

A Review on MHD Mixed Convection with Nanofluids in Regular and Irregular Geometries

Adekeye T^{1*}, Okekunle P. O¹, Adegun I. K²

¹Ph.D Student, ¹Professor, Department of Mechanical Engineering, Ladoke Akintola University of Technology, Ogbomoso, Oyo State, Nigeria

²Professor, Department of Mechanical Engineering, University of Ilorin, Ilorin, Kwara State, Nigeria

*Corresponding Author: tundeadekeye2008@gmail.com

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ABSTRACT

An extensive overview of magnetohydrodynamic (MHD) mixed convection of nanofluids in various enclosures is presented in this work. The study aims at reviewing the analytical, numerical and experimental studies on MHD mixed convection in several geometries between 2005 and 2020. The previous researches on the subject matter are grouped into regular and irregular shapes, their significant information with identified gaps summarized and presented in table 1 to give a panoramic survey. The outcome of the review study and analyses presented a notable heat transfer augmentation in various enclosures with increasing nanoparticle volume concentrations and some model parameters such as Reynolds number (Re), Richardson number (Ri) and Hartmann number (Ha). This survey can be seen as a significant connection between nanofluids application and heat transfer enhancement in MHD mixed convection in various enclosures. On the other hand, further studies are expected to investigate the effects of nanoparticle volume fractions on MHD mixed convection in different enclosures based on the identified gaps. The survey could be very useful as prediction parameters for designing a more compact, efficient and durable heat exchangers for industrial applications.

Keywords-Aspect ratio, Eccentricity, Enclosure, Magneto Hydrodynamic (MHD), Mixed convection, Nanofluid, Richardson Number

INTRODUCTION

Environmental and economic sustainability have drawn the attention of researchers and prompted them to seek alternative methods that offer maximum energy at low cost. Thermal system channel configuration and heat transfer fluid type are significant in providing the highest required energy transport [1]. Mixed convective heat transfer and fluid flow in irregularly shaped geometry are significant in engineering and technology because of their numerous applications such as cooling of microelectronic equipment, heat exchangers and solar collectors [2]. Free and forced convective flows as well as heat transfer in enclosures have been examined extensively due to their numerous areas of engineering applications, such as ventilation of rooms, lubrication technologies, and nuclear reactors, drying technologies, food processing, solar-powered systems and several others [2-7]. According to Morley et al.[8], any movement of a conducting material in a magnetic field that generates an electric current which in turn induces its magnetic field is called magneto hydrodynamic (MHD), examples of such are liquid metals, plasma, electrolyte or ionized gas and nanofluid. It has numerous industrial applications, originally in astrophysics, as in solar structure and geophysics, as in planetary magnetism, MHD pumps, MHD generators, nuclear reactors, electromagnetic casting, metallurgical processing, stability of convective flows and several others [9]. One of the uniqueness of MHD is that gas is not confined by a wall and thereby liable to instability and waves but it possesses a free surface. A closely

related application is an MHD accelerator to shoot plasma into fusion devices or to produce high-energy wind tunnels for simulating hypersonic flight. Other relevant applications of MHD include electromagnetic with fluid conductors, several storage devices, energy conversion appliances and control mechanisms in material manufacturing industries [10, 11].

The analysis of magnetohydrodynamics (MHD) flow and heat transfer for electrically conducting fluids are often experienced in electrical power generation astrophysical flow and solar power technology [12]. Also, further engineering and industrial circumstances where mixed convective heat transfer in the presence of a magnetic field is relevant, include cooling of electronic devices, furnace design flow and heat transfer in obstructed cavities such as micro-electronic devices, flat plate condensers in the refrigeration system, production of steel and aluminium, high- performance super-alloys or crystal among others [10].

Kherroubi et al. [4] investigated 3-D MHD mixed convection with a ventilated cavity 'L' shape filled by a nanofluid. Their results summarily established the following:

- Increasing the Reynolds number elevated the hydrodynamic field and enhanced heat transfer in a ventilated L-shaped cubic cavity.
- Also, the result showed that the magnetic field weakened the hydrodynamic structure as well as heat transfer in the cavity at a reduced Reynolds number. But, for Reynolds number at 500 ($Re=500$), the magnetic field effect was almost negligible.
- Nanoparticles improved the Nusselt number specifically for elevating Reynolds number values irrespective of any situation (presence or absence of the magnetic field).
- The influence of the third direction was insignificant with the presence of the magnetic field.

Fig. 1 depicts the physical model of the 3-D MHD mixed convection flow in L-shaped cubic

geometry filled with nanofluid, showing the inlet and outlet fluid flow and direction of magnetic field application on the cavity.

Again, it is important to note that the excellent performance of any electronic equipment is predicted by its operating temperature. Continuous cooling is highly needed to keep electronic devices within the expected temperature range. Increasing heat transfer rate, compactness and reliable operation are the problems confronting electronic device experts and researchers. These problems have called the attention of researchers and electronic experts to intensify their efforts on studying mixed convective heat transfer since it is the source of the air cooling system used [5].

Nanofluids on the other hand are dilute liquid suspensions of nanoparticles or mixtures of base fluid with a very small amount of solid metallic oxides with at least one critical dimension smaller than 100 nm which was first used by Choi (1995). In recent times, more attention has been paid to nanotechnology because of its enhanced properties associated with heat transfer. Nanofluid is useful in buildings, heating, heat exchangers, and power plants, automobile cooling applications, cooling of electronic devices, cooling of transformer coil, the transportation industry, microchips and solar absorption to mention a few [13]. The roles of nanofluids are numerous considering the heat exchanger devices for different engineering and industrial applications [14].

The different geometries where MHD mixed convection saturated with nanofluids is applied include the square, rectangular, circular, cylindrical, trapezoidal, triangular, elliptical and other non-conventional geometries such as U-shaped, L-shaped, C-shaped, T-shaped among others. The prime objective of this study is reviewing the analytical, numerical and experimental studies on MHD mixed convection in several geometries between 2005 and 2020.

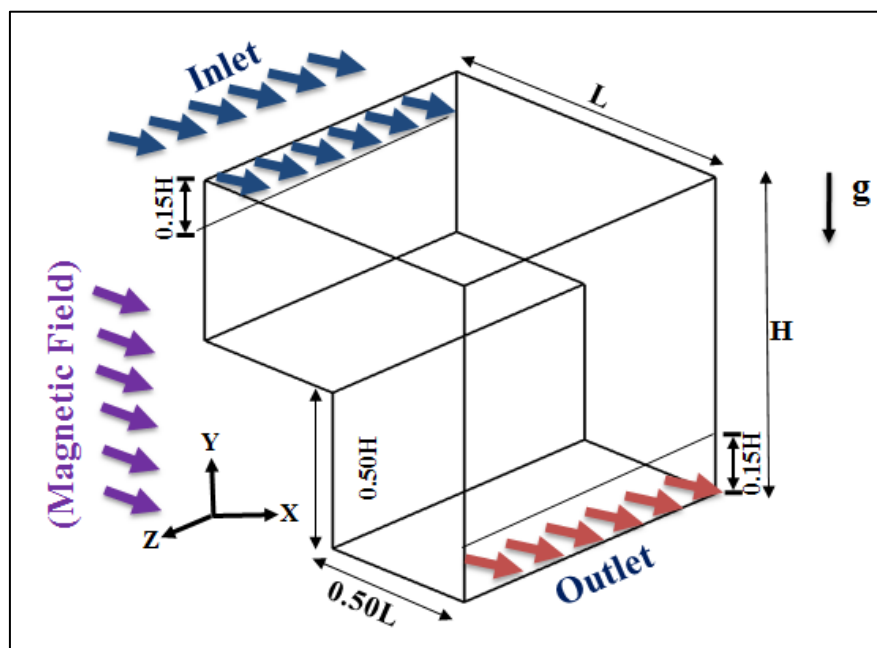


Figure 1: Physical model of the MHD mixed convection in L-shaped enclosure saturated with nanofluid according to Kherroubi et al.(2020) [4].

MHD MIXED CONVECTION OF NANOFLUIDS IN REGULAR ENCLOSURES

In this segment, experimental and numerical studies reported by researchers on MHD mixed convective heat transfer and fluid flow in regular configurations filled with nanofluids are presented.

Square and Rectangular configurations

A set of the most reported enclosures comprises square and rectangular configurations. A number of these were reviewed and are hereby presented.

Rahman et al. [6] investigated MHD mixed convection in an obstructed lid-driven square cavity. The result showed that obstacle has a noticeable impact on the fluid flow, and magnetic field has a significant impact on both the flow and heat transfer characteristics. Fatih and Hakan [15] presented MHD mixed convection in a nanofluid-filled lid-driven square enclosure with a rotating cylinder. The researchers concluded that when the cylinder rotated in the clockwise direction, heat transfer enhancement moved towards both ends of the bottom wall but decreased within the parametric range of $0.35 \leq x \leq 0.75$. Mehmood et al. [16] studied the MHD mixed convection in a square

enclosure filled with alumi-water nanofluid using the KKL model. They concluded that:

- At a constant value of the Richardson number, the stream function reached the maximum level.
- An increase in heat transfer was a function of Darcy number, Porosity, temperature ratio, magnetic field inclination and nanofluid.

Chamkha et al. [17] investigated the effects of the partial slip on entropy generation and MHD mixed convection in a square lid-driven porous cavity filled with Cu-water nanofluids. The results are summarily presented as follows:

- Heat transfer enhancement reduced the Nusselt number.
- When the volume fraction was increased, the Nusselt number and entropy generation decreased.

Nagehan [18] studied the effect of a uniform MHD on unsteady natural convection of nanofluid in a square cavity. Dual Reciprocity Boundary Element Method (DRBEM) was employed. He concluded that Rayleigh' number increased and heat transfer was enhanced in the enclosure due to a strong buoyancy force. Also, it was reported that the impact of the Hartmann number on the temperature profile was pronounced at $Ra = 10^5$. In the same vein, it was concluded that volume fraction increment is strongly dependent on the increasing values of

the Hartmann number, (i.e. at $Ha = 10$ to 60). Iman and Mohammed [19] investigated the natural and mixed convection of a nanofluid in the square porous cavity by employing Buongiorno's model. They concluded that the presence of a sinusoidal temperature profile on the firewalls of the enclosure resulted in heat transfer enhancement. Etif [20] studied MHD mixed convection flow in a lid-driven rectangular enclosure. He concluded that the magnetic field had stronger influence on the flow when it is horizontally applied than in the vertical direction. Also, it was established that the magnetic field suppressed the fluid flow and the rate of heat transfer in both directions. Zahan et al. [21] studied the MHD effect on conjugate heat transfer in a copper water nanofluid-filled rectangular enclosure. They concluded that the rate of heat transfer increased with increased Rayleigh number but decreased with increased Hartmann number. Javad and Mohammad [22] investigated the effect of a

magnetic field on mixed convective heat transfer in a lid-driven rectangular enclosure using a finite volume approach with a SIMPLE algorithm. They concluded that the Hartmann (Ha) number has a dominant control on fluid flow and heat transfer characteristics as shown in Fig\ 2.

Circular Enclosures

Another common regular configuration is circular. Several researchers have carried out significant numerical and experimental works on this particular geometry.

Mohammadreze and Rouzbeh [23] investigated MHD Go-water nanofluid and heat transfer between two parallel moving disks. They concluded that the velocity field around the mid-point of the channel increased but reduced around the wall. It was also pointed out that transverse positioning of the magnetic field suppressed the flow motion.

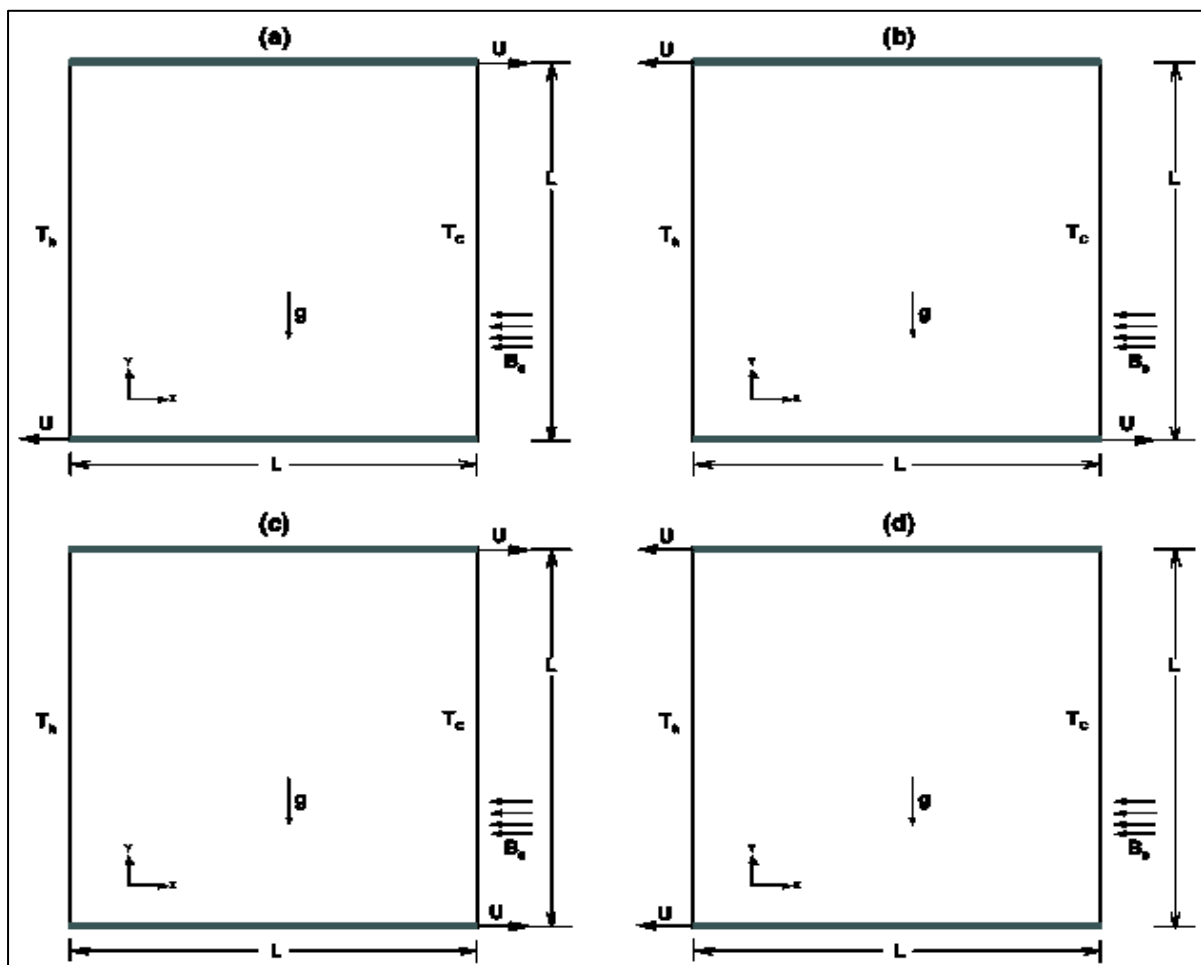


Figure 2: Schematic flow configuration of the problem: a) RL configuration, b) LR configuration, c) RR configuration and d) LL configuration according to Javad and Mohammad (2013) [22].

Gaffar [24] investigated experimentally mixed convective flow in an incline circular tube with Al_2O_3 -water and hybrid nanofluid. He concluded that experiment 1 (i.e. thermally developing laminar mixed convection flow of water and water/ Al_2O_3 mixture in an inclined copper tube subjected to uniform heat flux) showed that the application of nanoparticle volume concentration from (0-4%) resulted in a deteriorating rate of heat transfer for horizontal orientation but the rate of heat transfer was found to be almost constant for vertical inclination both subjected to the same conditions. Also, experiment 2 presented that the Nusselt number elevated with Al_2O_3 -Cu/ hybrid nanoparticle application (10.95%) than pure water. Also, convective heat transfer coefficient (h) augmented with increasing Reynolds number ($\text{Re}=1730$), the result showed optimum heat transfer augmentation of 13.56%.

Mansour et al. [25] experimentally studied mixed convection in a circular tube filled with water- Al_2O_3 nanofluid with uniform heat flux.

The study established that:

- Elevating nanoparticle volume concentration (0-4%) retarded the ratio of heat transfer for horizontal orientation. But the rate of heat transfer was found to be constant of the vertical inclination orientation both subjected to the same condition
- There is a discrepancy between the experimental, analytical and numerical data in terms of heat transfer augmentation under buoyant forces concerning the usage of single phase and homogenous fluid model for nanofluid with free convection influence.

Emad et al.[26] studied MHD mixed convection of annulus circular enclosure saturated with Non-Newtonian nanofluid. The study unveiled that:

- The isotherm lines experienced circular contours for all the values of Richardson numbers and power law index at $\text{Ha}=0$.
- Optimum stream function increased with the flow index when $\text{Ha}=15$.
- The result also revealed that for $\text{Ha}=15, 30$ and 60 , the stream function was increased 9 times, 5.5 times and 5.7 times respectively.
- It was reported that at $\text{Ri}=0.01$ and 0.001 , the rate of heat transfer deteriorated with

the increasing volume fraction.

- Increasing magnetic field application elevated the impact of nanoparticles on heat transfer augmentation at $\text{Ha}=0$.
- The average rate of heat transfer elevated with elevating magnetic field application (Ha) but the behaviour was found to be different with each value of Ha and power law.
- The average rate of heat transfer increased with the deteriorating Richardson number due to heat transfer augmentation caused by forced convection.

MHD MIXED CONVECTION OF NANOFLUIDS IN IRREGULAR CONFIGURATIONS

Significant studies on experimental and numerical analyses of MHD mixed convective heat transfer and fluid flow in irregular enclosures saturated with nanofluids have been carried out. A review of irregular enclosures such as Trapezoidal, Cylindrical, Triangular and other non-conventional geometries are presented in this section.

Trapezoidal Enclosures

The important review of Trapezoidal configuration is presented below

Ali et al. [27] presented the MHD effect on mixed convection in a lid-driven trapezoidal cavity with Cu-water-based nanofluid. The result showed that heat transfer enhancement for the aiding condition was more than the reversing lid-driven case. Muhammad *et al.*[28] analyzed MHD natural convection in the trapezoidal cavity with a circular block. They concluded that the local Nusselt number has an optimum value around the edge of the wall but the reverse was the case around the mid-point of the wall even though the bottom wall was subjected to the same condition.

Ali et al. [27] studied the impact of a rotating cone on the mixed convection in a double lid-driven 3D porous trapezoidal nanofluid-filled cavity under the influence of magnetic field. The finite element technique was employed. Findings from this study showed that:

- Heat transfer augmentation was accomplished with carbon nanotube particles at reduced magnetic field strength.

- The aspect ratio of the cone has heat transfer augmentation up to 95%.

Muhammad et al. [28] investigated MDH mixed convection flow in a lid-driven trapezoidal enclosure ($\phi = 30^\circ$) with the influence of the rotations of a heated triangular block or obstacle ($\text{Rot} = 0^\circ - 90^\circ$). The results of the researchers were presented as follows and also shown in Fig. 3 and 4:

- The introduction of heated triangular obstacle rotation resulted in a very small impact of Re , Pr and Ha (fixed) numbers on the streamlines and isotherms structure of the configuration.
- The average rate of heat transfer increased the rotations of the triangular block due to elevating Re and fixed Ha and also by

elevating Rot at 90° deteriorating Rot at 60° respectively.

- Also, the mean temperature augmented with elevating Re and it increased for $\text{Rot} = 0^\circ$.

Cylindrical Enclosure

Significant research works carried out on cylindrical geometry are presented below

Ruchika et al. [29] numerically analyzed mixed convection in inclined cylinders with velocity and thermal slip effects as shown in Fig. 5 and 6. They concluded that the Nusselt number (Nu) deteriorated with increased thermal slip parameters. Also, the temperature of nanofluids deteriorated with increased Prandtl number.

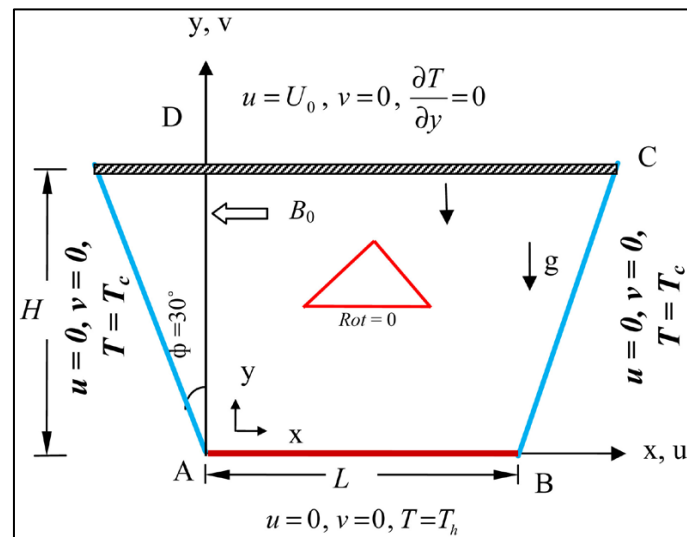


Figure 3: Schematic diagram of Lid-driven Trapezoidal enclosure according to Muhammad and Laek(2020) [30].

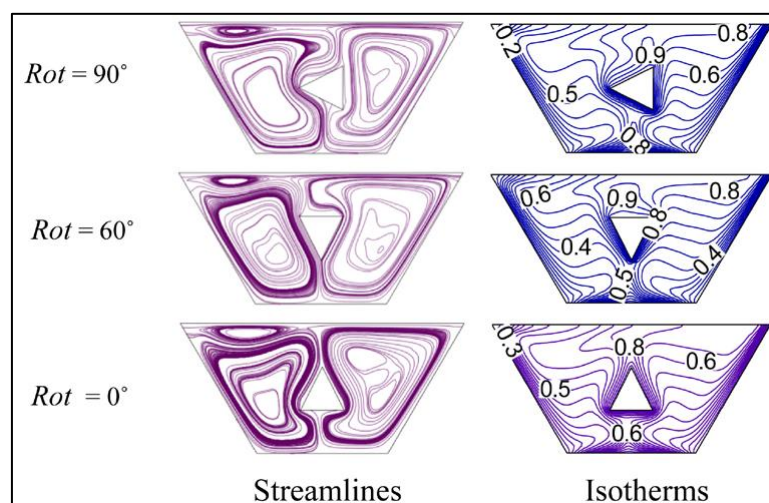


Figure 4: Streamlines and isotherms for various rotations or orientations of the heated triangular block according to Muhammad and Laek(2020) [30].

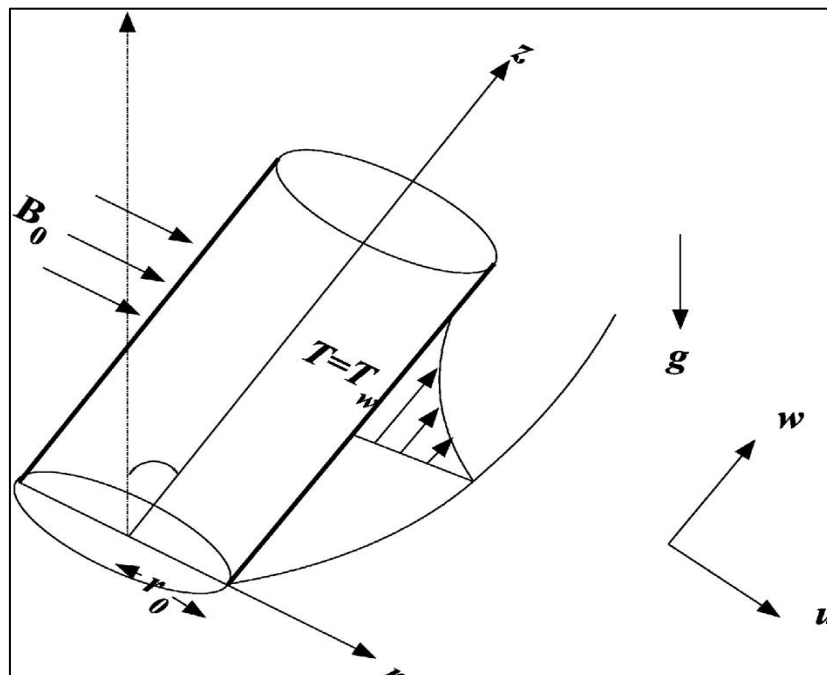


Figure 5: Shows the physical model coordinate system according to Ruchika et al.(2016) [29].

Poornima et al. [31] reported MHD mixed convection dissipating flow of cylindrical shaped Cu-water nanofluid in a vertical moving surface. The result obtained established that nanotubes were preferred to the spherical-shaped type due to their higher thermal conductivity for heat transfer enhancement. Sandip et al. [32] investigated mixed convection flow with a circular cylinder saturated with water-based nanofluid. The researchers concluded that the rate of heat transfer elevated with increasing volume concentration, Φ and Re number. When $Ri = 1$ and $\Phi = 25\%$, maximum heat transfer augmentation was found to be 62%. Shukla et al. [33] investigated MHD mixed convection nanofluid multiple-slip flow and heat transfer in a vertical cylinder with entropy generation. The Homotopy Analysis Method (HAM) was employed. They concluded that there is an increase in temperature as a result of an increase in curvature and magnetic field applied but decreased with Richardson number. Sourtiji et al. [34] studied MHD buoyancy-drift-influenced flow in a cylindrical-triangular configuration saturated with Cu-water nanofluid. Their findings are presented below:

- Velocity and temperature profiles within the cavity strongly relied on both Hartmann and Rayleigh numbers.
- Also, it was reported that heat transfer augmentation due to nanofluid application

was more pronounced at increased values of Hartmann numbers.

Triangular Enclosure

The important review carried out on the Triangular cavity is presented below:

Amin Judat [35] investigated experimental and numerical analyses of laminar forced convection in a triangular enclosure filled with TiO_2 -water nanofluid. He concluded that the use of nanofluid in the study retarded the wall temperature but augmented the Nusselt number (Nu) by 5% with 0.6% and 12% nanofluid volume concentrations. Also, it was revealed from the results that increasing the values of the Re number augmented the rate of heat transfer.

Thamer et al. [36] experimentally studied thermally developing mixed convection in a horizontal equilateral triangular channel. They concluded that both the temperature ratio and local Nusselt number increased with increased flow rate. Rahman [37] investigated the effect of an inclined magnetic field on free convective flow in the equilateral triangular enclosure using water and kerosene-based fluids. He concluded that increased magnetic field application reduced Nusselt number while increased magnetic field inclination angle improved strongly the heat transfer enhancement.

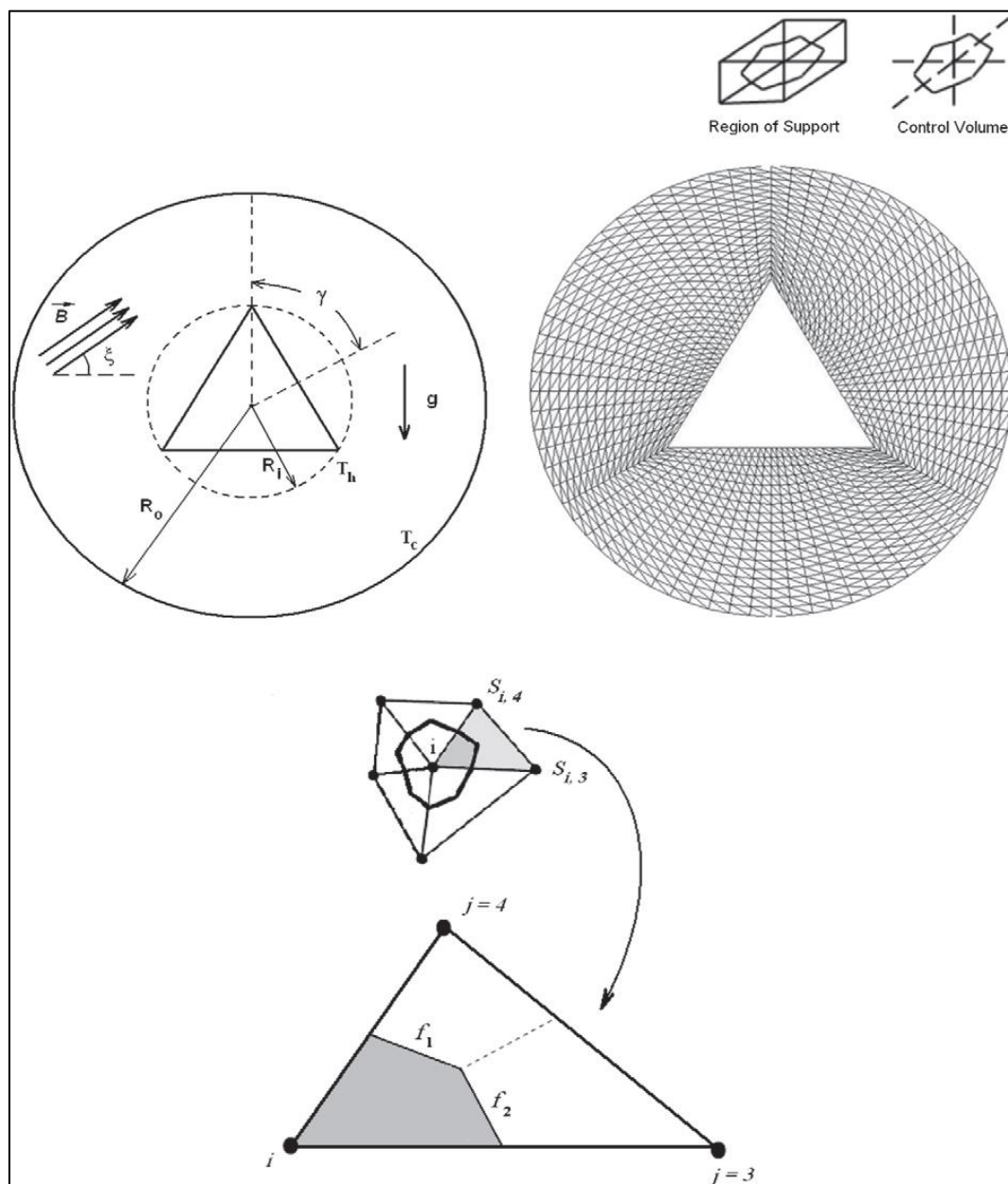


Figure 6: (a) Schematic diagram of the problem, (b) the mesh of enclosure used in this study, (c) a sample unstructured control volume for node i and its triangular elements according to Sourtiji et al.(2014) [34].

Javad et al. [38] numerically studied MHD mixed convection in a triangular enclosure filled with micro polar nanofluid. Finite element method was employed. They concluded that heat transfer enhancement was higher with nanofluid than with base fluid. Also, high Grashof, Prandtl and Darcy numbers enhanced better heat transfer.

Other Non-Conventional

In this section, geometries apart from the common irregular configurations such as C-

shape, U-shape, and T-shape, elliptical to mention a few are presented.

Armaghani et al. [39] investigated MHD mixed convection of nanofluid in an open C-shaped enclosure. The results showed that an increase in Hartmann number increased the heat transfer enhancement. Also, a high Reynolds number resulted in heat transfer augmentation while increased nanofluids volume fraction gave better heat transfer. Oztop et al. [2] investigated MHD mixed convection flow in a nanofluid-filled and partially heated wavy-walled lid-driven enclosure. The finite volume method was

employed. They concluded that the heat transfer and flow characteristics were dependent on Richardson and Hartmann's number.

Nandita and Anuruddhe [40] presented transient MHD mixed convection in an L-shaped enclosure using ferrofluid (Fe_3O_4). The result established that electrically conducting fluid (MHD) had a very strong influence on the Nusselt number. It was also pointed out that the free convective heat transfer performed

excellently well in this kind of mixed convective flow because increased values of Nusselt numbers were obtained for increased values of Grashof numbers.

Mustapha et al. [41] investigated transient MHD blood flow in irregular multi-stenosed arteries. The result indicated that complicated flow separation responsible for gradual and advanced arterial diseases could be monitored and prevented Fig. 7.

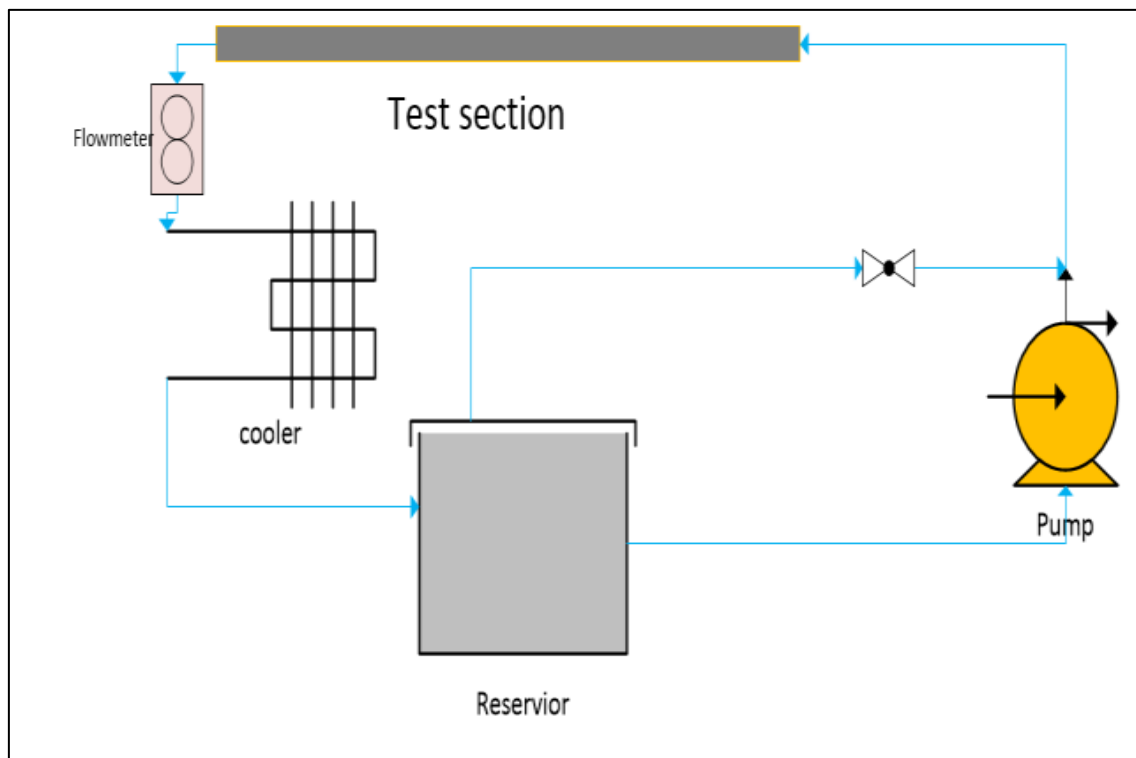


Figure 7: Schematic diagram of experimental setup used to measure the convective heat transfer according to Amin Judat (2014) [35].

Hossan and Gorla [42] studied the joule heating effect on MHD mixed convection boundary layer flow with variable electrical conductivity. They concluded that the rate of heat transfer and local shear stress increased with a very high value of the local magnetic parameter (ϵ). Mohammad et al. [43] reported the effect of heat source/sink on MHD mixed convection flow on a vertical surface in a porous medium filled with nanofluid. The findings from their work showed that both suction and injection cases were more pronounced for Al_2O_3 nanoparticles than for Cu application.

Aaize et al. [44] reported unsteady MHD flow of a different shape of Al_2O_3 in ethylene glycol and water-based nanofluid. Their results indicated that due to Brownian motion presence,

particles like platelets had greater viscosity than blade and brick ones though subjected to the same conditions. Das et al. [45] reported entropy analysis on MHD pseudo-plastic nanofluid flow through a vertical porous channel with convective heating. Their result showed that magnetic field application suppressed the fluid velocity but had a significant influence on the fluid temperature. Tasawa et al. [46] reported the MHD flow of nanofluid with homogenous-heterogeneous reactions with velocity slip. They concluded that there was an increased value of skin coefficient with Ag-water nanofluid more than with Cu-water nanofluid. Macha and Naikoti [47] investigated MHD mixed convection of a non-Newtonian power-law over a vertical plate with variable density. Their result

showed that an increase in Lewis number resulted in a reduction in the volume function of the nanoparticles. Rashidi et al. [48] investigated MHD mixed convective heat transfer of nanofluid in a sinusoidal wall. The results showed that the Hartmann number increased with constant values of some model parameters such as Reynolds, Grashof, Nusselt, and Poiseuille numbers as well as nanoparticle volume fraction.

Hayat et al. [49] considered the MHD 3-D flow of nanofluid over a convectively heated non-linear stretching surface. They concluded that both the temperature and nanoparticle concentration were increased as a result of increased Biot number. Ahmed et al. [50] investigated MHD natural convection in an inclined T-shaped enclosure for different nanofluids. They concluded that the rate of heat transfer was greatly influenced by high Rayleigh number, inclination, aspect ratio, heat generation and concentration of nanofluid but not significantly influenced by reduced Hartmann number. Tao and Defu [51] reported the thermal lattice Boltzmann for the MHD convection flow of nanofluid. They concluded that inclination and Hartmann number have a strong impact on flow and temperature patterns. It was also established that the usage of Cu-water nanofluid was significant in fluid flow patterns. Priyadarsan et al. [52] considered heat transfer effects on the MHD 3-D flow of nanofluid. Their results showed that internal heat generation and absorption parameters influenced the Nusselt number which resulted in the boundary layer alteration.

Ullah et al. [53] carried out an analysis of various semi-numerical schemes of MHD squeezing fluid flow in the porous medium. The researchers employed the optimal homotopy asymptotic method (OHAM), Homotopy perturbation method (HPM), Differential transforms method (DTM) and Adomian decomposition method (ADM). They concluded that based on the analytical result, DTM and Daftardar Jafari technique (DJT) provided a very good accuracy around the centre of the domain while the degree of accuracy decreased around the beginning and the end of the domain considered. Khan et al. [54] investigated a ferromagnetic nanofluid flow over an extending surface under the influence of the Prandtl model. The researchers used the fourth-order Runge-Kutta technique. The result indicated that

ethylene glycol-based nanofluid was found to be better than water-based one due to very strong thermophysical properties. Also, magnetic field applications played a prominent role in predicting the characteristics of fluid flow.

Mahdy and Hoshoudy [55] did a theoretical analysis on the two-phase MHD mixed convection nanofluid flow of a dusty tangent hyperbolic past a non-linearly stretching sheet. Runge-Kutta-Fehlberg method (RK45 approach) was employed. They concluded that a high concentration of dust particles resulted in a decrease in the velocity profile of the nanofluid and dust phases. Shafie et al. [56] studied the mixed convection flow of Brinkman Hybrid nanofluid based on the Atangana-Baleann Model. The Laplace transform method was used. They concluded the velocity and temperature distribution followed the same trend for fractional parameters α and both reduced for high values of α . Also, velocity distribution reduced with high volume concentration while temperature distribution increased with high volume concentration. Tlili et al. [57] investigated a 3-D MHD AA7072-AA7075 methanol hybrid nanofluid flow above a non-uniform thickness surface with a slip effect. They concluded that the influence of Lorentz or Laplace force was reduced on hybrid nanofluid when compared with non-hybrid type. Also, it was indicated that the wall thickness significantly increased the rate of heat transfer. Extensive works were also carried out by some researchers [58-64].

BIBLIOMETRIC ANALYSIS OF MHD MIXED CONVECTION RESEARCH

Significant statistical analyses are provided in this section of the review. The first aspect is the relevancy of MHD mixed convection globally in addressing the ever-increasing problems associated with advancing technology in industry. The rate of growth in the last one and half decades (15 years) based on published literature is presented in Fig.8. It shows the devotion given to this unique and remarkable field of research. The rate of growth is remarkable from 2005 to 2016 as indicated on the plot and started growing again between 2018 and 2020. There is every tendency for the number to outperform the growth in 2016 in a few years to come.

Also, the review reveals that the

publisher, Elsevier, accounts for over 80% of the published literature. Fig. 9 presents the solution methods mostly employed by researchers over the years. Only four (4) researchers reported experimental work while just one researcher used an analytical approach in addressing heat transfer problems. In the same vein, Fig. 10 shows the most extensively used nanoparticles in

the survey. The most common geometries considered in this survey are presented in Fig.11. The square-related configurations received more attention as a single geometry on MHD mixed convection. The next enclosure mostly considered is cylindrically related, then circular and rectangular Table 1.

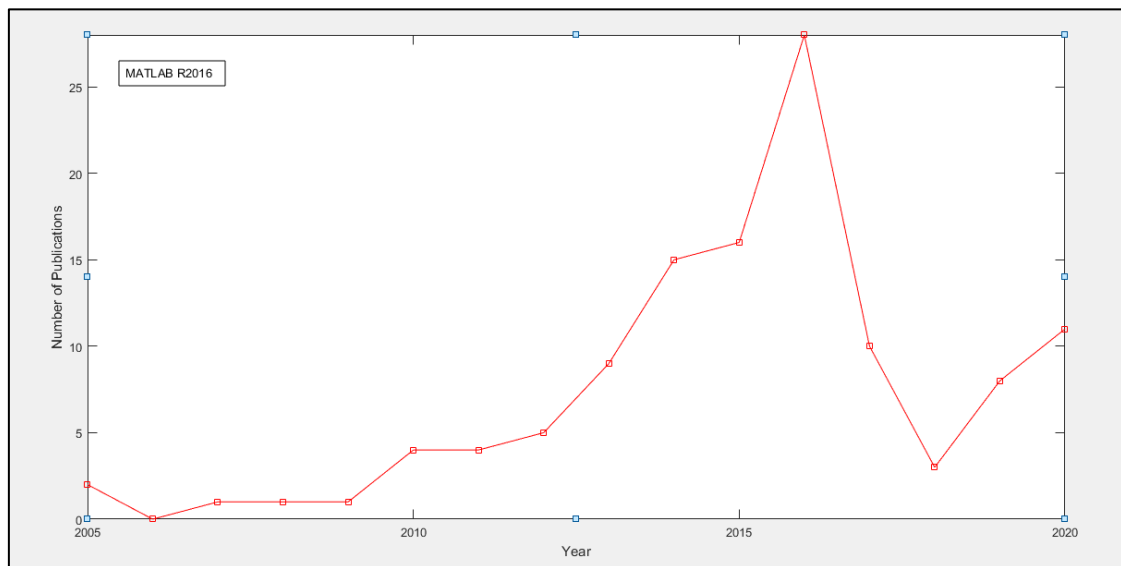


Figure 8: The trend of published literature between 2005-2020.

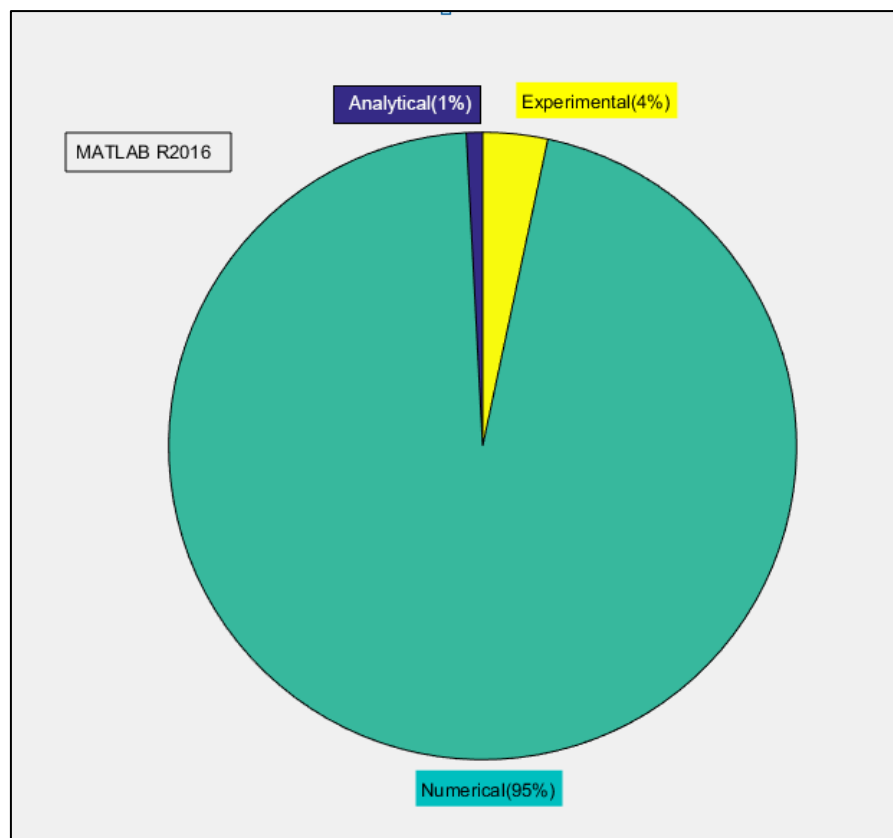


Figure 9: The solution methods applied.

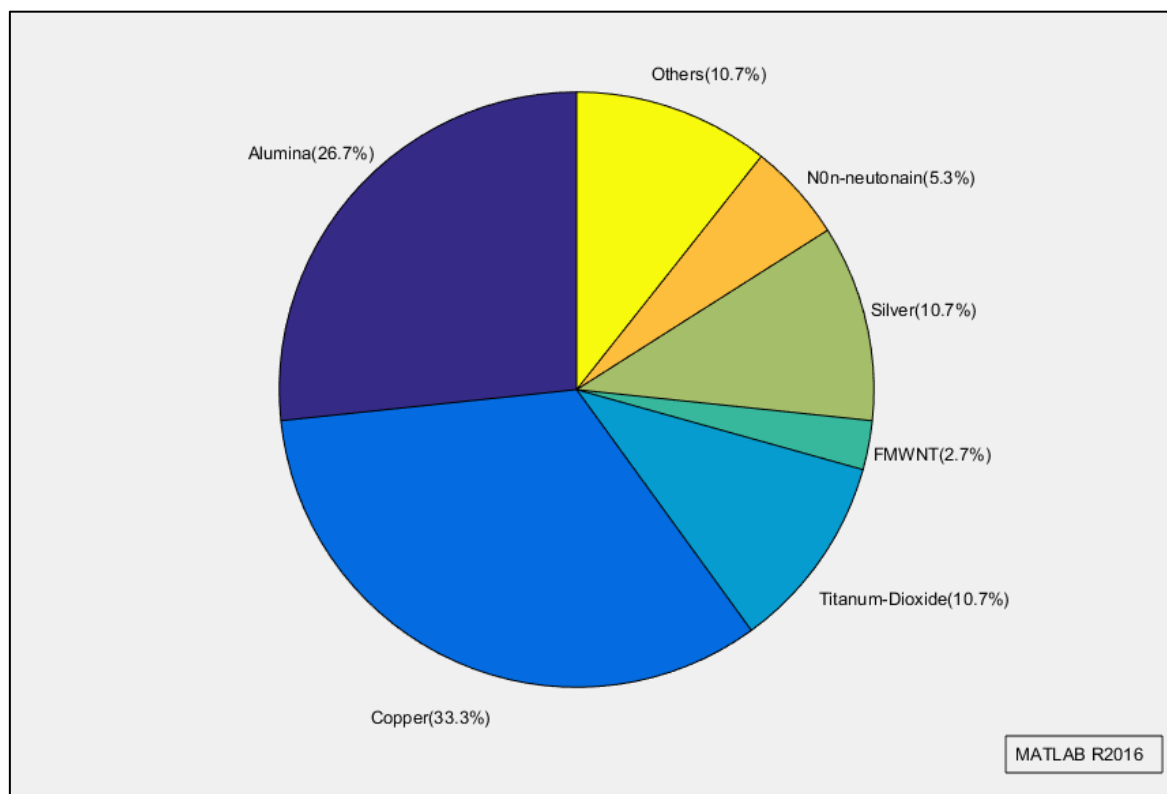


Figure 10: The nanoparticles mostly used.

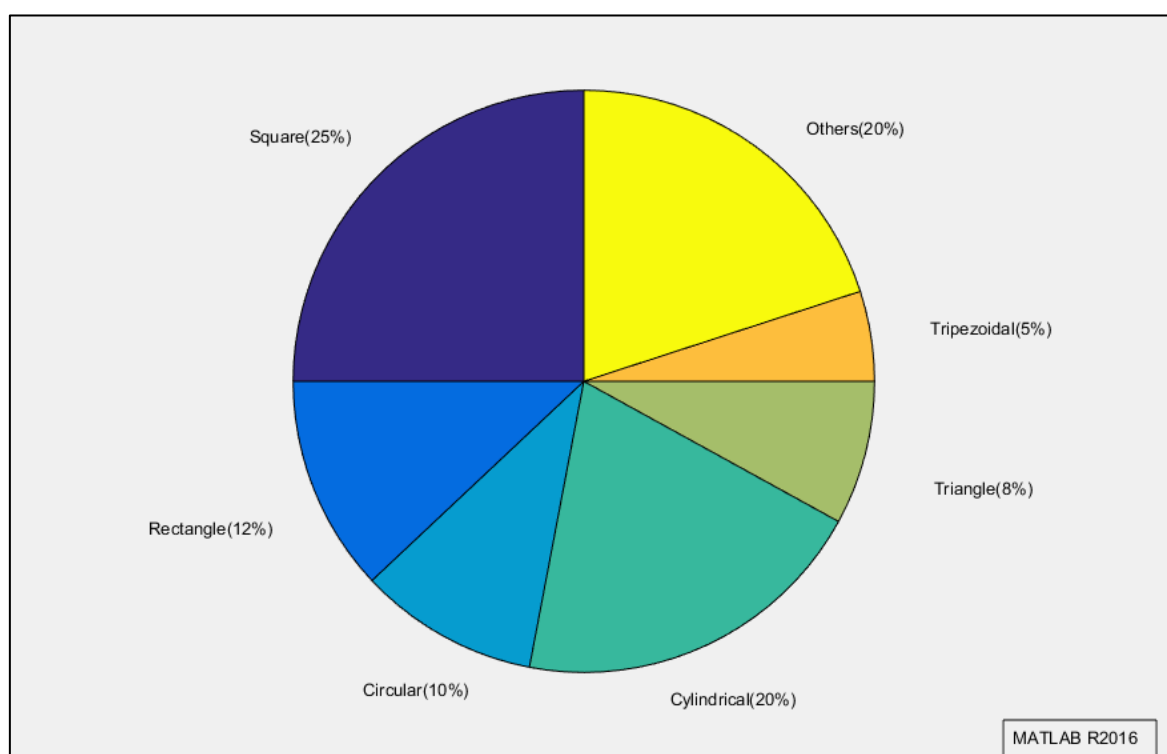


Figure 11: The geometry mostly used.

Table 1: Overview of all the significant information on selected MHD mixed convection in regular and irregular configurations on solution methods and geometries with identified gaps.
[22,24,25,32,34,65-109].

Solution Method & Geometry	Reference	Year	Parameters & Parametric Range	Nanoparticle & Concentrations	Optimum Heat Transfer Augmentation (%)	Conclusion	Gap
Numerical	Hayat <i>et al.</i> [65]	2010	$Ha = 0, 0.7, 1.4$ and 2.1 $Pr = 6.2$ $\Gamma = 0, 0.2, 0.4$ and 0.6 $\omega = 0.3, 0.6, 0.9$ and 1.2 $Ri = 0, 0.5, 1$ and 1.5 $R = 0.3, 0.6, 0.9$ and 1.2	Cu-water Ag-water $\Phi = 0, 0.1, 0.2$ and 0.3	–	The results indicated that velocity profiles are enhanced by Ag-water nanoparticles for elevated radiation parameters. Also, the Nusselt number augmented for elevated Ri	The research paid adequate attention only to MHD mixed convection for the combined silver and copper nanofluids.
Experimental(circular-cylinder)	Mansour <i>et al.</i> [25]	2011	$Ra = 5 \times 10^5$ to 9.6×10^5 $Re = 30 - 900$ for vertical tube and horizontal $= 1 \times 10^5 - 4 \times 10^5$ $Pr = 7$ $P = 190 - 420W$ $Gr = 1 \times 10^6 - 3 \times 10^6$ for horizontal tube $Gr = 1 \times 10^5 - 4 \times 10^5$ for vertical tube	Water- $Al_2O_3, 0 - 4\%$		The result indicated that upper nanoparticle volume concentration retarded the ratio of heat transfer for horizontal orientation. The rate of heat transfer was found to be constant for the vertical inclination orientation both subjected to the same	The study was limited to experimental only while analytical and numerical approaches were not considered.

			$Ra = 0.5 - 1 \times 10^6$ $Ri = (0, 2, 4 \text{ and } 6) \times 10^2$			condition. Also, it is evident from the results that there is a discrepancy between the experimental, analytical and numerical data in terms of heat transfer augmentation under buoyant forces concerning the usage of single phase and homogeneous fluid model for nanofluid with free convection effect	
Numerical(Elliptic duct)	Shariatetal.[66]	2011	$Re = 300$ $Ri = 0 - 2$ $AR = 0.25, 0.5, 0.75 \text{ and } 1$ $Z = 0 - 90$ at intervals of 15	Al_2O_3 -water, 0%, 2% and 5%	—	The result showed that at any value of Reynold (Re) and Richardson (Ri) number, upper or elevated value of nanoparticle concentration enhanced the rate of heat transfer. However, the elevated value of aspect ratio (AR) in the	The study paid adequate attention to elliptic ducts while different configurations and orientations, and experimental and analytical approaches were not researched.

						geometry reduced the local-frictional factor and had no significant impact on the rate of heat transfer. The result established that the elliptic duct with $AR = 0.7$ gave the optimum heat transfer rate.	
Numerical(Trapezoidal)	Uddin [67]	2011	$Pr = 0.71$ $Re = 100$ $Ri = 0.1 - 100$ $Ha = 0, 10, 20 \text{ and } 50$ $Le = 0.1 - 50$ $Br = 1 - 10$	—	—	The researchers concluded that elevated Hartmann number (Ha) and Richardson number had a significant impact on temperature and velocity profiles. Also, the Nusselt number was not remarkable for deteriorated values of Ri but augmented as values of Ri elevated and the Le number increased.	MHD mixed convection using analytical or theoretical and experimental approaches with different orientations and geometries was not considered.

Numerical(Square)	Rehena and Salma [68]	2011	$Re = 30 - 300$ $Ha = 0 - 50$ $Pr = 0.71$ (fixed) $Ra = 10^4$ (fixed) $\Lambda = 0 - 3$	–		The researchers concluded that the rate of heat transfer was maximum at the upper value of Re and least Ha numbers using the three undulations.	Adequate attention was only paid to mixed convection in a lid-driven square configuration with sinusoidal corrugated bottom surfaces.
Numerical(Circular cylinder)	Sandip <i>et al.</i> [32]	2012	$Pr = 0.7 - 100$ $Ri = 0 - 2$ $Re = 80 - 180$ at intervals of 20	–		The researchers concluded that the rate of heat transfer augmented with elevated Re and Pr numbers.	The research paid full attention to unsteady, forced and mixed convection in a circular cylinder
Numerical(Circular cylinder)	Sheikholeslami <i>et al.</i> [69]	2012	$Ra = 10^4 - 10^6$ $Ha = 0, 20, 40, 60$ $Pr = 6.8$ $\lambda = 2.5$	CuO-water, 0%, 2%, 4% and 6%	0.3%	The result indicated that the rate of heat transfer was enhanced or augmented due to an addition of nanofluid but reduced with Hartmann number.	The research was limited to horizontal circular in a square configuration.
Numerical(Vertical channel)	Reddy <i>et al.</i> [70]	2016	$Pr = 0.7$ $Ha = 0 - 5$ $Ri = 0, 50, 100, 200$	–	–	The researchers concluded that the velocity profile deteriorated with the upper value of Ha number but the	The study was limited to numerical analysis of a vertical channel only but analytical experimental solution methods in different geometries

						temperatur e profile deteriorate d with elevated natural convection effect for fixed Hartman(Ha) number.	renot considered.
Numerical(Square)	Kefayati <i>et al.</i> [71]	2012	Ha = 0 – 100 Ri = 0.01 – 100 $\theta = 0 - 90$	–	–	The result showed that the Nusselt number (Nu) deteriorate d with augmentin g Ha for different Ri and the direction of magnetic field strength. Also, the Nu number was enhanced for elevating Ri.	The research was limited to MHD mixed convection in a lid-driven square configuration with a linearly heated wall. While several configuration s nanofluid types and orientations were not considered.
Numerical(Circular-cylinder)	Sandip <i>et al.</i> [32]	2012	Pr = 6.2 Re = 80 - 100 at intervals of 20 Ri = 1 and – 1 (constant)	Water- based $\Phi = 0\%,$ 1%, 3%, 5%, 5%, 10%, 15%, 20%	62%	The researchers concluded that the rate of heat transfer increased with the volume concentrati on of Φ and Re number. When Ri = 1 and Φ at 25%, augmentati on is 62%	The research was limited to mixed convection in a circular cylinder configuration filled with water-based nanofluid.
Numerical(Square)	Javad and Mohamm ad [22]	2013	Gr = 10^4 Ri = 0.1 – 10 Ha = 0 – 55	CuO-water. 0 – 6%	2.46%	At Gr = 10^4 , the Nusselt number increased	The research only paid adequate attention to a square cavity

			Re = 100			with the decreasing Richardson and Hartmann number. Also, the increased concentration of nanoparticles reduced the Nusselt number in the configuration	for adiabatic horizontal and Isoflux heated walls.
Experimental and analytical (copper tube)	Gaffar [24]	2013	Re=360-1730 K=0.62W/mK $\mu = 0.93$ $\rho = 1001.3$ Gp=4176.83 JKg.K Pr = 7 Gr – 7.3×10^4 P = 298W.m Ra = $(0.5 - 1.5) \times 10^4$ Ri = 2×10^2 4×10^2 and 6×10^3	Al ₂ O ₃ -water Al ₂ O ₃ -Cu (hybrid nanoparticles), 0-4%, 0.1%	13.56%	In experiment 1, the result (experimental and analytical data) showed that the nanoparticle concentration enhanced changes in the temperature profile for vertical orientation but at elevated value, it decreased the rate of heat transfer for horizontal orientation while the rate of heat transfer was found to be constant for vertical orientation subjected to the same condition.	The study was narrowed down to experimental hybrid nanofluid for vertical, horizontal and circular orientation only.

						Also, for the second experiment performed on a straight circular tube, the rate of heat transfer for Al_2O_3 -Cu/water hybrid nanofluid was found to be 10.95% when compared with pure water while convective heat transfer coefficient (h) augmented with increasing Reynolds number. The result also showed an optimum heat transfer augmentation of 13.56%.	
Numerical(Concentric annulus)	Sheikholeslami <i>et al.</i> [72]	2013	$\text{Ha} = 0 - 100$ $\text{Ra} = 10^4 - 10^6$	Al_2O_3 -water $\Phi = 4\%$	—	The researchers concluded that heat transfer augmentation on increased with the Hartmann number but deteriorated with the Rayleigh number value.	The research only paid adequate attention to the MHD effect in a concentric annulus between a cold square and a heated elliptic cylinder filled with Al_2O_3 -water-based nanofluid.

Numerical(Stretching surface)	Yohannes and Shanker [73]	2013	$Pr = 6.2$ $Ha = 0, 0.8, 1 \text{ and } 2$ $K1 = 0, 1, 2 \text{ and } 3$ $Sc = 1, 3, 5, 7$ $r = 0, 0.5, 1$ $Sr = 0.0, 0.25 \text{ and } 0.8$	Cu-water Ag-water, $\Phi = 0.05, 1, 0.15 \text{ and } 0.2\%$		The results showed that the Nusselt number at the plate surface decreased with increasing nanoparticle concentration, Ha , Eckert number. Also, it was evident that Cu-water nanofluid possesses a higher Nusselt number than Ag-water nanofluid.	The study paid full attention to only heat transfer in a stretching sheet using Cu and Ag-water nanofluid.
Numerical(Circular-cylinder)	Farid <i>et al.</i> [74]	2013	$Ha = 0, 10, 20 \text{ and } 50$ $Ri = 0.1 - 5$	—	—	The result indicated that the decreasing values of Ha numbers augmented the rate of heat transfer and velocity profiles	The work paid full attention to mixed convection flow in a lid-driven cavity incorporated with the heated circular hollow cylinder.
Numerical(Half-annulus)	Sheikhholeslami <i>et al.</i> [75]	2013	$Ra = 10^3 - 10^5$ $Ha = 0, 20, 60 \text{ and } 100$ $Pr = 6.2$ $\theta = 0^\circ, 45^\circ \text{ and } 90^\circ$	Cu-water $\Phi = 0\%, 2\%, 4\% \text{ and } 6\%$	—	Their result showed that increasing the Ha number reduced both the velocity and temperature profiles and the rate of heat transfer in	The research work was limited to an inclined, steady, natural convection in a half-annulus cavity while several geometries, and orientations with or without

						the configuration. Also, it was revealed that at $Ra = 10^5$, the heat transfer augmentations for $\theta = 90^\circ$ were higher than all Ha numbers considered.	nanofluid were not considered.
Numerical(Cylindrical triangle)	Sourtiji <i>et al.</i> [34]	2014	$Ra = 10^3 - 10^5$ $Ha = 0, 10, 20, 30, 50$ $AR = 1.5, 2.0, 3.0$ $Pr = 0.7$	CuO-water 0%, 1%, 3% and 5%	16.1%	The result revealed that velocity and temperature profiles within the cavity intensely rely on both Hartmann and Raleigh numbers. Also, it was reported that heat transfer augmentation due to nanofluid application was more pronounced at increased values of Hartmann numbers.	The study only paid adequate attention to MHD-free convection in a cylindrical-triangular configuration but several cavities are available for study.
Numerical(Elliptic-cylinder)	Sheikhholeslami <i>et al.</i> [76]	2014	$Ra = 10^3 - 10^5$ $Ha = 0, 20, 60$ and 100 $Pr = 0.733$ $Gr = 2 \times 10^4 - 2 \times 10^5$ $\theta = 0^\circ$,	CuO-water, 0%, 2%, 4% and 6%	1.6%	Their findings showed that heat transfer augmentation increased with the Hartmann	The research was limited to MHD natural convection flow using CuO-water nanofluid and hot elliptic cylinder

			$30^{\circ}, 60^{\circ}, 90^{\circ}$ $e = 0.9$			number but deteriorated with the Rayleigh number.	enclosure.
Numerical(Semi-annulus)	Sheikhholeslami <i>et al.</i> [77]	2014	$Pr = 6.8$ (fixed) $Ra = 10^4 - 10^6$ $\frac{\sigma}{L} = 0.2, 0.4, 0.6$ and 0.8 $AR = 3.5$ (fixed) $Ha = 0 - 40$	Cu-water, $\Phi = 0, 2\%, 4\%$ and 6%	—	The researchers concluded that the rate of heat transfer was dependent on nanoparticle volume concentration but independent of increasing values of Hartmann number and the location of interval cylinder at higher Rayleigh number. It was also shown that heat transfer augmentation increased with increasing Ha number but deteriorated with increasing Ra number.	The study paid adequate attention to MHD-free convection in an eccentric annulus cavity filled with Cu-water nanofluid. Experimental and analytical approaches are gaps.
Numerical(Square)	Ghedi and Valipour [78]	2014	$Gr = 10^3 - 10^5$ $Ha = 0$ to 100 $Re = 100$ (fixed)	CuO-water, 0-5%	1.2%	The result showed that the application of nanofluid (CuO-water) i.e. increasing the volume concentration	The research focused only on MHD mixed convection in a square lid-driven orientation.

						on augmented the Nu number	
Numerical(Triangular)	Fatih <i>et al.</i> [79]	2014	$Ri = 0.01 - 100$ $Ha = 0 - 50$ $\theta = 0 - 90^\circ$	CuO-water, 0 – 5%	11.6%	Their result revealed that increasing Richardson and Hartmann numbers in the configuration resulted in a reduction of both local and average Nusselt numbers.	The work was limited to diagonal positioned triangular configuration only.
Numerical(vertical plate)	Mohammad <i>et al.</i> [80]	2014	$Ha = 0 - 1$ $Q = 0 - 0.5$	Cu, Al ₂ O ₃ , TiO ₂ , water 0 – 0.2%	–	The researchers concluded that suction improves the velocity profile and retards the separation of the boundary layers. Also, the injection part are higher for Al ₂ O ₃ and lowest for Cu nanoparticles	The research was limited to a vertical plate saturated with nanofluid.
Numerical(Cylindrical-triangular)	Fatih and Hakan [81]	2014	$Ra = 10^4 - 10^6$ $Ha = 0 - 50$ $Gr = 10^4 - 10^6$ $\omega = -20, -10, 0, 10$ and 20 $Ri = 0-2$	Cu-water, 1%, 3% and 5%	33.3%	Their findings revealed that increasing H number reduced the entire entropy generation but augmented Nu. Also,	The research only paid complete attention partly to the heated triangular cavity with nanofluid and rotating adiabatic cylinder closed.

						heat transfer augmentations of 50.4% and 37.4% were obtained for positive and negative angular rotational speeds. Besides, optimum augmentations of 33.3% are recorded for the nanofluid concentration of 5% compared to a convection flow.	Analytical and experimental methods were not considered
Numerical(Cylindrical)	Fatih and Hakan [82]	2014	$Ri = 0.001 \leq Ri \leq 10$ $Ha = 0 \leq Ha \leq 50$ $\omega = -10 \leq \omega \leq 10$	Cu-water, 0-5%	8.9%	The results indicated that 17% heat transfer angular rotation was actualized for $Ri = 10$ in comparison with $Ri = 1$. Also, the average Nu number deteriorates with elevating Ha. Besides, 8.9% of heat transfer augmentation is actualized for the nanofluid	The research was limited to a square cavity saturated with Cu-water nanofluid and a rotating cylinder enclosed while there are several geometries and orientations were not considered.

						concentration of $\Phi = 5\%$ in comparison with the conventional fluid of $\Phi = 0$.	
Numerical(Vertical plate)	Mohammad <i>et al.</i> [83]	2014	Ha = 0, 0.5	Cu-water Al ₂ O ₃ -water TiO ₂ -water $\Phi = 0 - 0.2$	—	The result indicated that increasing Hartmann number enhanced the velocity profiles and the deteriorating heat source/sink reduced the velocity profile.	The study was limited to the MHD duct for high Hartmann number heat transfer within a vertical plate.
Numerical(Square)	Abdul <i>et al.</i> [84]	2014	Pr = 0.71 Ha = 0, 20, 50 and 100 Ra = $10^4 - 10^6$	—	—	The researchers concluded that increased magnetic field strength enhanced the rate of heat transfer.	The research strictly paid attention to the influence of Ra and Ha on natural convection in a square configuration while there are various parameters, cavities and orientations were not considered.
Numerical(Cylinder)	Sharma and Konwar [85]	2014	Re = 0.02, 0.05, and 0.1 Sr = 0.01, 0.04 and 0.08 Du = 0.01, 0.04 and 0.08 Gr = 0.02, 0.05 and 0.1 Ha = 0.01,	—	—	Their findings showed that the effects of Du, Ha, and Le numbers on velocity profile were lower than those of Re, and Gr numbers	The work paid full attention only to a porous horizontal cylinder enclosure.

			0.03 and 0.08 Le = 0.09, 0.2 and 0.4				
Numerical(Cylinder)	Mohsen <i>et al.</i> [86]	2015	Ha = 0,20,60 and 100 Ra = $10^3 - 10^5$ Pr = 0.733 Gr = 2×10^4 to 2×10^8	Al ₂ O ₃ - water, 0 – 4%	–	The rate of heat transfer increased with Rayleigh number and decreased with increasing Hartmann number.	The study was narrowed to MHD natural convection in a horizontal cylindrical enclosure filled with Al ₂ O ₃ -water- based nanofluid.
Numerical(Tube)	Aghaei <i>et al.</i> [87]	2015	Pr = 6.13 Re = 10,000 – 100, 000	Al ₂ O ₃ - water, 0, 0.001, 0.1, 0.2, 0.4 Size: 22,33, 7 and 100 nm	2.02%	The researchers concluded that for a given volume concentration, 0.04, the rate of heat transfer was found to be 7 times the Reynolds number values (10,000 to 100,000) for turbulent conditions.	The study was limited to a turbulent, force- curvature flow using Al ₂ O ₃ -water nanofluid in a tube while different geometries, orientations and nanofluid types were not considered.
Numerical(A Half-moon shaped)	Rabbi <i>et al.</i> [88]	2015	Re = $10^3 - 10^5$ Ha = 0 – 100	–	–	The result indicated that the rate of heat transfer was independent of various geometric shapes at Re = 10^6 .	The work was limited to a half- moon-shaped enclosure.
Numerical(Stretching surface)	Sheikholeslami <i>et al.</i> [89]	2016	Pr = 6.2 Ha = 0, 4, 8 and 12 VR = 0.1, 0.3, 0.6, and 0.9	CuO-water $\Phi = 0.04$	–	The result revealed that the rate of heat transfer was dependent	The research was limited to forced convection flow, stretch surface and CuO-water

			R = 0, 2, 6 and 10			on both the velocity and temperature profiles but independent of the Ha number and radiation variable.	nanofluid while there are numerous geometries, nanoparticles and orientations were not considered.
Numerical(Cylindrical)	Sheikholeslami <i>et al.</i> [90]	2015	Ra = $10^3 - 10^5$ Ha = 0, 20, 60 and 100	Al ₂ O ₃ -water $\Phi = 0 - 0.04$	–	The result revealed that the rate of heat transfer increased with augmenting Rayleigh number but an increase in Hartmann number (Ha) decreased the rate of heat transfer.	The study was limited to a horizontal cylindrical cavity filled with Al ₂ O ₃ -water nanofluid while different geometries, orientations and nanoparticles were not considered.
Numerical(Square)	Kakali and Alim[91]	2015	Ri = 0.01 – 10 Pr = 0.03 – 5.43 Ha = 0, 20, 40 and 60 Re = 100	–	–	The researchers concluded that obstruction magnitude with Ha and Pr variables had a serious impact on both fluid flow and heat transfer characteristics. Also, increased Ha reduced the Nusselt number while Ha = 0 augmented the Nusselt number.	The study considered a square cavity having a triangular obstacle while different nanoparticle addition and orientation were not considered.

Numerical(Cylindrical)	Prornima <i>et al.</i> [31]	2015	$Pr = 6.2$ $Ha = 0.0, 0.02, 0.4, 0.6$ and 0.8 $Ec = 0.0, 0.1, 0.3, 0.5$ and 0.7 $Ri = 0, 1, 3, 5, 10$	Cu-water, Al_2O_3 -water Ag-water TiO_2 -water CuO-water $\Phi = 0, 0.05, 0.1, 0.15$ and 0.2	–	The result indicated that the Nusselt number decreased with increasing Eckert number for constant value of viscosity variables. Also, skin friction and the rate of heat transfer decreased for increasing nanoparticle volume concentrations.	The study only paid adequate attention to a cylindrical shaped cavity filled with nanotubes.
Numerical(Vertical plate)	Mohammed <i>et al.</i> [92]	2015	$\xi = 0.1, 1$ $Ha = 0 - 0.5$ $Pr = 6.2$	Metallic and non-metallic Cu-water Al_2O_3 -water CuO-water Ag-water TiO_2 -water $\Phi = 0, 0.1$ and 0.2	–	The researchers concluded that magnetic field applications enhanced the heat transfer of Cu nanofluid but decreased with increasing volume concentration.	The analysis was restricted to MHD convection flow in a vertical plate while horizontal inclined and several geometries were not considered.
Numerical(Triangular)	Ahmed [93]	2015	$Ha = 0 - 50$ $Ri = 0.1 - 10$ $\theta = 0, 30$ and 45° $Pr = 0.7$	–	–	The researcher concluded that the optimum Nusselt number was attained at $Ri = 1, Ha = 0$ and $\theta = 30$ conditions.	The research was limited to a lid-driven differentially heated trapezoidal configuration. Experimental, theoretical approaches with several geometries

							and orientations were not considered.
Numerical(Triangular)	Fatih <i>et al.</i> [79]	2016	Ri=0.01 and 100, Ha= 0 and 50, $\Theta= 0^0$ and 90^0	CuO-water 0 – 5%	11.6%	The rate of heat transfers (Nu_L and Nu_a) decreased with increasing Richardson number but increased with increasing Hartmann number. Also, the Nusselt number increased with increasing nanoparticle concentration.	The study was limited to MHD mixed convection in a nanofluid diagonal triangular configuration while there were several orientations and enclosures.
Numerical(Cylinder)	Ruchika <i>et al.</i> [29]	2016	Ri = 1 $\gamma = 0.1$ S = 2.5 Pr = 5 M = 0.1	Nanofluid mode of Buongiorno	–	Nusselt number (Nu) decreased with increasing thermal slip parameter. Also, the temperature of nanofluids decreased with increasing Prandtl number	The study was limited to MHD mixed convection in an inclined cylinder while there were various orientations and geometries not considered.
Numerical	Reddy and Chamikha [94]	2016	M = 0.1, 0.4, 0.8 Nc = 0.1, 2.0, 4.0 Nb = 0.3, 0.6, 0.9 Le = 3.0, 4.0, 4.5, 5 Nv = 2.0, 5.0, 10.0, 20.0	Al ₂ O ₃ -kerosene (44 nm) TiO ₂ -water (21 nm) 3%	–	A notable heat transfer augmentation was observed as the sizes of nanoparticles were reduced. It	The research was limited to a conical cavity under the influence of various sizes and shapes of nanoparticles while several orientations

			Nt = 0.1, 0.3, 0.5 Nr = 0.01, 0.6, 1.2 $Pr_{H_2O} =$ 6.161 $Pr_{kero} =$ 28.10			was also evident that the nature of nanoparticl e fluid (base flow) determined the free convection heat transfer. Besides, the temperatur e and concentrati on profiles increased with the increasing values of thermopho retic parameters	in different configuration s were not considered.
Numerical(Cylindr ical)	Brahiman d Rachid [95]	2016	Re = 350 – 2,500 Ha = 0,5,10,15, 20 Ri = 0 – 2 at an interval of 0.5 Ri = 0,0.5,1 & 2 Re = 400	–		The result indicated that increasing the values of Richardso n's number reduced Reynolds number. The implicatio n is that increasing values of Ri at a constant value of Re obstructed the fluid flow.	The study strictly focused on counter- rotating cylindrical cavities.
Numerical(Michroc hanel)	Arash <i>et al.</i> [96]	2016	Ha=0,20, 40 Re=10 – 500 $\beta = 0.0,$ 0.4 and 0.8	FMWNT/w ater 0%,1%,2%, 0.03%	–	The result indicated that nanofluid consisting of water and carbon nanotube (FMWNT) enhanced	The research focused only on MHD force convection in microchannel s.

						Nusselt number in a microchannel well. Also, the effect of the Ha number at the fully developed part was not significant with reducing values of Re.	
Numerical(Semi-annulus)	Oglakkaya and Bozkaya [97]	2016	$Ha = 0, 20, 50, 100, 300$ and 500 $Ra = 10^3 - 10^5$ $\Theta = 0^\circ, 30^\circ, 45^\circ, 60^\circ, 90^\circ$ $Pr = 6.2$ (fixed) $Re = 10^3 - 10^5$	Cu-water $\Phi = 0, 2\%, 6\%, 10\%, 20\%$	—	The results revealed that increasing Rayleigh number was dependent on heat transfer augmentation. Also, the Nusselt number reduced with increasing Ha number and reduced with increasing inclination angle.	The numerical analysis was limited to MHD natural convection in a nanofluid with saturated semi-annulus
Numerical(Microchannel)	Karimipour et al. [98]	2016	$Ha = 0 - 40$ $Re = 10 - 100$ $\beta = 0.0, 0.04, 0.08$	Water and FMWNT carbon nanotubes $\Phi = 0.1\%, 0.2\%$	—	The result indicated that the reduction of the Ha number elevates the velocity profile. Also, the optimum Nusselt number was attained at maximum	The research was restricted to a 2-D, steady, MHD forced convection in a microchannel saturated with water/FMWNT carbon nanotubes while different configurations and orientations

						nanofluid volume concentration, Reynolds number and Hartmann number from the microchannel wall.	have not been considered.
Numerical(Non-linear surface)	Duler and Gopinath [99]	2016	Pr = 6.8 (fixed) Ec = 0.1 m = 0.2 Hm = 0, 0.2, 0.3, 0.5 and 0.7	Cu, Al ₂ O ₃ and TiO ₂ -water $\Phi = 0.05, 0.10, 0.15$ and 0.20	—	The results indicated that Hall's current variables augments the velocity profile and reduced temperature profile on a stretching sheet but it was otherwise for shrinking sheets. Besides, the rate of heat transfer deteriorated for stretching and shrinking sheets by increasing the Hartmann number and Eckert number.	The numerical study was limited to the influence of Hall current on MHD heat transfer of nanofluid in non-linear stretching and shrinking sheet
Numerical(Sinusoidal heated cavity)	Miliki <i>et al.</i> [100]	2016	Ha = 0 – 80 q = -10, -5, 0, 5, 10 Ra = 10 ³ – 10 ⁶ Pr = 5.82	CuO-water, 0 – 4%	—	The researchers concluded that the optimum stream function value increased with the increasing	The study paid full attention to MHD natural convection with uniform heat flux in a sinusoidal heated cavity.

						Rayleigh number but decreased as magnetic field strength (Ha) increased. Also, the Ha number deteriorated the Nusselt number and flow pattern.	
Numerical(Square)	Baker <i>et al.</i> [101]	2016	Ha = 0, 10, 30 and 60 Re = 100 Gr = $10^3 - 10^5$ Pr = 6.2 Ri = 0.1, 1.0 and 10	–	–	The result indicated that the Nusselt number (Nu) increased with increasing Richardson number (Ri) but deteriorated with elevating Hartmann number (Ha).	The research was limited to a lid-driven squared configuration filled with water.
Numerical	Aissa <i>et al.</i> [102]	2016	Ri = 0.0 – 2.00 Ha = 0 – 50 at intervals of 10 Re = 1750 – 2900	–	–	The result indicated that the application of an axial magnetic field has a significant impact on base fluid flow and heat transfer characteristics.	The study was narrowed down to the Czochralski configuration subjected to an axial magnetic field while different geometries, and orientation with nanofluid addition were not considered.
Numerical(Channel)	Rashidi <i>et al.</i> [101]	2016	Re = 500 – 1000 Gr = $10^4 - 10^6$ Ha = 0, 5	Al ₂ O ₃ -water, 0-4%	–	The rate of heat transfer increased with the	The study was limited to a chemical with sinusoidal

			and 10			augmentin g Grashof number (Gr) for nanofluids of various volume concentrati ons. Again, the rate of heat transfer increased with the elevating Poiseuille number and Hartmann number (Ha).	walls filled with Al_2O_3 - water nanofluid while several geometries, orientations and nanoparticles were not considered.
Numerical(Cylindr ical)	Mahfoud and Bessaih [102]	2016	Ri = 0, 0.5, 1 and 2 Ha = 0, 20 and 30 Re = 100 – 1000	–	–	The researchers concluded that by increasing the Ri number at a fixed Re number, the fluid flow became weakened in the cavity.	The research paid adequate attention only to a cylindrical geometry in a counter- rotating flow.
Numerical(Vertica l plate)	Macha and Naikoti[4 7]	2016	Ha = 0.5, 1.0 and 1.5 Nt = 0.2, 0.5 and 0.8 Nb = 0.2, 0.5 and 0.8 Pr = 0.7, 1.0, 2.0 and 7.0 Le = 2, 4, 6	Non- Newtonian power-law nanofluid	–	The result indicated that augmentin g Brownian motion and Lewis number deteriorate s the volume concentrati on and temperatur e profile	The numerical analysis is limited to a vertical plate with variable density
Numerical(Stretchi ng plate)	Wagas <i>et al.</i> [103]	2016	Ha = 0.0, 0.4, 0.8 and 1.2 Pr = 0.7	–	–	The researchers concluded that the rate of heat transfer	The research was limited to MHD mixed convection of micropolar

			$Ri = 0.0, 0.4, 0.8$ and 1.2 $Bi = 0.1, 0.5, 1.0$ and 1.5 $K = 0.0, 0.2, 0.4$ and 0.6			augments for decreasing Ri , Bi and Pr numbers but deteriorated at high values of Ha and Ec .	liquid in a nonlinear stretched surface.
Numerical(Cylinder)	Selvarasu <i>et al.</i> [104]	2016	$Re = 20, 40$ $Pr = 0.7$ $Ri = 0 - 3$ $Ha = 0, 0.5, 1, 4$ and 7		–	The researchers concluded that the rate of heat transfer increases with augmenting Ri and Pr numbers but showed monotonically elevation with Ha number.	The research was limited to mixed convection flow in a circular cylinder with the application of a magnetic field.
Numerical(T-shaped)	Ahmed <i>et al.</i> [105]	2016	$Ha = 0 - 100$ $AR = 0.3 - 0.9$ $\Delta = 0.2 - 0.8$ $Ra = 10^3 - 10^6$	Various nanofluid $\Phi = 0 - 0.2\%$	–	The researchers concluded that when the AR of the configuration elevates, the heat transfer turned to convection from conduction mode. Also, the rate of heat transfer augments with elevating Ra , AR , θ (inclined) and volume fraction concentration	The research paid full attention to only T-shaped cavities for various nanofluids.
Numerical(Elliptic)	Adekeye	2017	$Ha = 0 -$		5.49%	The	The analysis

-cylinder)	<i>et al.</i> [106]		50 $Da = 10^{-3}$ $- 10^{-5}$ $Gr = 10^4 - 10^6$ $Pr = 0.7$ $e = 0, 0.2, 0.4, 0.6, 0.8$ $\theta = 0^\circ, 30^\circ, 60^\circ$ and 90°			maximum heat transfer enhancement was actualized at eccentricity, e value of 0.8 and within the parametric range $58^\circ \leq \theta \leq 90^\circ$	was limited to MHD-free convection in an elliptic cavity while different orientations and usage of nanoparticles were not considered.
Numerical(Rectangular)	Baker <i>et al.</i> [107]	2020	$Ha = 0, 10, 30$ and 60 $Re = 100.0$ $Pr = 6.2$ $Gr = 10^4$ $Ri = 0.1 - 10$	—	—	The researchers concluded that Ha has a considerable influence on velocity and temperature profiles. It was evident that as the values of Ha increased, the fluid flow was mitigated and consequently Nusselt number reduced.	The study paid full attention to MHD mixed convection in a rectangular configuration while several geometries and orientations were not considered.
Numerical(U-shaped)	Ali <i>et al.</i> [108]	2020	$Ra = 10^3 - 10^6$ $AR = 0.2, 0.4$ and 0.6 $\Phi = 0, 0.04, 0.08$ and 0.1 $n = 0.6, 1$ and 1.4 $\theta = 30^\circ$	Non-Newtonian nanofluid $\Phi = 5\%$	—	The effect of magnetic field (Ha) and index power law (n) on the rate of heat transfer is large when Ha was greater than 30. Also, the impact of inclination angle on the rate of	The research work paid full attention to a Non-Newtonian natural convection in a U-shaped configuration but analytical, experimental solution methods were not considered.

						heat transfer was noticeable at $AR = 0.2$, $n = 1$ and 1.4 and $\theta = 30^\circ$.	
Numerical(Hall)	Ibrahim and Anbessa [109]	2020	$Q = 0.0, 0.5$ and 1.0 $Nb = 0.2, 0.4$ and 0.6 $Nt = 0.5, 1$ and 1.5 $\beta = 1, 4, 6$ $Pr = 10$	Brownian motion parameter Thermophoresis parameter	–	The temperature parameter is augmented with elevating values of Nb , Nt , and thermal reduction. parameter (R) and Φ but deteriorates with elevating values of C and n	A 3-D MHD mixed convection filled with Casson nanofluid was considered
Numerical(Cylinder)	Sharma <i>et al.</i> [85]	2014	$Ha = 100$ $Re = 1000-3000$ $\beta = 0.1 - 0.4$ $G/d = 0.5, 1, 2, 2.5, 3, 3.5, 4, 4.5$	–	The Center line gives heat transfer augmentation of 48%	The result indicated that the cylinder situated with gaps to the heated wall of between 0.83 and 1.4 diameters is finest and offsetting the cylinder from the wake.	Experimental and analytical methods were not considered. Attention was only given to a cylindrical configuration.

CONCLUSION

The most significant conclusions drawn from this review are enumerated below:

- The magnetic field has a major impact on both fluid flow and heat transfer characteristics.
- The rate of heat transfer increases with increasing volume concentration and Re number.
- At a constant value of the Richardson number, the stream function reaches the maximum level.
- Heat transfer enhancement is higher with

nanofluids than with base fluids.

- At a constant value of Rayleigh number, the rate of heat transfer augments with a decreasing Richardson number.
- From the survey, only four experimental studies were reported and just one analytical while about 95% of all the studies employed numerical methods.
- The most extensively used nanoparticles; according to the survey are copper and alumina.
- The most common geometries considered in this survey are cylindrical, square, circular and rectangular.
- This is a unique research field that would need extensive work on experimental and analytical solution methods.

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