperature and velocity. It was also noticed that hybrid-nanofluid has less thermal conductivity than tri-hybrid nanofluid. Adnan et al. [86] numerically analyzed free convection of (Cu-Cuo-Al_2O_3) ternary nanomaterial in annular fin under magnetic field with heat source. It was observed that internal heating source (Q=0.2, 0.6, 0.8) support thermal improvement and keep fin efficiency. Siddique et al. [87] has examined HT flow in channel saturated with nanofluid and heated by heat source. It was found that the temperature is raised by the Al_2O_3 nanoparticles significantly more than by the TiO_2 nanoparticles. Kalidoss et al. [88] experimentally studied the heat conductivity of 55-TiO_2 nanofluids for intake of photovoltaic. They were discovered that the heat conductivity changes by the addition of nanoparticles; an improvement of 1.57 % is observed at 250 ppm relative to base fluid.

Alhashash.[89] numerically examined the thermal transfer in composite cavity. It was found that for whole Da range, the average Nu drops as thickness of porous medium rises. However, a high thermal conductivity ratio in the cavity results in a more noticeable improvement of heat transfer. Memon et al. [90] conducted on hybrid nanofluid in 2D cavity channel for photovoltaic thermal to investigate the electrical performance. This investigate aimed at examined a solar energy by passing of hybrid nanofluid. Simulation and Modeling were carried out by utilizing COMSOL. FEM utilized to solve the key equations. It was shown that the efficiency of the cell rises by 0.3% when the volumetric concentration of Cu is raised from the less to the large at Re = 1000. schematic.8 illustrated of the solar cell flow channel, Cu as an absorber, and silicon cell. Figure 7 illustrated of the solar cell flow channel, copper as an absorber, and silicon cell [90].

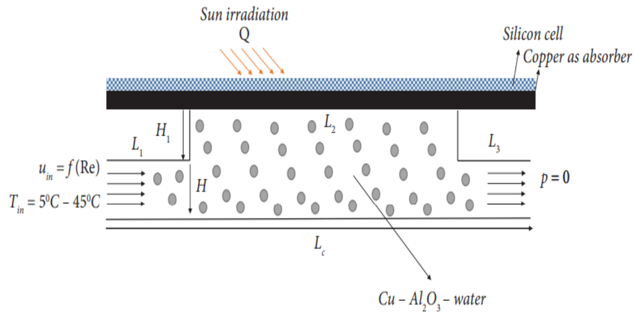
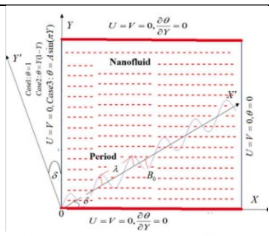
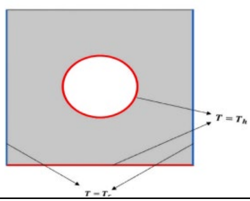
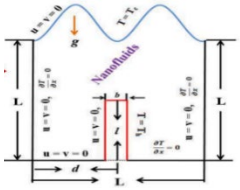
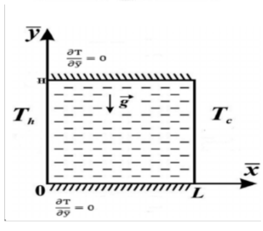
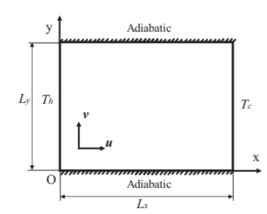
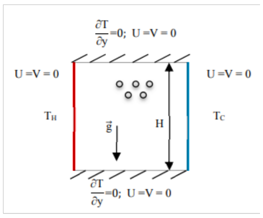
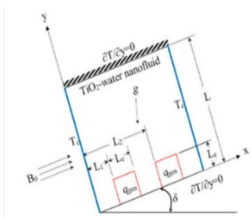
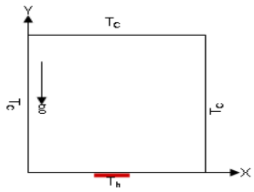
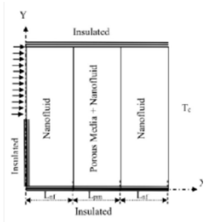
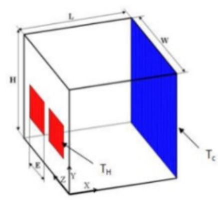
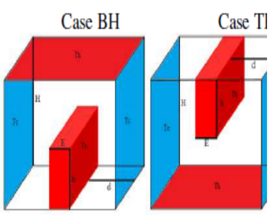


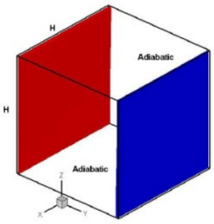
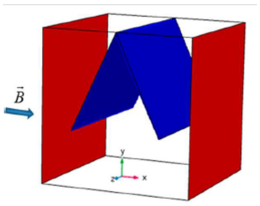
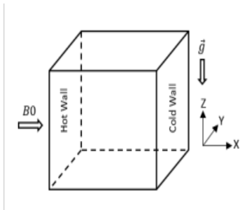
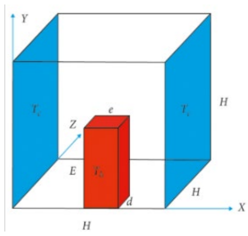
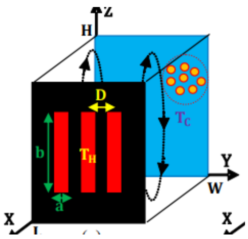
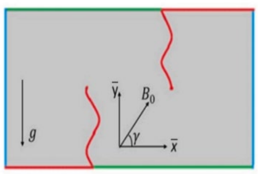
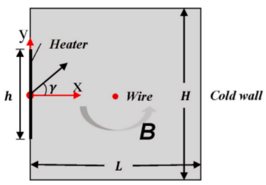
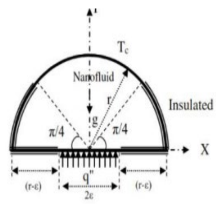
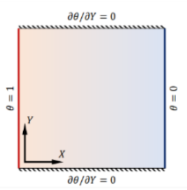
Figure 7. The photovoltaic cell flow channel [90]

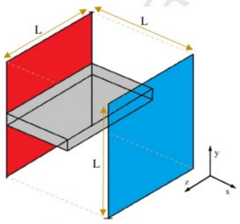
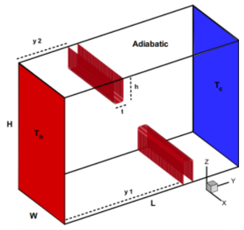
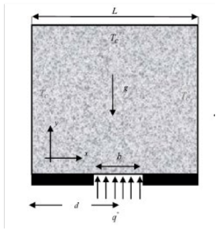
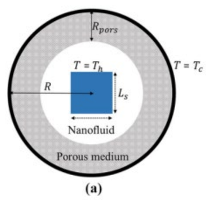
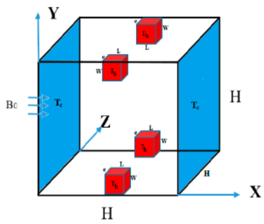
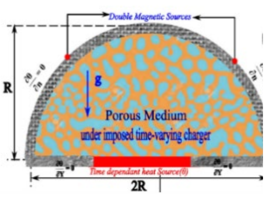
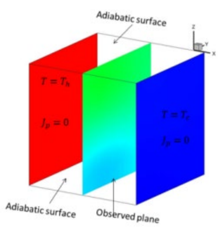
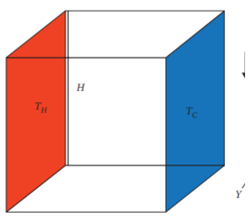
Raza et al. [91] considered hybrid nanofluid (Kerosene and water base fluid with Cu and Al_2O_3 nanoparticle) flow in through a channel. It was observed that MoS2 nanoparticles have less influence in nanofluids compared to GO-based suspension. Parvin et al. [92] examined the impact of pertinent parameters, including heat transfer, non-Newtonian nanofluid on fluid motion, and inclined magnetic field. Results showed that the average Nu greater amount occur when inclination angle γ=90. Nayak et al. [93] conducted computation simulations to evaluate free convection flow inside hexagonal cavity filled with Al_2O_3-water at different locations subject to cold diamond obstacle. In this investigation, the Nusselt number enhanced by 76.16% when Rayleigh number was increased from (Ra=10^5 $to 10^6$).Table 2 shows cavities in different shapes and their case.

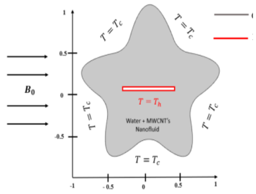
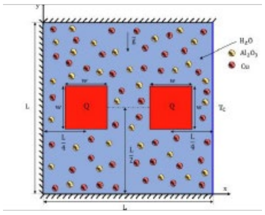
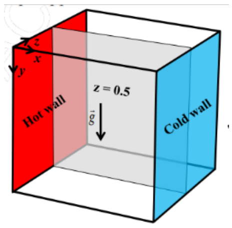
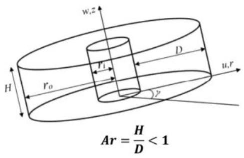
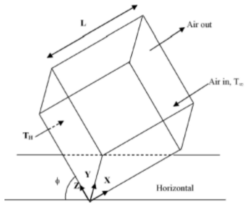
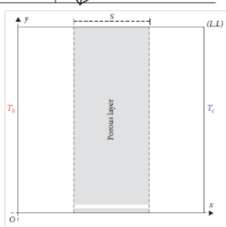
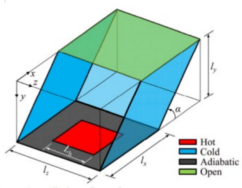
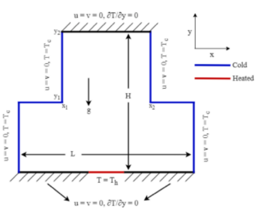
Table 2. Cavities in different shapes

Ref.	Cavity Geometry Shapes	The study Parameters	Cavities Shapes	Types of Base Fluids and Nanoparticles	Results
[19]	square	$10 \leq Ha \leq 100, 10^4 \leq Ra \leq 10^6, 0.1 \leq \lambda \leq 1, 0 \leq \emptyset \leq 0.05$		CU, Zn, Al_2O_3, Co/H_2O and kerosene	The best heat transfer achieved in this study was with Co-kerosene NF. The natural heat transfer increases with an increasing (∅) and reduces with an increasing (Ha)
[22]	square	$100 \leq Re \leq 150, 0.01 \leq Ri \leq 0.1, 0.01 \leq \emptyset \leq 0.1$		Diamond/water	They were found that the higher performance of nanoparticles in lamina shape in terms of heat transfer and temperature distribution

[23]	square	$0 \leq Ha \leq 50, 10^4 \leq Ra \leq 10^6, 0 \leq \emptyset \leq 0.1$		Al_2O_3,Cu,Co,TiO_2,Ag,CuO /H_2O	The natural heat transfer is enhanced by 7.65% for nanoparticles of blade-shaped, while it is enhanced by 2.86% for nanoparticles of spherical-shaped
[25]	square	$1.0 \leq M \leq 3.0, 100 \leq Ra \leq 1000, 0.1 \leq Re \leq 0.5, 5.2 \leq Pr \leq 7.2, 0.01 \leq \emptyset \leq 0.09$		TiO_2/EG	The high value of the magnetic field increases the temperature inside the enclosure. The greater average Nusselt number occurs at a high value of Ra
[26]	sq square	$0.01 \leq \emptyset \leq 0.05, 10^3 \leq Ra \leq 10^6$		Cu/H_2O	It was observed that increasing the values of nanoparticles and Rayleigh number leads to a rise in the local Nusselt number along the cooler wall
[30]	square	$0 \leq \emptyset \leq 0.08, 10^4 \leq Ra \leq 10^5$		Al_2O_3/H_2O	The heat transfer is significantly enhanced with a Al_2O_3 nanoparticle and Rayleigh number
[32]	square	$0 \leq \emptyset \leq 0.06, 0 \leq Ha \leq 20, 10^3 \leq Ra \leq 10^6$,tilt angle of cavity 0° $to 45^\circ$		TiO_2/H_2O	A lower value of the average Nusselt number is obtained when the magnetic field is applied. At constant Ha, higher Joule heating parameters produce a reduced Nu and increased entropy. A higher tilt angle of the cavity reduces natural convective
[94]	square	$10^3 \leq Ra \leq 10^6$		TiO_2, Cu, Ag, Al_2O_2/H_2O	Cu, Ag, Al_2O_2 have higher HT Compared to TiO_2 because of the heat conductivity. The natural heat transfer enhances when nanoparticles added to pure water for all values of Rayleigh number
[95]	square	$0 \leq \varphi \leq 0.1$ $0 \leq Ha \leq 50$ $10^4 \leq Ra \leq 10^7$, $10^{-5} \leq Da \leq 10^{-1}$, $Q = 0$ $to 20$		TiO_2/H_2O	Increasing the porous layer thickness leads to a reduction in Average Nusselt number due to the reduction in the fluid penetration
[96]	Cubical	$10^3 \leq Ra \leq 10^5$ $0 \leq \emptyset \leq 0.2$ $0.15 \leq Pr \leq 6.2$		Cu, Al_2O_3, TiO_2/H_2O	The natural heat transfer improves by adding nanoparticles to pure water, and average Nusselt number rises with all values of nanoparticles
[97]	Cubical	$10^3 \leq Ra \leq 10^5$ $0 \leq \emptyset \leq 0.3$		Cu -water	The buoyancy force become large when the Ra increase

[98]	Cubical	$10^4 \le R \le 10^8$ $0 \le \emptyset \le 0.03$		Cuo, Al_2O_3/H_2O	By using nanofluid, we can earn 26% increasing in thermal transfer rate
[99]	Cubical	$0 \le Ha \le 100, 10^3$ $\le Ra \le 10^5, 0 \le \emptyset$ $\le 4.5\%, V$ $- shape\ 0\ to 80^{\circ}$		CNT/H_2O	By increasing the nanoparticles of CNT and opening angle of the obstacle, the natural HT is improved. Increasing Ha from (0 to 100) reduces the Nu, while entropy generation increases by30%
[100]	Cubical	$10^3 \le Ra \le 10^7, 0$ $\le Ha \le 200, 0 \le \emptyset$ ≤ 0.05		CU/H_2O	At high values of magnetic field at $Ra=10^5$, heat transfer completely changes from convection to conduction, and the effect of Cu nanoparticles on enhancing average the Nusselt number is negligible
[101]	cubical	$10^3 \le Ra \le 10^6, 0$ $\le \emptyset \le 0.1$		Al_2O_3, Cu, TiO_3/H_2O	At low Ra values, the impact of nanoparticles is bigger, so 6% rise in volume fraction for length heat source of 0.5 results in relative rise in the Nusselt number of roughly 9% for $Ra=10^6$and 26% for $Ra=10^3$. TiO_3 and Al_2O_3 have less heat transfer than Cu
[102]	Cubical	$0 \le \emptyset \le 0.1$ $10^3 \le Ra \le 10^6$ $0 \le \gamma \le 90$ $0 \le R_d \le 0.5$		Cu, TiO_2, Ag,Al_2O_3/H_2O	Heat transfer is enhanced by 14% when adding Cu nanoparticles at Rayleigh number ($Ra=10^6$), while heat transfer improves by 34% in the present of thermal radiation
[62]	rectangular	$0 \le Ha \le 100$ $10^3 \le Ra \le 10^6$ $0 \le \varphi \le 0.1$ $0 \le \gamma \le 3\pi/4$		CuO/H_2O	It is discovered that the Nusselt number at the top of heated wavy rod rises as the angle of inclination rises under the effect of an external magnetic field
[63]	rectangular	$45 \le \gamma \le 90$ Ha= 0 to 10 Ra=10^3 to 10^6 $0 \le \varphi \le 0.05$		Ferro-nanofluid	It was discovered that the average Nusselt number reduces from 3.789 to 2.866 as Hartmann number rises from Ha=0 to Ha=10, while the Nusselt number rises from 0.888 to 3.319 as Rayleigh number rises from $10^3\ to 10^6$
[72]	Semi Circular	$-45 \le \gamma \le 45$ $0 \le \varphi \le 0.15$ $10^4 \le R \le 10^7$		Cu/H_2O	The average Nusselt number rises with increasing Cu concentration and Rayleigh number
[74]	Quadratic	Pr=62 $0 \le \varphi \le 0.02$ $0 \le Ha \le 50$ $10^{-5} \le Da$ $\le 10^{-1}, 10^3 \le Ra$ $\le 10^6$		Cu/H_2O	It was found that increasing the Darcy number and Rayleigh number lead to enhances natural heat transfer

[37]	cubical	$0 \le \emptyset \le 3\%$ $10^3 \le R \le 10^5$		CuO/H_2O	The average Nusselt Number and heat transfer are improved by increasing CuO nanoparticles and Rayleigh number. Additionally, it was noted that when nanofluids move through the porous fins, their velocity reduces
[64]	rectangular	$10^3 \le Ra \le 10^8$		CuO/H_2O	The study of the lowest and highest Nusselt numbers indicated that, under identical circumstances changing the baffle configuration raises the Nusselt number by more than 57%
[75]	square	$10^5 \le Ra$ $\le 10^7, 10^{-5} \le Da$ $\le 10^{-3}, 0 \le \emptyset$ ≤ 0.02		Cu, Al_2O_3, Tio_3, Ag/H_2O	When a porous medium is present and the Ra number varies, the average Nu rises in proportion to solid volume fraction
[76]	circular	$10^{-5} \le Da \le 10^{-2}$ $0.1 \le L_s \le 0.4$ $0.1 \le R_{por} \le 0.4$ $0 \le \varphi \le 0.05$ $Ra=10^4$ $\varepsilon = 0.6$		Cu/H_2O	As the porous layer radius, inner square length, and volume concentration rise, the Nu reduce. The velocity fields and fluid penetrations in the porous layer are decreased when the radius of the porous layer is increased
[103]	cubical	$10^3 \le Ra \le 10^5$ Pr= 0.7 $0 \le \emptyset \le 0.06$, $0 \le Ha \le 60$, $10 \le d \le 130$		Cu/H_2O	The average Nusselt number decrease as Hartmann number increases. Meanwhile, the average Nusselt number decreases with increasing the nanoparticles size. The natural heat transfer is enhanced with increasing Cu nanoparticles concentration and Ra
[104]	Semi Circular	$10^{-5} \le Da \le 10^{-1}$ $0.1 \le \varepsilon \le 0.9$, $10^4 \le Ra$ $\le 2 * 10^6$, $10 \le Ha \le 300$, $0 \le Mn \le 2000$		Cu/H_2O	the convection impacts become impaired and flow intensity is significantly reduced when Hartmann number is increased from 10 to 300. A reduce in ε from0.9 to 0.1 results in rise in the average Nusselt number around 60%.and decrease total heat (Q) around 15%
[105]	Cubical	$10^5 \le Ra \le 10^6$ $10^{-4} \le Da \le 10^{-2}$ $0.01 \le \emptyset \le 0.03$		Al_2O_3/H_2O	The main results observed that the heterogeneous porous medium has higher heat transfer than the homogeneous porous medium in all direction. The heat transfer is improved in all porous scenario by an increasing Rayleigh number and Darcy number
[106]	Cubical	$10^3 \le Ra \le 10^6$ $0 \le \emptyset \le 0.05$		Al_2O_3, Cuo, TiO_2 nanoparticles EG-PG-Water-base fluids	At $Ra=10^3$, Al_2O_3-EG eahnces the heat transfer by 13% compared to pure EG. Propylene glycol-water-Al_2O_3 demonstrates lower heat transfer than EG-water -Al_2O_3

[77]	star	$20 \leq Ha \leq 80$ $10^4 \leq Ra \leq 10^6$ $0 \leq \varphi \leq 0.05$ Pr=6.2		MWCNT/H_2O	The results showed that Lorentz force is generated with a high magnitude of magnetic field, which leads to a reduction in the velocity field of the fluid. On the other hand, adding (MWCNT) nanoparticle to pure water improves the thermophysical properties, which leads to enhanced heat transfer and increase in the average Nusselt number at $\phi = 0.05$
[107]	square	$0 \leq \emptyset \leq 0.08,$ $10^3 \leq Ra \leq 10^7$		Cu-Al_2O_3/H_2O	The heat exchanger in the enclosure is improved by increasing the Ra number, which leads to a reduction in the maximum temperature. The temperature of the enclosure reduces by up 12% when fins are installed on the surfaces of the enclosure
[108]	cubical	$10^4 \leq R \leq 10^5$ $0 \leq Ha \leq 100,$ $0 \leq \gamma \leq 90^{\circ},$ $0 \leq \emptyset \leq 0.05$		CNT, CuO/H_2O	The average Nusselt number of CuO nanoparticles is 40% less than of CNT nanoparticles at $\alpha = 0^0, \emptyset = 0.05$, for all values of Hartmann number. Heat transfers enhanced by increasing Ra and concentration of CNT.
[83]	inclined porous annulus	$0 \leq Ha \leq 50$ $10^{-5} \leq\leq 10^{-1}$ $-6 \leq \gamma \leq 60$ $0 \leq Q \leq 20$ $0.5 \leq Ar \leq 2$		Ag-TiO_2 /H_2O	Natural convection decreases by 25.38% when the Hartmann number rise from 0 to 50. Increasing Darcy number leads to enhanced heat transfer. For convection -dominant scenario, an rise in heat generation(Q) from 0 to 20 results in 64.66% diminution of total heat transfer rate
[36]	open tilted cubic	$10^4 \leq R \leq 10^7$ $0 \leq \gamma \leq 180$		Air	It was observed that the heat transfer of the enclosure rises within the inclination angle range from 0 to 90, while the heat transfer of the enclosure reduces within inclination angle range from 120 to 180
[109]	square	$0 \leq Rk \leq 10$ $0 \leq \emptyset \leq 0.05$ $10^{-5} \leq Da$ $\leq 10^{-2}, Ra = 10^6$ $0 \leq \delta \leq 1$		Al_2O_3/H_2O	The average Nusselt number reduces for all values of Darcy number when the porous layer thickness (δ) rises. The heat transfer rises with a rise in the Darcy number
[110]	parallelogrammical	$10^3 \leq R \leq 10^5$ $0 \leq \emptyset \leq 0.05$ $5 \leq \gamma \leq 75$		Al_2O_3/H_2O	In all cases, heat transfer enhances as the inclination angle and A_2lO_3 nanoparticles concentration increase
[79]	T-shaped	$0 \leq Bn \leq 1$ $10^4 \leq R \leq 10^6$ $0 \leq \emptyset \leq 0.04$		Al_2O_3-Ag/H_2O	It was found that increasing the heater length from $\epsilon = 1/5$ to $\epsilon = 4/5$, $Ra = 10^6$, $Bn = 1$, and, $\phi = 0.02$, the average Nusselt number rises by 170.25% and speed up the velocity. However, increasing Bingham number reduces the average Nusselt number and the velocity

3. THE INFLUENCE OF USING NANOFLUIDS IN ENHANCING HT

Nanofluid's rheological properties and excellent thermal conductivity make it a desirable HT fluid for employe in improved (HT) applications. Nanofluids are used in many different fields because of their unique properties, which include increased stability and enhanced heat transfer performance [111]. A composite liquid comprising of two distinct phases, namely the liquid and solid phases, is referred to as a nanofluid. The fluid's purpose is to improve the base fluid's thermophysical and electrical characteristics [112-114]. The parameters of the base fluid are changed by adding nanoparticles, which improves performance over conventional fluids. Numerous nanofluids can be created by combining base fluids with nanoparticles as shown in Figure 8.

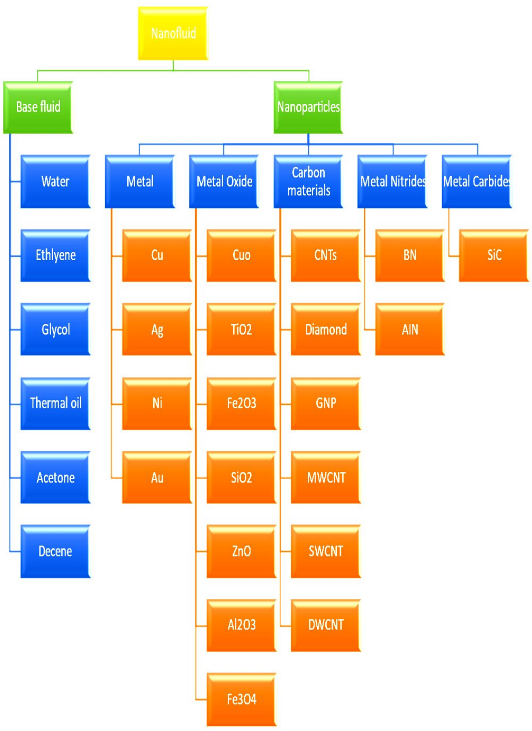


Figure 8. Illustration of various types of nanoparticles and base fluid [115]

Using a single-phase model for nanofluid makes it easier to apply computer simulation techniques since it simply requires sufficient correlation modifications to the article characteristics in the energy and Navier-Stokes formulations. The simplicity of single-phase nanofluids has attracted the attention of numerous authors to study the behavior of nanofluids in heat transfer [116]. Free convection in a wavy octagonal cavity saturated with TiO_2 was performed by Saha et al. [117] to examine how TH and fluid movement occur within the enclosure under specific conditions. The outcomes showed that as the buoyant force increased, heat transfer increased, while HT reduced with elevating Lorentz force. Hu et al. [118] studied the effect of Ra, density, and nanoparticles concentration of Al_2O_3 on free HT and flow patterns evolution. The outcome indicated that increasing the volume fraction of Al_2O_3 leads to improved convective thermal transfer. Uddin and Rasel [119] numerically analyzed natural convection flow within quadrilateral vessel filled with Cuo-water nanofluid. GFEM was utilized to solve the key equations using COMSOL-Multiphysics with MATLAB. It was discovered that heat transfer greatly rises as nanoparticle size drops and Ra and nanoparticles concentration rise. The optimal HT distribution was obtained at higher nanoparticle's concentration and Ra.

High-tech industries such as manufacturing, nanoelectronics, and vehicles have led to a variety of technological advances that have profound implications for a lot of contemporary scientific concerns, such as waste, energy consuming, and reusability. Nevertheless, several problems are barring further improvement in these sectors, one of which is the capacity to quickly cool the goods utilized [120, 121]. The raised thermal loads and thermal fluxes brought on by the rise in power and fall in characteristic sizes in novel products over the past ten years have resulted in a substantial increase in the requirement for a more effective cooling technique. Consequently, many companies are spending significant sums in producing improved heat transfer technologies. One such technology that increases the surface area of thermal transfer and fluid flow velocity is hybrid nanofluids. Al-Dulaimi et al. [122] numerically implemented natural HT convection flow in Ag-MgO-water hybrid nanofluid filled corrugated enclosure. They found that the study parameters Darcy, Rayleigh, and volume fraction had a noteworthy impact on the Nu, while the number of undulations had a smaller effect. Rehena et al. [123] examined the free convection within the solar collector filled with Al_2O_3-water nanofluid. It was observed that the highest value of the Prandtl number Pr enhanced the heat transfer. Meanwhile, it was also found that the nanofluid improves heat transfer by 26%, while the pure water enhances the heat transfer by 18%. Rasool et al. [124] investigated the HT of Cu-Al_2O_3/water hybrid nanofluid flow over dual solution of unsteady in existence of MF. The results showed that heat transfer was enhanced with hybrid-nanofluid compared to pure water. Malik et al. [125] studied the combine effects of porosity, heat radiation, changing MF, thermophoresis, and Brownian movement on hybrid (Ag-TiO_2/water) nanofluid flow across a rotating disk. once the ordinary differential equation was created by converting the partial differential equation, it was solved by MATLAB using the bvp4c method. It was found that as the magnetic coefficient input rises, the velocity gradient of hybrid nanofluid decreases. the outcome demonstrated that as increases thermophoresis, the concentration and temperature increase. The amount of average Nu decreases by 37.73% and 29.43% with magnetic field 0.8 and 2.2 respectively. Jakeer et al. [126] numerically computed influence of heated square baffle location on magneto-hybrid Cu-Al_2O_3/water nanofluid flow in lid-driven porous enclosure. The outcome indicated that the HT of nanofluids is less than that of hybrid nanofluids. It was also found that the velocity and thermal transfer rate rise with rising Darcy number values. Thermal physical of hybrid nanofluid [127-129].

Electric conductivity of hybrid nanofluid is expected as:

$$\frac{\sigma_{hnf}}{\sigma_{bf}} = \frac{[\sigma_2 + 2\sigma_{bf} - 2\emptyset_2(\sigma_{bf} - \sigma_2)]}{[\sigma_2 + 2\sigma_{bf} + 2\emptyset_1(\sigma_f - \sigma_2)]} \tag{18}$$

where,

$$\frac{\sigma_{hbf}}{\sigma_f} = \frac{[\sigma_1 + 2\sigma_f - 2\emptyset_1(\sigma_f - \sigma_1)]}{[\sigma_1 + 2\sigma_f + 2\emptyset_1(\sigma_f - \sigma_1)]} \tag{19}$$

The expression for the density of a hybrid nanofluid is:

$$\rho_{hnf} = -\rho_f(\emptyset_2 - 1)\left((\emptyset_1 - 1) - \left(\rho_{\frac{1}{\rho_f}}\right)\emptyset_1\right) + \emptyset_2\rho 2 \tag{20}$$

The hybrid nanofluid's thermal conductivity is expressed as follows:

$$\frac{k_{hnf}}{k_{bf}} = \frac{\left[k_2 + (m-1)k_{bf} - (m-1)\emptyset_2(k_{bf} - k_2)\right]}{\left[k_2 + (m-1)k_{bf} + \emptyset_2(k_{bf} - k_2)\right]} \tag{21}$$

where,

$$\frac{k_{bf}}{k_f} = \frac{\left[k_1 + (m-1)k_f - (m-1)\emptyset_1(k_f - k_1)\right]}{\left[k_2 + (m-1)k_f + \emptyset_1(k_f - k_1)\right]} \tag{22}$$

Viscosity of hybrid nanofluid is expressed as:

$$\mu_{hnf} = \frac{\mu_f}{(1-\emptyset_1)^{2.5}(1-\emptyset_2)^{2.5}} \tag{23}$$

Heat capacity of hybrid nanofluid is expressed as:

$$\rho c_{hnf} = (\rho cp)_f(1-\emptyset_2)((1-\emptyset_1) + \left(\frac{(\rho cp)_1}{(\rho cp)_f}\right)\emptyset_1 \tag{24}$$

3.1 Horizontal magnetic field effects

Previous studies proposed combining nanoparticles into the base fluid utilized for HT to improve heat characteristics (like oils, ethylene, water, and glycol). Since then, authors have been more attracted in investigating the usage of nanofluids, and several of them continue to have serious concerns about the fluids' ability to exchange heat. Ferrofluid, or magnetic nanofluid, is one of the many varieties of nanofluids being studied for a diverse of uses currently [130]. It is a kind of the magnetic nanoparticles are suspended in an antiferromagnetic carrier fluid, forming a heterogeneous mixture. The influences of an external MF on the properties of magnetic nanofluids have been the subject of numerous studies [131].

Magnetohydrodynamic generalized by the effect of Newtonian heating, MF, and the Ohmic heating principle with convective cooling, two parallel horizontal plates have been studied for the Couette flow of Jeffrey nanofluid by Abeer [109]. A drop in velocity characteristics of the nanofluid results from the Lorentz force functioning to impede the movement of fluid in a fluid with electrical conductivity when a MF was employed horizontal to the tendency of the fluid motion. Saleem et al. [132] studied free convection flow within an L-shape enclosure saturated with Cu-water nanofluid in existence of MF. It was found that natural convection improved by adding 20% nanofluid to based fluid, with the Nusselt number increasing by up to 47% at Ha=0, while the effect of nanofluid was smaller at Ha=100. Dogonchi et al. [133] examined magnetic nanofluid thermal transfer flow in a porous enclosure. the results indicated that the concentration of the convection flow has a reverse relation with the inclination angle of MF and Hartmann whereas it has a direct relation with Da and Ra. Ahmad et al. [134] implemented the influence of localized MF on HT in tri-hybrid-nanofluid. The outcome found that trihybrid nanofluid has better heat transfer than nanofluid.

4. THE INFLUENCE OF THE CAVITY TILT ANGLE ON THE THERMAL AND FLUID FIELDS

Free convection flow inside 2D square cavity saturated with various type of nanofluid have been numerically analyzed with incline periodic magnetic field [19]. The FEM was utilized to solve the model equations. It was found that the MF period and inclination angle both had a substantial effect on the HT analysis. How the MF affects free convection flow in partially heated rectangular enclosure saturated with nanofluid have been examined [62]. The parameters that affect the flow are the inclination angle, Ha, Ra, and Pr. It can be observed that the vortices become considerably more perturbed at increasing slop of the applied magnetic field. Additionally, it was found that when the applied MF tilt rises, the Nu reduces. Li and Liao [135] investigated HT of Al_2O_3 saturated 2-D square enclosure with applied incline exterior MF. It was found that transfer patterns and flow structure are significantly impacted by the magnetic field directions.

5. POROUS MEDIA EFFECTS INSIDE THE CAVITY TO IMPROVING HEAT TRANSFER

Zhang et al. [136] numerically investigated free convection flow within 2D porous annulus saturated with nanofluid Cu-water. The impacts of HT characteristics, Darcy number, temperature distribution, nanoparticle diameter, porosity, Nanoparticle's concentration on the flow pattern were studied in detail. It can be discovered that for all taken Rayleigh numbers, there is a constant rise in the total HT rate with an elevate in porosity; the influence of porosity is especially noticeable at large value of Ra. It was also observed that as the Da reduces and the Ra rises, the Brownian motion becomes more pronounced, and the Nu is large when there is Brownian motion present than when it is not. Bouafia et al. [137] investigated the hydrodynamic and thermal free convection movement within porous partially wavy enclosure filled with nanofluid (Al_2O_3). According to the first findings, raising the modified Rayleigh number guarantees that the porous medium becomes more permeable, which in turn raises the buoyant force and average Nusselt number. The second set of data demonstrated how the corrugated wall's amplitude affects the rate of thermal transmission within the porous enclosure, increasing the average Nu in the process. Zhao et al. [138] were observed that the porous medium with spherical shapes has less heat transfer than porous medium with square shapes due to more surfaces and greater flow mixing. Hatami and Ghasemi [139] investigated the impact of four elements, Brownian, Drag, thermophoresis, and forces of gravity acting on the nanoparticles. It was found that the temperature enhanced by 1.36%when the value of the viscosity parameter was increased.

6. CONCLUSION

In summary, three methodologies have been explored in this article, which describes several research options of heat transfer enhancement technology inside the cavities. New functional nanofluids, a magnetic field, and porosities of porous media are to be used. In order to accomplish this, published research findings from numerous studies were recast using a standard parameter, making it easier for research organizations to compare data and to spot patterns in thermal property and heat transport. Many attempts have been made to improve its performance. It is discovered that there are still a lot of disagreements in the published literature on the levels of thermal transfer enhancement and the associated augmentation methods when it comes to nanofluids. The causes that go beyond these disputes are examined. Furthermore, as a well-modeled passive enhancement technique, flow and HT within porous media are described in this study. It is discovered that there aren't many studies that focus on improving heat transfer through systems that are supported by flexible or flexible-complex seals. It is hoped that this contribution would encourage more people to get interested in cavity technology. Any newbie to this sector of technology should find it useful. The primary conclusions can be summarized as follows:

1. It was found that the Nusselt number is unaffected by the small Rayleigh number in the Hartmann number at present. Furthermore, because of an increase in buoyancy force, a high Rayleigh number causes the heat transfer to switch from conduction to convection. Furthermore, it was noted that with high Rayleigh numbers, the Nusselt number falls in the current Ha number.
2. The lowest thermal conductivity nanoparticles are thought to have the lowest rate of heat transfer.
3. When the heat lines on the free convection inside the solar collector containing the Al_2O_3-water nanofluid are visible. The heat transfer was shown to be improved by the Prandtl number Pr at its maximum value. The nanofluid was also found to increase heat transmission by 26%, while pure water improved heat transfer by 18%.
4. The local Nusselt number progressively decreases from the bottom to the top of the hot wall and abruptly increases as we approach the top corner of the wall, yet the heat transfer rate is higher at the top corner of the hot wall.
5. The strength of the flow circulation increases with increasing wave number values due to the influence of nonuniform heating; nevertheless, the strength of the flow circulation diminishes at high wave numbers.
6. At the expense of a greater friction factor or higher pumping power, the hybrid nanoparticle loading increases the rate of heat transfer and the thermal efficiency index.
7. When a magnetic field is applied horizontally to the tendency of the fluid motion, the Lorentz force operates to impede the flow of an electrically conducting fluid, which results in a decrease in the velocity characteristics of the nanofluid.
8. At high value of Rayleigh number, increasing porosity of porous medium, Darcy number and solid volume fraction of nanoparticles lead to an enhancement in the Nusselt number by 17%, 26%, and 23.5% respectively, while increasing the undulation N and Hartmann number reduces the Nusselt number by 13%.
9. With the same cross-sectional area, the parallelogram and trapezoid cavities have poorer heat transfer capacities than the rectangular. The Nusselt number of the fluids in the trapezoid is less than that in the parallelogram cavity by 14.4%. At aspect ratio A=2, the Nusselt number is enhanced by 93% in the rectangular cavity compared to aspect ratio A=1.

Finally, Table 2 provides an overview of the different kinds of geometrical cavities and the approximate maximum heat transfer enhancement levels attributed to each enhancer that is covered in this research.

7. RECOMMENDATIONS

The future work of the present problem would be:

- Studying the energy losses (entropy generations) that provides precision calculations for the industry requirements.
- Research on the energy efficiency of thermal systems using porous media and nanofluids is required.
- According to the literature, researchers have concentrated on nanoparticles ranging from (10-50nm). This is due to the size of the nanoparticles plays vital part in improving heat transfer, with smaller nanoparticles demonstrating excellent heat transfer. It is recommended for authors to focus on nanoparticles smaller than this size in solar collectors using the same design of the enclosure.

REFERENCES

[1] Selimefendigil, F., Senol, G., Öztop, H.F., Abu-Hamdeh, N.H. (2023). A review on nano-Netwonian nanofluid applications for convection in cavities under magnetic field. Symmetry, 15(1): 41. https://doi.org/10.3390/sym15010041

[2] Waini, I., Ishak, A., Pop, I. (2019). Unsteady flow and heat transfer past a stretching /shrinking sheet in a hybrid nanofluid. International Journal of Heat and Mass Transfer, 136: 288-297. https://doi.org/10.1016/j.ijheatmasstransfer.2019.02.101

[3] Choi, S.U.S., Eastman, J.A. (1995). Enhancing thermal conductivity of fluids with nanoparticles. In Conference: 1995 International Mechanical Engineering Congress and Exhibition, San Francisco, CA, United States.

[4] Ganesh, N.V., Al-Mdallal, Q.M., Hirankumar, G., Kalaivanan, R., Chamkha, A.J. (2022). Buoyancy-driven convection of MWCNT - Casson nanofluid in a wavy enclosure with a circular barrier and parallel hot/cold fins. Alexandria Engineering Journal, 61(4): 3249-3264. https://doi.org/10.1016/j.aej.2021.08.055

[5] Nemati, H. (2018). A general equation based on entropy generation minimization to optimize plate fin heat sink. Engineering Journal, 22(1): 159-174. https://doi.org/10.4186/ej.2018.22.1.159

[6] Bowo, A.D., Amrizal, Ibrahim, G.A. (2022). Geometry optimization of PV/T-TEG collector under different operating conditions using CFD simulation and Taguchi method. Engineering Journal, 26(8): 1-11. https://doi.org/10.4186/ej.2022.26.8.1

[7] Al-Zamily, A.M.J. (2014). Effect of magnetic field on natural convection in a nanofluidfilled semi-circular enclosure with heat flux source. Computers & Fluids, 103: 71-85. https://doi.org/10.1016/j.compfluid.2014.07.013

[8] Azzouz, R., Hamida, M.B.B. (2023). Natural convection in a circular enclosure with four cylinders under magnetic field: Application to heat exchanger. Processes, 11(8): 2444. https://doi.org/10.3390/pr11082444

[9] Pal, G.C., Nammi, G., Pati, S., Randvi, P.R., Baranyi, L. (2022). Natural convection in an enclosure with a pair of

cylinders under magnetic field. Case Studies in Thermal Engineering, 30: 101763. https://doi.org/10.1016/j.csite.2022.101763
[10] Yuan, Z.H., Dong, Y.K., Jin, Z.L. (2023). Numerical simulation of MHD natural convection and entropy generation in semicircular cavity based on LBM. Energies, 16(10): 4055. https://doi.org/10.3390/en16104055
[11] Begum, Z., Saleem, M., Islam, S.U., Saha, S.C. (2023). Numerical study of natural convection flow in rectangular cavity with viscous dissipation and internal heat generation for different aspect ratios. Energies, 16(14): 5267. https://doi.org/10.3390/en16145267
[12] Berrahi, F., Benissaad, S., Chreifa, A., Medale, M. (2014). Natural convection with volumetric heat generation and external magnetic field in differentially heated enclosure. Proceedings of the Institution of Mechanical Engineers Part C Journal of Mechanical Engineering Science, 228(15): 2711-2727. https://doi.org/10.1177/0954406214521792
[13] Saha, S.C., Islam, S.U., Zia, Z., Saleem, M., Ahmad, S. (2023). Thermal analysis of magneto-natural convection flows within a partially thermally active rectangular enclosure. Energies, 16(11): 4462. https://doi.org/10.3390/en16114462
[14] Bilal, S., Shah, I.A., Ghachem, K., Aydi, A., Kolsi, L. (2023). Heat transfer enhancement of MHD natural convection in a star-shaped enclosure, using heated baffle and MWCNT–water nanofluid. Mathematics, 11(8): 1849. https://doi.org/10.3390/math11081849
[15] Khelifa, A., Kabeel, A.E., Attia, M.E.H., Abdelgaied, M., Arıcı, M., Abdel-Aziz, M.M. (2023). 3D numerical analysis of a photovoltaic thermal using bi-fluid: Al_2O_3–water nanofluid at various concentrations. International Journal of Thermofluids, 20: 100523. https://doi.org/10.1016/j.ijft.2023.100523
[16] Zafar, M., Sakidin, H., Sheremet, M., Dzulkarnain, I., Nazar, R.M., Hussain, A., Said, Z., Afzal, F., Al-Yaari, A., Khan, M.S., Khan, J.A. (2023). The impact of cavities in different thermal applications of nanofluids: A review. Nanomaterials, 13(6): 1131. https://doi.org/10.3390/nano13061131
[17] Motsa, S.S., Makukula, Z.G., Share, S. (2013). Spectral local linearisation approach for natural convection boundary layer flow. Mathematical Problems in Engineering, 2013: 765013. http://doi.org/10.1155/2013/765013
[18] Falah, A.A., Sana, J.Y., Iman, G.M., Raad, Z.H., Hayder, I.M. (2024). Enhancing thermal performance in a magnetized square cavity: Novel Insights from mixed convection of Ag-MgO nanofluid around a rotating cylinder. International Journal of Thermofluids, 22: 100630. https://doi.org/10.1016/j.ijft.2024.100630
[19] Huda, M.N., Alam, M.S., Hossain, S.M.C. (2024). Thermal performance investigation of transient natural convective nanofluid flow in a square cavity with inclined periodic magnetic field. International Journal of Thermofluids, 21: 100540. https://doi.org/10.1016/j.ijft.2023.100540
[20] Khan, S.A., Yasmin, S., Imran,,M., Muhammad, T., Alhushaybari, A., Farooq, U., Waqas, H. (2023). Computational analysis of natural convection with water based nanofluid in a square cavity with partially active side walls: Applications to thermal storage. Journal of Molecular Liquids, 382: 122003. https://doi.org/10.1016/j.molliq.2023.122003
[21] Faraz, N., Nisar, M.S., Khan, Y., Hussain, A., Iqbal, K. (2023). Natural convection of Cu-H_2O nanofluid inside hexagonal enclosure fitted with a square cavity with a non-uniformly heated wall(s). Results in Physics, 51: 106648. https://doi.org/10.1016/j.rinp.2023.106648
[22] Rashid, U., Lu, D., Lqbal, Q. Nanoparticles impacts on natural convection nanofluid flow and heat transfer inside a square cavity with fixed a circular obstacle. Case Studies in Thermal Engineering, 44: 102829. https://doi.org/10.1016/j.csite.2023.102829
[23] Saha, T., Islam, T., Yeasmin, S., Paeveen, N. (2023). Thermal influence of heated fin on MHD natural convection flow of nanofluids inside a wavy square cavity. International Journal of Thermofluids, 18: 100338. https://doi.org/10.1016/j.ijft.2023.100338
[24] Hidki, R., Moutaouaki, L.E., Zrikem, Z., Abdelaki, A., Boukendi, M. (2023). Impact of Cu, Al_2O_3-water hybrid nanofluid on natural convection inside a square cavity with two heat-generating bodies. Materials Today: Proceedings, 72(P7): 3749-3756. https://doi.org/10.1016/j.matpr.2022.09.292
[25] Sreedevi, P., Reddy, P.S. (2022). Effect of magnetic field and thermal radiation on natural convection in a square cavity filled with TiO_2 nanoparticles using Tiwari-Das nanofluid model. Alexandria Engineering Journal, 61(2): 1529-1541. https://doi.org/10.1016/j.aej.2021.06.055
[26] Xu, D.J., Hu, Y., Li, D.C. (2019). A lattice Boltzmann investigation of two-phase natural convection of Cu-water nanofluid in a square cavity. Case Studies in Thermal Engineering, 13: 100358. https://doi.org/10.1016/j.csite.2018.11.009
[27] Islam, M.S., Islam, S., Siddiki, M.N.A.A. (2023). Numerical simulation with sensitivity analysis of MHD natural convection using Cu-TiO_2-H_2O hybrid nanofluids. International Journal of Thermofluids, 20: 100509. https://doi.org/10.1016/j.ijft.2023.100509
[28] Selimefendigil, F., Oztop, H.F. (2021). Impact of a rotating cone on forced convection of Ag–MgO/water hybrid nanofluid in a 3D multiple vented T-shaped cavity considering magnetic field effects. Journal of Thermal Analysis and Calorimetry, 143: 1485-1501. https://doi.org/10.1007/s10973-020-09348-w
[29] Dey, D., Dash, S.K. (2023). An experimental investigation on the nanofluids in a cavity under natural convection with and without the rotary magnetic field. Heliyon, 9(11): e22416. https://doi.org/10.1016/j.heliyon.2023.e22416
[30] Bouamoud, B., Houa, S. (2017). Mesoscopic study of natural convection in a square cavity filled with alumina base nanofluid. Energy Procedia, 139: 758-765. https://doi.org/10.1016/j.egypro.2017.11.283
[31] Rahmati, A.R., Tahery, A.A. (2018). Numerical study of nanofluid natural convection in a square cavity with a hot obstacle using lattice Boltzmann method. Alexandria Engineering Journal, 57(3): 1271-1286. https://doi.org/10.1016/j.aej.2017.03.030
[32] Tasnim, S., Mitra, A., Saha, H., Islam, M.Q., Saha, S. (2023). MHD conjugate natural convection and entropy generation of a nanofluids filled square enclosure with multiple heat-generating elements in the presence of Joule heating. Results in Engineering, 17: 100993. https://doi.org/10.1016/j.rineng.2023.100993

[33] Priyadharsini, S., Sivaraj, C. (2022). Numerical simulation of thermo-magnetic convection and entropy production in a ferrofluid filled square chamber with effects of heat generating solid body. International Communications in Heat and Mass Transfer, 131: 105753. https://doi.org/10.1016/j.icheatmasstransfer.2021.105753
[34] Ghaffarpasand, O. (2016). Numerical study of MHD natural convection inside a sinusoidally heated lid-driven cavity filled with Fe_3O_4-water nanofluid in the presence of Joule heating. Applied Mathematical Modelling, 40(21-22): 9165-9182. https://doi.org/10.1016/j.apm.2016.05.038
[35] Hasan, M.M., Uddin, M.J., Nasrin, R. (2022). Exothermic chemical reaction of magneto-convective nanofluid flow in a square cavity. International Journal of Thermofluids, 16: 100236. https://doi.org/10.1016/j.ijft.2022.100236
[36] Hinojosac, J.F., Alvarez, G., Estrada, C.A. (2006). Three-dimensional numerical simulation of the natural convection in an open tilted cubic cavity. Revista Mexicana de Física, 52(2): 111-119. https://www.scielo.org.mx/pdf/rmf/v52n2/v52n2a4.pdf.
[37] Esfe, M.H., Barzegarian, R., Bahiraei, M. (2020). A 3D numerical study on natural convection flow of nanofluid inside a cubical cavity equipped with porous fins using two-phase mixture model. Advanced Powder Technology, 31(6): 2480-2492. https://doi.org/10.1016/j.apt.2020.04.012
[38] Alsabery, A.I., Chamkha, A.J., Saleh, H., Hashim, I. (2017). Transient natural convective heat transfer in a trapezoidal cavity filled with non-Newtonian nanofluid with sinusoidal boundary conditions on both sidewalls. Powder Technology, 308: 214-234. https://doi.org/10.1016/j.powtec.2016.12.025
[39] Qi, C., Li, C.Y., Li, K., Han, D. (2022). Natural convection of nanofluids in solar energy collectors based on a two-phase lattice Boltzmann model. Journal of Thermal Analysis and Calorimetry, 147: 2417-2438. https://doi.org/10.1007/s10973-021-10668-8
[40] Guedri, K., Abdel-Nour, Z., Sajadi, S.M., Dheyaa J.J., Abderrahmane, A., Soheil, S., Ahmad, A., Obai, Y, Baghaei, S., Wael, A.K. (2024). Investigation of free convection in a wavy trapezoidal porous cavity with MWCNT- Fe_3O_4/Water hybrid nanofluid under MHD effects: Galerkin finite element analysis. Case Studies in Thermal Engineering, 56: 104243. https://doi.org/10.1016/j.csite.2024.104243
[41] Venkatadri, K., Fazuruddin, S., Bég, O.A., Ramesh, O. (2023). Natural convection of nanofluid flow in a porous medium in a right-angle trapezoidal enclosure: A Tiwari and Das' nanofluid model. Journal of Taibah University for Science, 17(1): 2263224. https://doi.org/10.1080/16583655.2023.2263224
[42] Sompong, P., Witayangkurn, S. (2013). Natural convection in a trapezoidal enclosure with wavy top surface. Journal of Applied Mathematics, 1-7. https://doi.org/10.1155/2013/840632
[43] Malkeson, S.P., Alshaaili, S., Chakraborty, N. (2023). Numerical investigation of steady state laminar natural convection of power-law fluids in side-cooled trapezoidal enclosures heated from the bottom. Numerical Heat Transfer, Part A: Applications, 83(7): 770-789. https://doi.org/10.1080/10407782.2022.2157353
[44] Job, V.M., Gunakala, S.R. (2016). Unsteady MHD free convection nanofluid flows within a wavy trapezoidal enclosure with viscous and joule dissipation effects. Numerical Heat Transfer, Part A: Applications, 69(4): 421-443. https://doi.org/10.1080/10407782.2015.1080946
[45] Venkatadr, K., Gaffar, S.A., Prasad, V.R., Khan, B.M.H., Beg, O.A. (2019). Simulation of natural convection heat transfer in a 2D trapezoidal enclosure. International Journal of Automotive and Mechanical Engineering, 16(4): 7375-7390. https://doi.org/10.15282/ijame.16.4.2019.13.0547
[46] Aghaei, A., Khorasanizadeh, H., Sheikhzadeh, G.A. (2019). A numerical study of the effect of the magnetic field on turbulent fluid flow, heat transfer and entropy generation of hybrid nanofluid in a trapezoidal enclosure. The European Physical Journal Plus, 134: 310. https://doi.org/10.1140/epjp/i2019-12681-3
[47] Rahman, M.M., Amri, K.A., Pop, I. (2021). Darcy–Boussinesq convective flow in a trapezoidal enclosure with thermal stratification. Journal of Thermal Analysis and Calorimetry, 145: 3325-3337. https://doi.org/10.1007/s10973-020 09912-4
[48] Alomari, M.A., Al-Farhany, K., Hashem, A.L., Al-Dawody, M.F., Redouane, F., Olayemi, O.A. (2021). Numerical study of MHD natural convection in trapezoidal enclosure filled with (50%MgO-50%Ag/water) hybrid nanofluid: Heated sinusoidal from below. International Journal of Heat and Technology, 39(4): 1271-1279. https://doi.org/10.18280/ijht.390425
[49] Mustafa, A.W., Ghani, I.A. (2012). Natural convection in trapezoidal enclosure heated partially from below. Al-Khwarizmi Engineering Journal, 8(1): 76-85.
[50] Khan, N.Z., Bilal, S., Riaz, A., Muhammad, T. (2024). Coupled effects of variable permeability and adiabatic undulating walls on natural convective flow in a trapezoidal cavity: Finite element analysis. Results in Physics, 56: 107267. https://doi.org/10.1016/j.rinp.2023.107267
[51] Miroshnichenko, I.V., Sherement, M.A. (2018). Turbulent natural convection heat transfer in rectangular enclosures using experimental and numerical approaches: A review. Renewable and Sustainable Energy Reviews, 82(P1): 40-59. https://doi.org/10.1016/j.rser.2017.09.005
[52] Zhang, X.W., Yu, J.J., Su, G.H., Yao, Z.H., Hao, P.F., He, F. (2016). Statistical analysis of turbulent thermal free convection over a small heat source in a large enclosed cavity. Applied Thermal Engineering, 93: 446-455. https://doi.org/10.1016/j.applthermaleng.2015.10.011
[53] Abderrahmane, A., Khetib, Y., Ghodratallah, P., Jasim, D.J., Rawa, M., Qasem, N.A.A., Younis, O., Akbari, O., Salahshou, S. (2024). Thermal performance of 3D Darcy-forchheimer porous rectangular wavy enclosures containing a water-Fe_3O_4 ferro-nanofluid under magnetic fields. Case Studies in Thermal Engineering, 53: 103790. https://doi.org/10.1016/j.csite.2023.103790
[54] Sheikholeslami, M., Gorji-Bandpy, M., Ganji, D.D., Soleimani, S. (2014). Natural convection heat transfer in a cavity with sinusoidal wall filled with CuO–water nanofluid in presence of magnetic field. Journal of the

Taiwan Institute of Chemical Engineers, 45(1): 40-49. https://doi.org/10.1016/j.jtice.2013.04.019
[55] Mustafa, M., Mushtaq, A., Hayat, T., Ahmad, B. (2014). Nonlinear radiation heat transfer effects in the natural convective boundary layer flow of nanofluid past a vertical plate: A numerical study. PLoS One, 9(9): e103946. https://doi.org/10.1371/journal.pone.0103946
[56] Freidoonimehr, N., Rashidi, M.M., Mahmud, S. (2015). Unsteady MHD free convective flow past a permeable stretching vertical surface in a nano-fluid. International Journal of Thermal Sciences, 87: 136-145. https://doi.org/10.1016/j.ijthermalsci.2014.08.009
[57] Khan, M.S., Karim, I., Ali, L.E., Islam, A. (2012). Unsteady MHD free convection boundary-layer flow of a nanofluid along a stretching sheet with thermal radiation and viscous dissipation effects. International Nano Letters, 2: 24. https://doi.org/10.1186/2228-5326-2-24
[58] Bilal, E.H., Kaddiri, M. (2024). Enhancing the convective heat transfer in vertical and horizontal rectangular enclosures using nanofluids: The crucial role of aspect ratio. Physics of Fluids, 36(1): 012008. https://doi.org/10.1063/5.0186490
[59] Thirumalaisamy, K., Sivaraj, R., Reddy, A.S. (2024). Fluid flow and heat transfer analysis of a ternary aqueous Fe_3O_4 + MWCNT + Cu/H_2O magnetic nanofluid in an inclined rectangular porous cavity. Journal of Magnetism and Magnetic Materials, 589: 171503. https://doi.org/10.1016/j.jmmm.2023.171503
[60] Vinodhini, N., Prasad, V.R. (2023). NUMERICAL study of MAGNETO convective Buongiorno nanofluid flow in a rectangular enclosure under oblique magnetic field with heatgeneration/absorption and complex wall conditions. Heliyon, 9(7): e17669. https://doi.org/10.1016/j.heliyon.2023.e17669
[61] Muhammad, N., Naveed, A. (2023). Method of moments solution to ethylene glycol based Al_2O_3 nanofluid flow through expanding/contracting rectangular channel. Heliyon, 9(12): e22415. https://doi.org/10.1016/j.heliyon.2023.e22415
[62] Rehman, K., Shatanawi, W., Bahaidarah, H.M.S., Abbas, S., Khan, A.U. (2023). Thermal case study of nanofluid flow in partially heated rectangular enclosure rooted with sinusoidal heated rods and inclined magnetic field. Case Studies in Thermal Engineering, 45: 102982. https://doi.org/10.1016/j.csite.2023.102982
[63] Li, M.G., Zheng, C., Zhao, Q., Chen, X., Wu, W.T. (2021). Anisotropic heat transfer of ferro-nanofluid in partially heated rectangular enclosures under magnetic field. Case Studies in Thermal Engineering, 26: 101145. https://doi.org/10.1016/j.csite.2021.101145
[64] Peiravi, M.M., Alinejad, J., Ganji, D.D., Maddah, S. (2019). 3D optimization of baffle arrangement in a multi-phase nanofluid natural convection based on numerical simulation. International Journal of Numerical Methods for Heat & Fluid Flow, 30(5): 2583-2605. https://doi.org/10.1108/hff-01-2019-0012
[65] Aich, W., Hajri, I., Omri, A. (2011). Numerical analysis of natural convection in a prismatic enclosure. Thermal Science, 15(2): 437-446. https://doi.org/10.2298/TSCI090720036A
[66] Saha, G., Saha, S., Hasan, M.N., Islam, M.Q. (2010). Natural convection heat transfer within octagonal enclosure. IJE Transactions A: Basics, 23(1): 1-10. https://doi.org/10.1007/978-1-4419-5860-0_1
[67] Grosana, T., Revnic, C., Popa, I., Inghamc, D.B. (2009). Magnetic field and internal heat generation effects on the free convection in a rectangular cavity filled with a porous medium. International Journal of Heat and Mass Transfer, 52(5-6): 1525-1533. https://doi.org/10.1016/j.ijheatmasstransfer.2016.08.025
[68] Saha, S.C. (2011). Scaling of free convection heat transfer in a triangular cavity for Pr>1. Energy and Buildings, 43(10): 2908-2917. https://doi.org/10.1016/j.enbuild.2011.07.016
[69] Saleha, H., Roslanb, R., Hashima, I. (2011). Natural convection heat transfer in a nanofluid-filled trapezoidal enclosure. International Journal of Heat and Mass Transfer, 54(1-3): 194-201. https://doi.org/10.1016/j.ijheatmasstransfer.2010.09.053
[70] Saha, G. (2010). Finite element simulation of magnetoconvection inside a sinusoidal corrugated enclosure with discrete isoflux heating from below. International Journal of Heat and Mass Transfer, 37(4): 393-400. https://doi.org/10.1016/j.icheatmasstransfer.2009.12.001
[71] Matin, M., Pop, I. (2013). Natural convection flow and heat transfer in an eccentric annulus filled by copper nanofluid. International Journal of Heat and Mass Transfer, 61: 353-364. https://doi.org/10.1016/j.ijheatmasstransfer.2013.01.061
[72] Al-Zamily, A., Amin, M.R. (2015). Natural convection and entropy generation in a nanofluid-filled semicircular enclosure with heat flux source. Procedia Engineering, 105: 418-424. https://doi.org/10.1016/j.proeng.2015.05.028
[73] Alam, M.S., Keya, S.S., Salma, U., Hossain, S.M.C., Billah, M.M. (2022). Convective heat transfer enhancement in a quarter-circular enclosure utilizing nanofluids under the influence of periodic magnetic field. International Journal of Thermofluids, 16: 100250. https://doi.org/10.1016/j.ijft.2022.100250
[74] Jino, L., Vanav, K.A. (2021). Fluid flow and heat transfer analysis of quadratic free convection in a nanofluid filled porous cavity. International Journal of Heat and Technology, 39(3): 876-884. https://doi.org/10.18280/ijht.390322
[75] Bourantas, G.C., Skouras, E.D., Loukopoulos, V.C., Burganos, V.N. (2014). Heat transfer and natural convection of nanofluids in porous media. European Journal of Mechanics - B/Fluids, 43: 45-56. http://doi.org/10.1016/j.euromechflu.2013.06.013
[76] Aly, A.M. (2020). Natural convection of a nanofluid-filled circular enclosure partially saturated with a porous medium using ISPH method. International Journal of Numerical Methods for Heat & Fluid Flow, 30(11): 4909-4932. http://doi.org/10.1108/hff-12-2019-0919
[77] Bilal, S., Shah, I.A., Ghachem, K., Aydi, A., Kolsi, L. (2023). Heat transfer enhancement of MHD natural convection in a star-shaped enclosure, using heated baffle and MWCNT–water nanofluid. Mathematics, 11(8): 1849. https://doi.org/10.3390/math11081849
[78] Ali, L., Ullah, Z., Boujelbene, M., Apsari, R., Alshammari, S., Chaudhry, I.A., Abu-Zinadah, H., El-Sayed, S.B.A. (2024). Wave oscillations in thermal boundary layer of Darcy-Forchheimer nanofluid flow along buoyancy-driven porous plate under solar radiation

region. Case Studies in Thermal Engineering, 54: 103980. https://doi.org/10.1016/j.csite.2024.103980

[79] Jahan, I., Asha, N.E.J., Molla, M.M. (2024). Mesoscoping simulation of viscoelastic hybrid nanofluid having variable thermophysical properties in an inverted T-shaped enclosure with a localized heater. Case Studies in Thermal Engineering, 53: 103900. https://doi.org/10.1016/j.csite.2023.103900

[80] Zehba, A.S., Raizah, Aly, A.M., Ahmed, S.E. (2021). Natural convection flow of a nanofluid-filled V-shaped cavity saturated with a heterogeneous porous medium: Incompressible smoothed particle hydrodynamics analysis. Ain Shams Engineering Journal, 12(2): 2033-2046. https://doi.org/10.1016/j.asej.2020.09.026

[81] Al-Amir, Q.R., Hamzah, H.K., Ali, F.H., Al-Kouz, W., Hatami, M., Al-Manea, A., Al-Rbaihatf, R., Alahmer, A. (2023). Investigation of natural convection and entropy generation in a porous titled z-staggered cavity saturated by TiO_2-water nanofluid. International Journal of Thermofluids, 19: 100395. https://doi.org/10.1016/j.ijft.2023.100395

[82] Islam, M.S., Islam, S., Siddiki, M.N.A.A. (2023). Numerical simulation with sensitivity analysis of MHD natural convection using Cu-TiO_2-H_2O hybrid nanofluids. International Journal of Thermofluids, 20: 100509. https://doi.org/10.1016/j.ijft.2023.100509

[83] Reddy, N.K., K.Swamy, H.A., Sankar, M., Jang, B. (2023). MHD convective flow of Ag–TiO_2 hybrid nanofluid in an inclined porous annulus with internal heat generation. Case Studies in Thermal Engineering, 42: 102719. https://doi.org/10.1016/j.csite.2023.102719

[84] Asha, N.E.J., Molla, M.M. (2023). MRT-lattice Boltzmann simulation of MHD natural convection of Bingham nanofluid in a C-shaped enclosure with response surface analysis. Heliyon, 9(12): e22539. https://doi.org/10.1016/j.heliyon.2023.e22539

[85] Muhammad, A., Qasim, A., Ali, R., Almusawa, M.Y., Waleed, H., Ali, H.A. (2024). Computational results of convective heat transfer for fractionalized Brinkman type tri-hybrid nanofluid with ramped temperature and non-local kernel. Ain Shams Engineering Journal, 15(3): 102576. https://doi.org/10.1016/j.asej.2023.102576

[86] Adnan, M.M., AlBaidani, N.K., Mishra, M.M., Alam, M.M., Eldin, S.M., AL-Zahrani, A.A., Akgul, A. (2023). Numerical analysis of magneto-radiatedannular fin natural-convective heat transfer performance using advanced ternary nanofluid considering shape factors with heating source. Case Studies in Thermal Engineering, 44: 102825. https://doi.org/10.1016/j.csite.2023.102825

[87] Siddique, I., Sadiq, K., Jarad, F., Mesfer, M.K.A., Danish, M., Yaqoob, S. (2022). Analysis of natural convection in nanofluid flow through a channel with source/sink effect. Journal of Nanomaterials, 2022(2): 2738398. https://doi.org/10.1155/2022/2738398

[88] Kalidoss, P., Venkatachalapathy, S., Suresh, S. (2020). Optical and thermal properties of therminol 55-TiO_2 nanofluids for solar energy storage. International Journal of Photoenergy, 2020: 7085497. https://doi.org/10.1155/2020/7085497

[89] Alhashash, A. (2023). Free convection heat transfer in composite enclosures with porous and nanofluid layers. Advances in Mathematical Physics, 2023: 2088607. https://doi.org/10.1155/2023/2088607

[90] Memon, A.A., Memon, M.A., Haque, M.M. (2023). Numerical investigation of electrical efficiency with the application of hybrid nanofluids for photovoltaic thermal systems contained in a cavity channel. Journal of Mathematics, 2023: 5465847. https://doi.org/10.1155/2023/5465847

[91] Raza, A., Ali, R., Ali, A.H., Alfalqi, S.H. Chishti, K. (2024). Prabhakar fractional simulations for natural convective hybrid nanofluid mixed with Cu and Al_2O_3 nanoparticles flowing through a channel. Journal of Engineering Research, 12(1): 25-35. https://doi.org/10.1016/j.jer.2023.08.027

[92] Parvin, S., Roy, N.C., Sah, L.K. (2023). Natural convective non-Newtonian nanofluid flow in a wavy-shaped enclosure with a heated elliptic obstacle. Heliyon, 9(6): e16579. https://doi.org/10.1016/j.heliyon.2023.e16579

[93] Nayak, M.K., Dogonchi, A.S., Rahbari, A. (2023). Free convection of Al_2O_3-water nanofluid inside a hexagonal-shaped enclosure with cold diamond-shaped obstacles and periodic magnetic field. Case Studies in Thermal Engineering, 50: 103429. https://doi.org/10.1016/j.csite.2023.103429

[94] Bhuiyana, A.H., Alam, M.S., Alim, M.A. (2017). Natural convection of water-based nanofluids in a square cavity with partially heated of the bottom wall. Procedia Engineering, 194: 435-441. https://doi.org/10.1016/j.proeng.2017.08.168

[95] Al-Zamily, A.M.J. (2017). Analysis of natural convection and entropy generation in a cavity filled with multi-layers of porous medium and nanofluid with a heat generation. International Journal of Heat and Mass Transfer, 106: 1218-1231. http://doi.org/10.1016/j.ijheatmasstransfer.2016.10.102

[96] Sannad1, M., Abourida, B., Belarche, L., Doghmi, H., Ouzaouit, M. (2016). Numerical study of natural convection in a three-dimensional cavity filled with nanofluids. International Journal of Computer Science, 13(5): 51-61. http://doi.org/10.20943/01201605.5161

[97] Sannad, M., Abourida, B., Belarche, L., Doghmi, H., Ouzaouit. M. (2019). Effect of the heating block position on natural convection in a three-dimensional cavity filled with nanofluids. Journal of Applied Fluid Mechanics, 12(1): 281-291. http://doi.org/10.29252/jafm.75.253.29026

[98] Peiravi, M.M., Alinejad, J., Ganji, D.D., Maddah, S. (2019). Numerical study of fins arrangement and nanofluids effects on three dimensional natural convection in the cubical enclosure. Challenges in Nano and Micro Scale Science and Technology, 7(2): 97-112. http://doi.org/10.22111/TPNMS.2019.4845

[99] Soulayma, G., Lioua, K., Walid, H., Naim, B.A., Nidhal, B.K., Ali, J.C. (2022). Three-dimensional study of magnetohydrodynamic natural convection, entropy generation, and electromagnetic variables in a nanofluid filled enclosure equipped with inclined fins. ACS Omega, 7(14): 12365-12373. https://doi.org/10.1021/acsomega.2c00923

[100] Bouchta, S., Feddaoui, M. (2020). Numerical simulation of free convection in a three-dimensional enclosure full of nanofluid with the existence a magnetic field. European Journal of Electrical Engineering, 22(6): 405-411. https://doi.org/10.18280/ejee.220602

[101] Mohamed, S., Abourida, B., Belarche, L. (2020).

Numerical simulation of the natural convection with presence of the nanofluids in cubical cavity. Mathematical Problems in Engineering, 2020: 8375405. https://doi.org/10.1155/2020/8375405
[102] Moutaouakil, L.E., Boukendil, M., Zrikem, Z., Abdelbaki, A. (2020). Natural convection and thermal radiation influence on nanofluids in a cubical cavity. International Journal of Heat and Technology, 38(1): 59-68. https://doi.org/10.18280/ijht.380107
[103] Sannad, M., Hussein, A.K., Abidi, A., Homod, R.Z., Biswal, U., Ali, B., Kolsi, L., Younis, O. (2022). Numerical study of MHD natural convection inside a cubical cavity loaded with copper-water nanofluid by using a non-homogeneous dynamic mathematical model. Mathematics, 10(12): 2072. https://doi.org/10.3390/math10122072
[104] Mohsen, I., Bader, A., Ahmad, H., Mikhail, A.S., Mohamed, B.B.H. (2023). Free convection of nanofluids in a porous sensible heat storage unit: Combined effect of time periodic heating and external magnetic field. International Journal of Thermal Sciences, 192(PA): 108404. https://doi.org/10.1016/j.ijthermalsci.2023.108404
[105] Rashed, Z.Z., Alhazmi, M., Ahmed, S.E. (2021). Non-homogenous nanofluid model for 3D convective flow in enclosures filled with hydrodynamically and thermally heterogeneous porous media. Alexandria Engineering Journal, 60(3): 3119-3132. https://doi.org/10.1016/j.aej.2021.01.049
[106] Dayf, A., Feddaoui, M., Bouchta, S., Charef, A., Ihssini, H.E. (2021). Effect of nanoparticles and base fluid types on natural convection in a three-dimensional cubic enclosure. Mathematical Problems in Engineering, 2021: 8882790. https://doi.org/10.1155/2021/8882790
[107] Hidki, R., Moutaouakil, L.E., Boukendil, M., Charqui, Z., Zrikem, Z., Abdelbaki, A. (2023). Impact of Cu, Al_2O_3-water hybrid nanofluid on natural convection inside a square cavity with two heat-generating bodies. Materials Today: Proceedings, 72(P7): 3749-3756.https://doi.org/10.1016/j.matpr.2022.09.292
[108] Al-Rashed, A.A.A.A., Kalidasan, K., Kolsi, L., Aydi, A., Malekshah, E.H., Hussein, A.K., Kanna, P.R. (2018). Three-dimensional investigation of the effects of external magnetic field inclination on laminar natural convection heat transfer in CNT–water nanofluid filled cavity. Journal of Molecular Liquids, 252: 454-468. https://doi.org/10.1016/j.molliq.2018.01.006
[109] Abeer, A. (2023). Free convection heat transfer in composite enclosures with porous and nanofluid layers. Advances in Mathematical Physics, 2023: 2088607. https://doi.org/10.1155/2023/2088607
[110] Al-Rashed, A.A.A.A., Hassen, W., Kolsi, L., Oztop, H.F., Chamkha, A.J., Abu-Hamdeh, N. (2019). Three-dimensional analysis of natural convection in nanofluid-filled parallelogrammic enclosure opened from top and heated with square heater. Journal of Central South University, 26: 1077-1088. https://doi.org/10.1007/s11771-019-4072-0
[111] Kalsi, S., Kumar, S., Kumar, A., Alam, T., Dobrota, D. (2023). Thermophysical properties of nanofluids and their potential applications in heat transfer enhancement: A review. Arabian Journal of Chemistry, 16(11): 105272. https://doi.org/10.1016/j.arabjc.2023.105272
[112] Sundar, L.S., Sharma, K.V., Singh, M.K., Sousa, A.C.M. (2017). Hybrid nanofluids preparation, thermal properties, heat transfer and friction factor – A review. Renewable and Sustainable Energy Reviews, 68(P1): 185-198. https://doi.org/10.1016/j.rser.2016.09.108
[113] Moradi, A., Toghraie, D., Isfahani, A.H.M., Hosseinian, A. (2019). An experimental study on MWCNT–water nanofluids flow and heat transfer in double-pipe heat exchanger using porous media. Journal of Thermal Analysis and Calorimetry, 137: 1797-1807. https://doi.org/10.1007/s10973-019-08076-0
[114] Oparanti, S.O., Fofana, I., Jafari, R., Zarrougu, R. (2024). State-of-the-art review on green nanofluids for transformer insulation. Journal of Molecular Liquids, 396: 124023. https://doi.org/10.1016/j.molliq.2024.124023
[115] Murshed, S.M.S., Tan, S.H., Nguyen, N.T. (2008). Temperature dependence of interfacial properties and viscosity of nanofluids for droplet-based microfluidics. Journal of Physics D: Applied Physics, 41(8): 085502. https://doi.org/10.1088/0022-3727/41/8/ 085502
[116] Abouali, O., Ahmadi, G. (2012). Computer simulations of natural convection of single phase nanofluids in simple enclosures: A critical review. Applied Thermal Engineering, 36: 1-13. https://doi.org/10.1016/j.applthermaleng.2011.11.065
[117] Saha, T., Saha, G., Parveen, N., Islam, T. (2024). Unsteady magneto-hydrodynamic behavior of TiO_2-kerosene nanofluid flow in wavy octagonal cavity. International Journal of Thermofluids, 21: 100530. https://doi.org/10.1016/j.ijft.2023.100530
[118] Hu, Y.P., Wang, F.J., Zhang, Y.C., Li, Y.R., Li, M.H. (2022). Oscillatory natural convection of Al_2O_3-water nanofluid near its density maximum in a narrow horizontal annulus. International Communications in Heat and Mass Transfer, 136: 106207. https://doi.org/10.1016/j.icheatmasstransfer.2022.106207
[119] Uddin, M.J., Rasel, S.K. (2019). Numerical analysis of natural convective heat transport of copper oxide-water nanofluid flow inside a quadrilateral vessel. Heliyon, 5(5): e01757. https://doi.org/10.1016/j.heliyon.2019.e01757
[120] Das, S.K., Choi, S.U.S., Yu, W., Pradeep, T. (2007). Nanofluids, science and technology. Wiley Interscience, Hoboken. https://doi.org/10.1002/9780470180693
[121] Alshuhail, L.A., Shaik, F., Sundar, L.S. (2023). Thermal efficiency enhancement of mono and hybrid nanofluids in solar thermal applications – A review. Alexandria Engineering Journal, 68: 365-404. https://doi.org/10.1016/j.aej.2023.01.043
[122] Al-Dulaimi, Z., Kadhim, H.T., Jaffer, M.F., Al-Manea, A., Al-Rbaihat, R., Alahmer, A. (2024). Enhanced conjugate natural convection in a corrugated porous enclosure with Ag - MgO hybrid nanofluid. International Journal of Thermofluids, 21: 100574. https://doi.org/10.1016/j.ijft.2024.100574
[123] Rehena, N., Salma, P., Alim, M.A. (2013). Effect of Prandtl number on free convection in a solar collector filled with nanofluid. Procedia Engineering, 56: 54-62. https://doi.org/10.1016/j.proeng.2013.03.088
[124] Rasool, G., W. Wang, X.H., Lund, L.A., Yashkun, U., Wakif, A., Asghar, A. (2023). Dual solutions of unsteady flow of copper-alumina/water based hybrid nanofluid with acute magnetic force and slip condition. Heliyon,

9(12): e22737. https://doi.org/10.1016/j.heliyon.2023.e22737
[125] Malik, M.F., Shah, S.A.A., Bilal, M., Hussien, M., Mahmood, I., Akgul, A., Alshomrani, A.S., Az-Zo'bi, E.A. (2023). New insights into the dynamics of heat and mass transfer in a hybrid (Ag-TiO_2) nanofluid using Modified Buongiorno model: A case of a rotating disk. Results in Physics, 53: 106906. https://doi.org/10.1016/j.rinp.2023.106906
[126] Jakeer, S., Reddy, P.B., Rashad, A.M., Nabwey, H.A. (2020). Impact of heated obstacle position on magneto-hybrid nanofluid flow in a lid-driven porous cavity with Cattaneo-Christov heat flux pattern. Alexandria Engineering Journal, 60(1): 821-835. https://doi.org/10.1016/j.aej.2020.10.011
[127] Awan, A.U., Ali, B., Shah, S.A.A., Oreijah, M., Guedri, K., Eldin, S.M. (2023). Numerical analysis of heat transfer in Ellis hybrid nanofluid flow subject to a stretching cylinder. Case Studies in Thermal Engineering, 49: 103222. https://doi.org/10.1016/j.csite.2023.103222
[128] Shah, S.A.A., Awan, A.U. (2022). Significance of magnetized Darcy-Forchheimer stratified rotating Williamson hybrid nanofluid flow: A case of 3D sheet. International Communications in Heat and Mass Transfer, 136: 106214. https://doi.org/10.1016/j.icheatmasstransfer.2022.106214
[129] Acharya, N., Das, K., Kundu, P.K. (2016). The ramification of variable thickness on MHD TiO_2 and Ag nanofluid flow over a slender stretching sheet using NDM. The European Physical Journal Plus, 131: 303. https://doi.org/10.1140/epjp/i2016-16303-4
[130] Akbar, Y., Abbasi, F.M., Shehzad, S.A. (2021). Effectiveness of Hall current and ion slip on hydromagnetic biologically inspired flow of Cu - Fe_3O_4 /H_2O hybrid nanomaterial. Physica Scripta, 96: 025210. https://doi.org/10.1088/1402-4896/abcff1
[131] Selim, M.M., El-Safty, S., Tounsi, A., Shenashen, M. (2023). Review of the impact of the external magnetic field on the characteristics of magnetic nanofluids. Alexandria Engineering Journal, 76: 75-89. https://doi.org/10.1016/j.aej.2023.06.018
[132] Saleem, K.B., Marafie, A.H., Al-Farhany, K., Hussam, W.K., Sheard, G.J. (2023). Natural convection heat transfer in a nanofluid filled L-shaped enclosure with time-periodic temperature boundary and magnetic field. Alexandria Engineering Journal, 69: 177-191. https://doi.org/10.1016/j.aej.2022.12.030
[133] Dogonchia, A.S., Seyyedi, S.M., Hashemi-Tilehnoee, M., Chamkha, A.J., Ganjie, D.D. (2019). Investigation of natural convection of magnetic nanofluid in an enclosure with a porous medium considering Brownian motion. Case Studies in Thermal Engineering, 14: 100502. https://doi.org/10.1016/j.csite.2019.100502
[134] Ahmad, S., Ali, K., Ayub, A., Bashir, U., Rashid, F.L., Aryanfar, Y., Ali, M.R., Hendy, A.S., Shah, I., Ali, L. (2023). Localized magnetic fields and their effects on heat transfer enhancement and vortices generation in tri-hybrid nanofluids: A novel investigation. Case Studies in Thermal Engineering, 50: 103408. https://doi.org/10.1016/j.csite.2023.103408
[135] Li, W.K., Liao, C.C. (2023). Evaluation of heat transfer transition for nanofluids within an enclosure based on magnetic field angles. Case Studies in Thermal Engineering, 50: 103480. https://doi.org/10.1016/j.csite.2023.103480
[136] Zhang, L.Y., Hu, Y.P., Li, M.H. (2021). Numerical study of natural convection heat transfer in a porous annulus filled with a Cu nanofluid. Nanomaterials, 11(4): 990. https:// doi.org/10.3390/nano11040990
[137] Bouafia, I., Mehdaoui, S., Kadri, R., Elmir, M. (2020). Natural convection in a porous cavity filled with nanofluid in the presence of isothermal corrugated source. International Journal of Heat and Technology, 3(2): 334-342. https://doi.org/10.18280/ijht.380208
[138] Zhao, C.Y., Dai, L.N., Tang, G.H., Qu, Z.G., Li, Z.Y. (2010). Numerical study of natural convection in porous media (metals) using lattice Boltzmann method (LBM). International Journal of Heat and Fluid Flow, 31(5): 925-934. https://doi.org/10.1016/j.ijheatfluidflow.2010.06
[139] Hatami, M., Ghasemi, S.E. (2021). Thermophoresis and Brownian diffusion of nanoparticles around a vertical cone in a porous media by Galerkin finite element method (GFEM). Case Studies in Thermal Engineering, 28: 101627. https://doi.org/10.1016/j.csite.2021.101627

NOMENCLATURE

Ra	Rayleigh number
Ha	Hartmann number.
Pr	Prandtl number
Da	Darcy number.
Be	Bejan number.
Nu	Nusselt number
K	thermal conductivity, W.m^{-1}. K^{-1}
T	temperature, k
u,v,w,	the x,y, and z directions component , m/s
R_k	thermal conductivity ratio

Subscripts

Nf	nanofluid
S	solid particles
hnf,	hybrid-nanofluid
tri	trihybrid nanofluid
Ar	aspect ratio

Greek symbols

ε	porosity of porous medium
μ	dynamic viscosity , $\frac{kg}{m}.s$
∅	solid volume fraction
γ	inclination angle
α	thermal diffusivity m^2/s
θ	dimensionless temperature
δ	porous layer thickness