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A Review of Entropy Generation in Rectangular Cavities

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ABSTRACT

Entropy generation is a thermodynamic system attribute representing the direction or result of spontaneous changes within the system. This article uses an entropy generation analysis to examine the thermodynamic optimum in square cavities. Numerous studies have documented using entropy generation analysis as an evaluation measure. This research will utilise entropy generation in various types of convective heat transfer under multiple factors. Furthermore, the problem formulation and outcomes regarding entropy generation in square cavities are presented and summarised in a table. To summarise, the primary goal in dealing with this problem is to get an ideal configuration that maximises energy efficiency through minimising entropy generation and enhancing heat transfer rate. This review study sets the framework for future investigations into entropy production analysis to boost energy efficiency.

1. Introduction

Minimising entropy generation during fluid flow and heat transfer processes is crucial in most engineering and industrial applications. Researchers strive to reduce entropy generation to enhance efficiency and performance. This requires a comprehensive analysis of various factors contributing to irreversibilities, such as flow friction, mass diffusion, viscous dissipation, heat transfer, temperature differences, fluid mixing, chemical reactions, and electric resistance. The first and second laws of thermodynamics can be used to analyse the form of entropy generation irreversibility. However, the second law provides valuable insights as it expresses thermal efficiency as a ratio of the actual thermal efficiency.

The concept of entropy, introduced by Bejan *et al.,* [1], has revolutionised the field of energy efficiency. Various designs such as thermal storage, diesel engines, reactors, microchannels, two-phase flow, power generation, fuel cells, and solar-related applications have been optimised by minimising entropy generation. Extensive research has focused on these applications, highlighting

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the importance of identifying the conditions that maximise system efficiency while reducing entropy generation.

Understanding the mechanisms of entropy generation in convective heat transfer is crucial for designing and optimising energy-efficient systems. Entropy generation measures the thermodynamic irreversibility of a system, and convective heat transfer is one of the primary processes contributing to irreversibility. This article aims to investigate the phenomenon of entropy generation in square cavities to identify the current trend of research in this area. To this end, the study will comprehensively summarise all pertinent information in a tabular format to enhance and simplify the reader's comprehension of the subject matter. Refer to Table 1 for additional details.

2. Criteria of the Study

For the research, a thorough review of articles published in Scopus, WOS, Springer Link, and Science Direct was conducted to identify studies on entropy generation in square cavities. To ensure the quality of the study, strict inclusion and exclusion criteria were established, and the keywords "Entropy Generation" AND "Square Cavity" were utilised in the search. Although thousands of articles were initially encountered, many had to be eliminated due to inaccessibility and overlap. Ultimately, only 92 articles that met the criteria were selected as listed in Table 1, including conference proceedings and journals, which were obtained from a variety of sources, including Scopus (30), WOS (16), Springer Link (8), Science Direct (31), and others (7).

The 92 articles were analysed to draw valuable insights and compelling assumptions. The study spanned 23 years, from 2000 to 2023, and primarily focused on closed cavities, with only one study examining open cavities. Most of the analysed articles (71%) explored entropy generation in natural or free convection, including double-diffusive, magnetohydrodynamics (MHD), unsteady, conjugate, and transient natural convection. However, other types of convection, such as mixed convection, double-diffusive mixed and Marangoni convection, thermosolutal convection, MHD mixed convection, and Rayleigh–Bénard convection, were also examined. The study also observed that the analysed articles looked at cavities of different shapes, such as waviness (11%), presence of fins (10%), blockages inside the cavity (23%), porous media (12%), or inclinations of the cavity (11%).

The study investigated different working fluids, such as water, air, nanoparticles combined with water as a base fluid, hybrid nanofluids, and ferrofluids. Of the 92 papers analysed, the majority (53%) focused on the entropy generation when nanofluids were present. Among the nanoparticles used, Al_3O_2 was the most utilised (43%), followed by Cu (18%), CuO (14%), TiO_2 (6%), SiO_2 (4%), Ag and Fe_3O_4 (2% each). The researchers also examined hybrid nanofluids, with Cu-Al_3O_2 being a frequently chosen combination (63%). Other popular hybrid nanofluids included TiO_2-Cu, Al_2O_3-CuO, and Al_2O_3-Ag (13% each).

In the upcoming section, the 92 articles will be examined, focusing on the type of convection studied. The aim is to contribute to the ongoing research on entropy generation in this field. Ultimately, the analysis will help develop more efficient and effective cooling systems across various industries.

3. Entropy Generation in Natural Convective Heat Transfer

Natural convection is an essential process of fluid movement caused by temperature variations that result in density differences. This phenomenon is crucial in many industries and engineering applications as it facilitates heat transfer through fluid movement. Natural convection is observed with various working fluids, including air, water, and other liquids and gases. Over the years, multiple researchers have studied this phenomenon better to understand the impact of different factors on the process. The following will explore various studies on natural convection heat transfer and entropy generation within square and rectangular cavities. It will discuss the impact of different factors such as heat transfer capacity, fluid friction, inclination angles, adiabatic obstacles, Rayleigh number, Prandtl number, relaxation time, aspect ratio, and Hartmann number on thermal behaviours and fluid flow characteristics. The studies will highlight the relationship between these factors and entropy generation and their implications for heat transfer equipment design and minimising irreversibility within enclosures.

Luan *et al*., [2] examined the impact of different positions of hot and cold walls on water density inversion in a square cavity. The findings showed that entropy generation increased proportionately to the heat transfer capacity, while fluid friction did not play a significant role. Similarly, Oyewola *et al.,* [3] explored the numerical problem of convective heat transfer and entropy generation within a square cavity. The study found that the inclination angles and adiabatic obstacles significantly impact the system's thermal behaviours and fluid flow characteristics. The study by Baliti *et al.,* [4] explored the natural convection of fluid within a square cavity featuring adiabatic bodies. The findings revealed that elevating the Rayleigh number corresponds to an increase in the average Nusselt number. Additionally, high openings in the obstacles facilitated greater heat penetration along the right side of the cavity. Notably, locations with more significant temperature gradients exhibited higher levels of entropy generation. Boudebous and Ferroudj [5] compared entropy generation calculations for unsteady natural convection in a square cavity with vertical sides maintained at varying temperatures. The study revealed that each fluid, characterised by its Prandtl and Rayleigh numbers, corresponded to only one value of the irreversibility distribution ratio, ϕ. Additionally, it was found that the value of ϕ is inversely proportional to the square of the characteristic length, L. As a result, an increase in L (or Rayleigh number) decreases the value of ϕ. It is worth noting that the values of ϕ suggested by previous authors were overestimated, leading to oversized heat transfer equipment. Soleimani *et al.,* [6] examined the entropy generation resulting from natural convection heat transfer in an enclosed cavity on two occasions. The local entropy generation maps at low Rayleigh numbers resemble those generated by heat transfer. Conversely, the local entropy generation maps at high Rayleigh numbers resemble those caused by fluid friction. Erbay *et al.,* [7] examined entropy generation within a square enclosure experiencing transient laminar natural convection with partial heating from a vertical lateral wall. The findings revealed that at low Pr values, Ra number increases result in significant intervals of consistent entropy values, corresponding contours through the centre of the volume. The highest maximum entropy generation number was observed at the highest Ra number. Notably, this study's primary source of entropy generation was heat transfer under the examined conditions. Delavar *et al.,* [8] investigate the effect of changing the heater location on natural convection flows and entropy generation with non-linear phenomena within enclosed rectangular cavities. The variation of the temperature contours impacts the total dimensionless entropy generation in the cavity. With increasing the Rayleigh number, the dimensionless entropy generation decreases at all heater positions. In an investigation by Magherbi *et al*., [9], an incompressible fluid was observed within a heated square cavity. The results showed that as the Grashof number increased, there was a significant rise in both the amplitude and oscillation numbers of entropy generation, independent of the fixed relaxation time. Interestingly, an increase in relaxation time decreased the maximum entropy generation value, which occurred after a more extended period from the beginning of the transient state. Critical relaxation times were also established to obtain no oscillations of transient entropy generation in natural convection. These critical times were found to be 1/7, 1/8, and 1/10 for Gr = 10^4, 5 10^4, and 10^5, respectively. The researchers found that the maximum transient entropy generation occurred at an inclination angle of 60°, with a slight shift in the maximum observed with changes in the magnetic field's inclination angle. Shuja *et al*., [10] analysed heat transfer in a square cavity with a heat source. The study shows that solid surface areas facing the inlet and outlet of the cavity experience heightened heat transfer. The maximum amount of entropy generated occurs when the solid body is situated in the centre of the cavity, reducing the irreversibility ratio to its lowest possible value.

Ilis *et al.,* [11] studied rectangular cavities with unit area and varying aspect ratios. The findings showed that heat transfer irreversibility dominated low Ra values, while fluid friction irreversibility dominated high Ra values. The average Bejan number was a reliable criterion to predict the dominant irreversibility. The study also found that total entropy generation increased with the Rayleigh number, but the rate of increase depended on the aspect ratio. Interestingly, a tall cavity could exhibit less total entropy generation for the same Rayleigh number than a shorter one. The study conducted by Bouabid *et al.,* [12] on natural convection in an inclined rectangular air-filled cavity showed that total entropy generation increases with the aspect ratio of the cavity for high thermal Grashof number. The contributions of thermal and viscous irreversibility on entropy generation were investigated using a dimensionless number called the Bejan number, which increases as the aspect ratio increases at fixed values of the thermal Grashof number and irreversibility distribution ratio. At the local level, entropy generation is located on the low corner of the heated side and the upper corner of the cooled side of the enclosure. Morsli *et al.,* [13] studied natural convection heat transfer and entropy generation in rectangular cavities with different aspect ratios. The study found that fluid friction irreversibility is dominant for cavities with lower Ra values and increases with aspect ratio. In comparison, the fluid friction entropy generation is dominant for cavities with higher ϕ values and undulations. The total entropy generation increases with the Ra number, but the rate of increase depends on the aspect ratio. The study also found that the effect of the heat field is qualitatively equal to the impact of the Rayleigh number on the contribution of heat transfer irreversibilities to the entropy generation rates. El-Maghlany [14] conducted a study on enclosures with different aspect ratios and heat generation rates in dimensionless form. The results showed that the aspect ratios of the squares significantly impacted entropy generation during natural convection. Entropy generation rates were sensitive to changes in heat generation intensity, Rayleigh number, and aspect ratio. The study suggests that selecting a suitable aspect ratio through iso-contour mapping can minimise irreversibility within the enclosures under specified operating conditions. Numerical results of total entropy generation were correlated with aspect ratio, Rayleigh number, and heat generation.

Bouabid and Brahim *et al.,* [15] studied entropy generation in a two-dimensional steady MHD natural convection flow and mass transfer in a square confined cavity filled with a binary fluid. The study found that increasing the Hartmann number ($0 \leq Ha \leq 25$) decreases the entropy generation rate. However, an increase in Hartmann ($Ha > 25$) shows no significant effect on entropy generation. Additionally, entropy production decreases with the rise of the Soret parameter, and the influence of the buoyancy ratio on the entropy generation rate for different Soret parameters was also observed. It was interesting to note the existence of a minimum value in the entropy generation rate for a buoyancy ratio of about −1, and the values of the entropy generation rate tend to increase with increasing the absolute values of the Buoyancy ratio. The study by Kaluri and Basak [16] discusses the topic of entropy generation in square cavities with distributed heated sources, utilising the Galerkin finite element method. The researchers examine the impact of thermal and frictional irreversibilities and the influence of heat transfer and fluid friction irreversibilities during conduction and convection regimes. Additionally, the study investigates the effects of thermal mixing and temperature uniformity on fluid processing, focusing on minimising entropy generation. The results indicate that heat transfer irreversibility plays a more significant role in entropy generation during the conduction regime, whereas fluid friction irreversibility dominates during the convection regime.

Recently, researchers have been exploring using nanofluids, hybrid nanofluids, and ferrofluids to improve natural convection. Nanofluids contain nanoparticles with high thermal conductivity, hybrid nanofluids created by combining two or more different types of nanoparticles, and ferrofluid, which consists of nanoparticles of magnetic material suspended in a liquid carrier, can significantly enhance heat transfer. The following study examines several research papers investigating the effects of different factors such as nanoparticle concentration, magnetic field angle, and fin angle on natural convection and entropy generation.

The study by Sheremet *et al.,* [17] investigated the effects of nanoparticle concentration on entropy generation and natural convection in a differentially heated cavity that contained a centred hot block using a Cu-water nanofluid. The results revealed that higher nanoparticle concentration led to less effective cooling but increased the average Nusselt and Bejan numbers and total entropy generation. Additionally, increasing the size of the hot block led to the formation of low-intensity convective cells. Another study by Sheremet *et al.,* [18] delved into combining natural convection heat transfer and entropy generation in a square cavity filled with a nanofluid. The research found that higher Rayleigh numbers resulted in increased entropy generation along vertical walls, a more uniform distribution of nanoparticles, and an overall increase in average parameters. Additionally, increased variable temperature amplitude led to intensified convective flow and heat transfer and increased entropy generation and average Bejan number for high Rayleigh numbers. In contrast, low Rayleigh numbers decreased the average Bejan number. A study by Bouchoucha and Bessaïh [19] demonstrated the impact of nanofluids on natural convection and entropy generation within a square cavity. The findings suggest that increasing the volume fraction of nanoparticles results in a decreased total entropy generation while notably improving the average Nusselt number for Rayleigh numbers within the range of 10^4-10^6. Additionally, the study established Cu-water nanofluid as having superior heat transfer performance and a weaker total entropy production than other nanofluids. Overall, the study emphasises the significant influence of viscosity and thermal conductivity on total entropy generation. In the study by Reddy *et al.,* [20], MWCNTs and water-based nanofluid flow were investigated inside a square enclosure with radiation and magnetic field, focusing on isentropic lines and isotherms. The results showed that the total entropy generation of water-MWCNTs-based nanoliquid increases by a significant 18.42% with the addition of MWCNTs at a volume fraction of 4% to the base fluid water. These findings demonstrate the promising potential of this approach in enhancing the efficiency of fluid systems, which is a crucial step toward developing more sustainable technologies. Ishak *et al*., [21] analyse the effects of parameters such as solid wall thickness, heat source position, nanoparticle volume fraction, and Rayleigh number on entropy generation and heat transfer. The findings indicate that the presence of nanoparticles and the variation in these parameters significantly influence entropy generation, heat transfer, and fluid flow patterns within the cavities. The studies also highlight the importance of understanding the balance between heat transfer irreversibility and fluid friction irreversibility in determining the dominant factor in entropy generation. Additionally, the research emphasises the significance of conjugate convection, which involves thermal interaction between fluids and solids, in understanding entropy generation in engineering systems. Bouchoucha *et al*., [22] improved heat transfer in a square cavity filled with Al_2O_3/water nanofluid for different geometries. The study on entropy generation in a nano-fluid-filled enclosure with a stepped wall found that total entropy generation decreases with increased nanoparticle volume, except at Rayleigh number 104. The presence of nanoparticles has two contrary effects on entropy generation: it improves heat transfer but increases friction losses. The Ra number significantly impacts entropy generation, increasing with enhanced heat transfer flow. The study also highlights the influence of the thermal conductivity ratio and NP volume fraction on the Bejan number. The dimensional variation of the body affects the Nusselt number, thus impacting heat transfer and entropy generation. Alipanah *et al*., [23] investigate the impact of nanoparticles on entropy generation due to heat transfer and fluid friction irreversibility. The study examines the effect of adding nanoparticles to pure fluid, comparing results for a wide range of Rayleigh numbers and volume fractions. Nanoparticles increase entropy generation at higher Rayleigh numbers and decrease efficiency. Previous research on heat transfer enhancement using nanofluids is reviewed, and numerical simulations of entropy generation due to heat transfer and fluid friction irreversibility in various cavity configurations are discussed. Adding nanoparticles enhances heat transfer rates and entropy generation in the square cavity, with a more pronounced impact at lower Rayleigh numbers.

Alsabery *et al.,* [24] examined the effects of nanofluid and solid insert on entropy generation and natural convection in a square cavity. The findings revealed that a solid insert at the cavity's centre significantly influenced the local entropy generation. In contrast, the global entropy generation increased with the Rayleigh number. Moreover, the study demonstrated that a more oversized solid insert favoured the average Bejan number. The study by Xiong *et al.,* [25] analysed the natural convection of the SiO_2-water nanofluid in a square cavity with a square thermal column. The results show that when the temperature of the thermal column increases and $T \leq 0.5$, there is a reduction in the total entropy generation, but an increase in total generation occurs when $T \geq 1.0$. The minimum value of the total entropy is observed at $T = 0.5$. Furthermore, the volume fraction does not significantly impact the total entropy generation at low Rayleigh numbers. However, at high Rayleigh numbers, heat convection plays a vital role and affects the growth of the total entropy generation more than the volume fraction. A study by Sheikhzadeh and Nikfar [26] examined the impact of aspect ratio (AR) on a centred adiabatic rectangular obstacle. The researchers conducted numerical investigations on natural convection and entropy generation in a differentially heated enclosure filled with either water or nanofluid (Cu-water). Using nanofluid resulted in an increase in flow strength, Nusselt number, and entropy generation, as well as a decrease in the Bejan number, particularly at high Rayleigh numbers. At low Rayleigh numbers, entropy generation was found to be deficient, and as Ra increased, entropy generation and the Bejan number increased as well. The viscose entropy generation was found to be dominant in the overall entropy generation, and its behaviour was similar to that of the total entropy generation. The maximum entropy generation occurred at AR = 1/3 and 3, while the minimum was observed at AR = 1 and 1/2. The effect of changing AR on dimensionless entropy generation, Bejan number, and Nusselt number varied depending on the Rayleigh number. Sheikhzadeh *et al.,* [27] examined natural convection and entropy generation in a square cavity containing an obstacle and Cu-water nanofluid. The findings indicate that nanofluid generally enhances flow strength, Nusselt number, and entropy generation while reducing the Bejan number, particularly at high Rayleigh numbers. As the Rayleigh number increases, entropy generation and Bejan number terms also increase. In addition, increasing the obstacle dimensions (W/L) ratio raises entropy generation and lowers the Bejan number, although its impact on the Nusselt number depends on the Rayleigh number. Overall, the entropy generation increases with higher W/L and Ra values, but the ratio of Nusselt number and entropy generation improvement due to the W/L increase is crucial. It is also noteworthy that increasing W/L at low Rayleigh numbers significantly impacts the current thermal system. Khorasanizadeh *et al.,* [28] analysed the behaviour of Cu-water nanofluid in an enclosure with a conductive baffle on the bottom hot wall. The researchers found that increasing the Ra lowered the total entropy generation across all volume fractions and baffle positions. At $Ra = 10^4$, where conduction was the dominant heat transfer mechanism, the minimum entropy generation always occurred at $\phi = 0.08$, regardless of baffle position. However, due to solid viscose effects at $Ra = 10^4$, the maximum entropy generation occurred when the baffle was close to the left wall for every volume fraction. For $Ra = 10^5$ and 10^6, where convection was more significant, the minimum entropy generation always occurred at $\phi = 0$, regardless of the baffle position. Due to improved convection and enhanced viscose effects, the maximum entropy generation happened when the baffle was in the middle of the bottom wall.

Salari *et al.,* [29] studied the effects of natural convection of Cu-water nanofluid in rectangular cavities with different circular corners and aspect ratios on entropy generation. The results show that the total entropy generation increased with an increase in Rayleigh number, irreversibility coefficient, aspect ratio, or solid volume fraction. However, it decreased with an increase in corner radius. The Bejan number increased with an increase in corner radius or solid volume fraction but decreased with an increase in Rayleigh number, irreversibility coefficient, or aspect ratio. It is worth noting that the best way to minimise entropy generation is to decrease the Rayleigh number. The percentage of reducing total entropy generation and Nusselt number and the percentage of increasing Bejan number increased with an increase in corner radius while augmenting Rayleigh number. Li *et al.,* [30] studied alumina/water nanofluid's free convection and radiation heat transfer in a two-dimensional square cavity positioned at a 45° angle with the horizontal. The study revealed that an increase in the radiation parameter doubled the heat transfer rate and generated entropy by 1%. Conversely, a reduced Hartmann number reduced the generated entropy by 29%. Moreover, increasing the nanofluid's volume fraction by 6% resulted in a 3.7% increase in heat transfer rates and a 12.8% rise in generated entropy. Overall, the study's findings suggest that the Rayleigh number and pipe aspect ratio have a more significant impact on heat transfer and entropy generation than other factors.

Researchers have always used the study of natural convection in wavy wall cavities to investigate the impact of complex geometries on natural convection heat transfer and fluid flow characteristics. The use of wavy walls can lead to the formation of unique fluid flow patterns. These patterns result from secondary flows, which are generated due to the shape of the wavy walls. A study by Hatami [31] examined natural convection in a square wavy-walled cavity filled with nanofluid. The study found that an increase in the angle of the magnetic field (γ) resulted in a corresponding increase in the entropy generation and Nusselt number, while the Bejan number decreased. Moreover, an increase in the Hartmann number caused a decrease in the average Nusselt number but an increase in the Bejan number due to the increased irreversibility of heat transfer. Alsabery *et al.,* [32] examined the effects of Cu-Al_2O_3-water hybrid nanofluids on entropy generation, fluid flow, and heat transfer in a complex-shaped enclosure with a hot-half partition. The findings show that the increase in Ra and dimensionless heat source length (D) led to a rise in global entropy generation (GEG). At the same time, a higher value of solid volume fraction of hybrid nanofluid (ϕ) resulted in a decrease in GEG. The flow patterns and isothermal contours in the cavity varied due to differences in flow intensity and fluid viscosity caused by different parameters, which impacted the source of entropy generation. When Ra was raised, the fluid friction irreversibility (FFI) dominated the entropy generation. Still, the effect of the heat transfer irreversibility (HTI) increased with higher values of ϕ, and D. Geridonmez and Oztop [33] studied the two-dimensional, time-independent conjugate natural convection flow. The entropy generation in three cases of a wavy conducting solid block attached to the left wall of a square cavity was investigated. The study found that the rise in the Lorentz force reduces the fluid velocity, convective heat transfer (CHT), and total entropy. When Ha is changed from 10 to 100, there is a 71.58% reduction in total entropy generation and a 49.16% reduction in the average Nu along the interface. Additionally, Be number increases by 146.3% in Case 1. A study by Hussain [34] explored natural convection and entropy generation in a porous enclosure with a tilted sinusoidal corrugation and double-diffusive MHD. The study found that the inclined corrugated enclosure outperformed horizontal and vertical enclosures in enhancing entropy generation through fluid friction (S_Ψ), thermal gradients (S_θ), and total entropy generation (S_T).

Notably, there was a significant increase in entropy generation as the Rayleigh number increased. Additionally, the study found that the entropy generation due to the magnetic field (S_M) was higher when the enclosure was subjected to a horizontal magnetic field compared to a vertical magnetic field at different enclosure inclination angles. Parveen and Mahapatra [35] thoroughly investigated the heat and mass transfer complexities of a wavy enclosure that is selectively heated from the lower wall and contains nanofluid. Through the research, the researchers discovered that amplifying the Rayleigh number significantly increases the overall entropy generation, whereas expanding the buoyancy ratio, undulation number, and Hartmann number results in a considerable reduction in the total entropy generation. The findings provide a strong foundation for further exploration in this area. Cho [36] investigates the natural convection heat transfer and entropy generation in a partially heated wavy-wall square cavity filled with Al_2O_3–water nano-fluid. The study analyses the impact of nanoparticle volume fraction, Rayleigh number, and wavy-surface geometry on the Nusselt number, entropy generation, and Bejan number. The results indicate that increasing nanoparticle volume fraction boosts the Nusselt number but reduces entropy generation. On the other hand, increasing the amplitude and wavelength of the wavy surface decreases the Nusselt number but increases entropy generation and Bejan number. Additionally, the Nusselt number increases and entropy generation reduces as the peak in the wavy surface approaches the horizontal centre plane of the cavity, irrespective of the Rayleigh number.

Magnetic fields have been used in the study of natural convection as an external force that can be used to control and manipulate fluid flow within enclosures. Using magnetic fields in natural convection studies has led to unique findings, such as the ability to reduce entropy generation and improve heat transfer rates. Zhang *et al.,* [37] have found that in a closed cavity of water/alumina nanofluid subjected to an oblique magnetic field and radiation heat transfer, the mean Nusselt number and generated entropy increased with the Rayleigh number while the Bejan number decreased. The study discovered that the maximum heat transfer rate and entropy generation occurred with a 90° magnetic field, and the minimum Bejan number was observed with a 15° magnetic field at high Rayleigh numbers. However, the magnetic field angle did not significantly affect the heat transfer rate, generated entropy, or Bejan number at low Rayleigh numbers. Belhaj and Ben-Beya [38] studied the heat transfer and entropy generation of Carbone Nanotube (CNT)-water nanofluids in a square cavity with and without isothermal block under MHD natural convection. The results indicate that an increase in Ha causes a significant decrease in heat transfer and entropy generation, while adding the nanoparticles to the water has a negligible effect. Oueslati and Ben-Beya [39] studied magnetoconvection and entropy generation in a square cavity filled with liquid metal subject to a uniform magnetic field and driven by a lid. The study found that increasing the Hartmann number reduces the total entropy generation due to fluid friction and heat transfer. The research also revealed that thermal irreversible effects dominate entropy generation. The study showed that increasing the Richardson number strengthens irreversibility rates, especially for higher values. The study concluded that optimal heat transfer and irreversibility phenomena occur for all Hartmann numbers when horizontal walls move in opposite directions. Iftikhar *et al.,* [40] examine how non-uniform magnetic fields affect heat transfer and entropy generation in the convection flow of ferrofluid inside a cavity in the presence of thermal radiation. The results showed that as the Hartmann number increased, there was a decrease in both heat transfer and total entropy. At Ha ≥ 3, irreversibility due to heat transfer was observed throughout the enclosure. The study also found that magnetic numbers reduced fluid velocity and entropy generation while increasing energy transport due to the magnetocaloric effect. Additionally, it was observed that entropy generation and concentration of ferroparticles exhibited a reverse behaviour. Shi *et al.,* [41] examine the natural convection and entropy generation of air in a two-dimensional square enclosure under a magnetic quadrupole field. The relationship among the total entropy generation (S_{total}), the Rayleigh number, and the magnetic force number can be approximated as a linear increasing function. At lower γRa, thermal irreversibility is more significant; at higher γRa, the flow friction irreversibility is more critical. The result shows that the magnetic buoyancy force has potential applications for enhancing heat transfer, which leads to increased total entropy generation. Rahman *et al.,* [42] thoroughly investigated the influence of an externally applied magnetic field on the non-Newtonian power-law nanofluid in a rectangular-shaped enclosure, using the multiple-relaxation-time (MRT) lattice Boltzmann method (LBM). The study revealed that the entropy generation resulting from externally applied magnetic field and heat transfer irreversibility occurs in both shear-thinning and shear-thickening fluids, as indicated by the average Bejan number. Furthermore, the maximum value of the Bejan number was attained in the case of shear-thickening fluid for Ra = 10^4 and magnetic field angle γ = 0◦. These findings provide valuable insights into the behaviour of complex fluids under the influence of applied magnetic fields and have important implications for a wide range of practical applications. Tayebi and Chamkha [43] focus on the influence of the magnetic field on entropy generation and natural convection inside the enclosure filled with a hybrid nanofluid and a conducting wavy solid block. The findings indicate that the wavy solid block's magnetic field and conductivity ratio significantly affect the dynamic and thermal fields, heat transfer rate, and entropy generation due to heat transfer, fluid friction, and magnetic force. The study also highlights the effect of various parameters such as Rayleigh number, Hartmann number, and the ratio of fluid to solid thermal conductivities on heat transfer, entropy generation, and average Bejan number. Reddy *et al.*, [44] present a numerical investigation of magneto-free convective flow in a square cavity with internal heat generation using a Cu-water nanofluid embedded in an isotropic porous medium. The study explores the impact of various parameters such as the heat sink length, Hartmann number, Rayleigh number, and heat generation on entropy generation. The results show that increasing the nanoparticle volume fraction in the Rayleigh number decreases global entropy generation. In contrast, the average Nusselt number decreases as the volume fraction increases in the Hartmann number. Additionally, increasing the Darcy numbers enhances the nanoparticle volume fraction, and the total entropy generation increases with an increase in the nanoparticle volume fraction. The study also discusses the impact of heat generation on thermal performance and the influence of the magnetic field on the average Nusselt number.

The use of fins in natural convection studies has also been found to enhance heat transfer rates within enclosures significantly. Fins are extended surfaces attached to a surface to increase the surface area available for heat transfer, thus improving heat transfer by increasing the convective heat transfer coefficient. Al-Kouz *et al.,* [45] conducted a Computational Fluid Dynamics (CFD) study to analyse the entropy generation of a 2D laminar nanofluid flow in a square cavity with two solid fins attached to the hot wall. The study found that increasing the Knudsen number led to a reduction in entropy generation. For low Rayleigh numbers, the study revealed that entropy generation increased with an increase in the diameter of the fins. In contrast, higher Rayleigh numbers decreased with the same increase in diameter. The study also observed that heat-generated entropy generation increased with Rayleigh's number and diameter. Additionally, the team proposed a correlation model that shows the total entropy generation as a function of all the parameters investigated. Khetib *et al.,* [46] studied the effects of installing fins of varying types in a square cavity on free convective heat transfer. The findings revealed that angled fins placed at a cavity angle of 45 yielded the highest entropy production. In contrast, straight fins at a cavity angle of zero resulted in the lowest rate. Adjusting the fin angle in the horizontal cavity can enhance heat transfer by up to 6.4%, and bending the fins can result in a maximum improvement of 4.9%. A study by Rahimi *et al.,* [47] focused on natural convection and entropy generation in a square cavity filled with CuO-water nanofluid. The study revealed that internal active fins significantly impacted fluid flow, heat transfer, and entropy generation. The findings indicated that the Rayleigh number had a direct correlation with the entropy generation, as the temperature and velocity gradient increased when the flow changed from laminar to turbulent with an increase in Rayleigh number. Alnaqi *et al*., [48] numerically investigate the impact of various parameters such as Rayleigh numbers, Hartmann numbers, radiation parameters, and volume percentages of nanoparticles on heat transfer and entropy generation. The results show that increasing the Rayleigh and reducing the Hartmann numbers increases the Nusselt number. Additionally, adding 6% of nanoparticles to the base fluid increases the heat transfer rate and entropy generation. The study also observes that increasing the radiation parameter at high Rayleigh numbers increases the Nusselt number and entropy generation and decreases the Bejan number. The findings also indicate that the velocity gradient, temperature gradient, and the presence of nanoparticles in the fluid influence the total entropy generation. Shahi *et al*., [49] discuss the entropy generation due to the natural convection of a nanofluid in a square cavity with a protruded heat source. The study examines the impact of various factors on entropy generation. Severe temperature gradients near the heat source significantly increase local entropy generation. The addition of copper nanoparticles reduces entropy generation by enhancing thermal conductivity. The study also finds that nanofluids result in better performance efficiency than pure water. The heat source location significantly affects entropy generation, with the best results obtained when located at a specific position. The study also discusses the impact of solid concentration and heat source spacing on entropy generation.

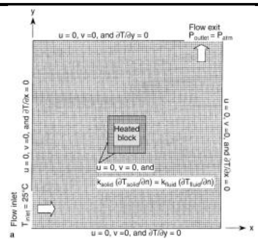
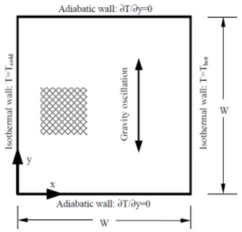
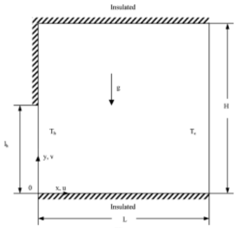
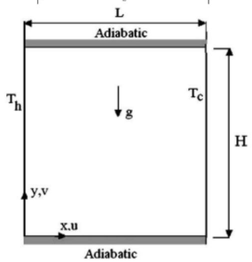
The use of a porous medium in the study of natural convection has a significant impact on the process. It is observed that the presence of a porous medium significantly alters the fluid flow characteristics and heat transfer behaviour. In particular, the porous medium has been found to affect fluid friction and thermal dispersion, which, in turn, notably impact the entropy generation within the system. Mahmud and Fraser [50] conducted a study investigating the effect of natural convection on entropy generation in a two-dimensional square-section enclosure. The enclosure was filled with porous media and was subjected to sinusoidal vibration in a zero-gravity environment. The researchers found that the periodic behaviour of the Nusselt number, Bejan number, and entropy generation rate was synchronised with the forced acceleration, meaning that all three parameters had the same period as the forced acceleration. Goqo *et al.,* [51] studied the flow in a square cavity filled with a porous medium saturated with a nanofluid and subjected to an applied magnetic field. The findings revealed that increasing the Rayleigh number led to increased entropy generation when particle Brownian motion occurred. The total entropy generation decreased as the radiation parameter increased for various Hartman number values. On the other hand, an increase in the Lewis number caused the entropy generation to improve. Charreh *et al.,* [52] delve into the intricacies of fluid flows, general heat transfer, and entropy generation during transient natural convection within a square cavity containing a saturated non-Darcy porous medium with dissipation effects and thermal radiation. The entropy generation analysis highlights the porous medium's significant impact on the system's irreversibility, with the entropy creation rate particularly pronounced around the solid vertical walls. Notably, the most remarkable entropy creation occurs at these vertical walls. The study by Sadeghi *et al.,* [53] delved into the natural convection heat transfer of CuO-water nano liquid within a traditional oil/water separator-shaped cavity with porous media. The research indicates that augmenting fluid permeability (Da) results in a noteworthy improvement in entropy generation. Additionally, including solid particles causes a substantial decrease in entropy generation. Javed *et al.,* [54] explore the free convection and entropy generation within a square chamber filled with water and divided by a corrugated porous partition saturated with water. The findings demonstrate the importance of entropy generation analysis in thermal system design to minimise irreversibility.

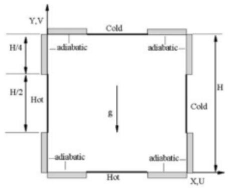
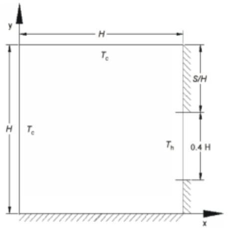
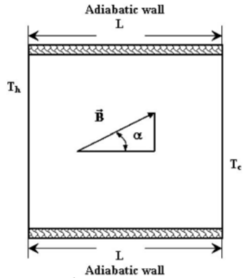
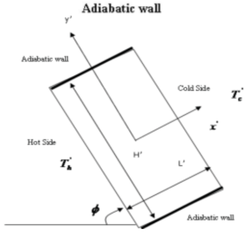
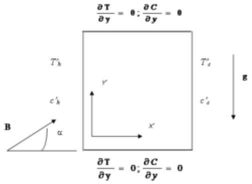
The study examines the impact of various parameters, such as the position, thickness, amplitude, and frequency of the porous partition, on entropy generation. It concludes that a lower partition thickness impedes the convection mechanism of heat transfer and results in decreased entropy generation. Furthermore, the study compares porous versus solid partitions and determines that using a porous partition increases the average Nusselt number while reducing entropy generation. Overall, the research provides valuable insights into the relationship between entropy generation and the design parameters of the porous partition. Akhter *et al.,* [55] investigated the behaviour of fluid flow, temperature, and entropy generation in a partially heated cavity filled with a hybrid nanofluid and a heat-conductive cylinder surrounded by a porous medium and an external magnetic field. The researchers found that increasing the Darcy number resulted in a faster fluid flow circulation, a higher rate of heat transfer, and increased entropy generation while decreasing the Bejan number for all Ra. Additionally, increasing the Darcy number caused gradual changes in the distribution of streamlines for higher Ra (≥ 106). The researchers observed an increase in local entropy generation with increasing Ra and Da but a decrease with Ha and ϕ. Isentropic line distributions were more sensitive to Ra, Ha, and Da changes but less sensitive to volume fraction. The study revealed that heat transfer and entropy generation components increased with increasing Ra but decreased with an increase in Ha, except for magnetic entropy. The researchers noted that heat transfer irreversibility dominated the entropy generation at a lower range of Ra, while fluid friction irreversibility dominated at a higher range. Tayebi [56] explores the impact of local thermal non-equilibrium (LTNE) on heat exchange and entropy generation in porous media. It introduces a new parameter, the ratio of entropy generation due to thermal diffusion in the fluid phase to that in the solid phase (Ty), to assess and compare thermal irreversibility. The study visualises maps of LTNE sources and entropy generation due to thermal diffusion in both phases and investigates the influence of various dimensionless properties on these processes. The findings reveal that as the system transitions from LTNE to local thermal equilibrium (LTE), the thermal irreversibility in both phases becomes more similar. Additionally, the study shows that increasing certain parameters intensifies the total average entropy generation in the system. In contrast, the corresponding average Bejan number reduces, indicating that the irreversibility of thermal effects becomes a minor contributor to the total entropy produced. Kaluri and Basak [57] discuss the application of entropy generation minimisation (EGM) to optimise natural convection in porous square cavities with discrete heat sources. This study aims to enhance thermodynamic efficiency and minimise energy wastage by examining the permeability of the porous medium and the effects of distributed heating on thermal mixing, temperature uniformity, and entropy generation. The conclusions drawn from the research indicate that utilising multiple heat sources for distributed heating is an effective approach for achieving optimal thermal processing. This method leads to a balanced level of thermal mixing, greater temperature consistency, and improved energy efficiency. Cimpean and Pop [58] thoroughly explore entropy generation analysis about a square-inclined cavity filled with porous media and saturated by a nanofluid. In this study, sinusoidal temperature distribution on the side walls is applied to the cavity, and various parameters and boundary conditions are examined to gauge the impact on fluid flow, heat and mass transfer characteristics, and entropy generation. Through validation against prior results, this analysis has implications for optimising electronic devices and cooling processes. It offers a comprehensive understanding of nanofluid behaviour in porous media and its potential for application in thermal systems. Kefayati [59] studied the analysis of heat transfer and entropy generation in the context of natural convection of non-Newtonian nanofluids in a porous square cavity using the Finite Difference Lattice Boltzmann Method (FDLBM). The study examines the impact of various parameters on flow, thermal fields, and entropy generation. Results show that adding nanoparticles enhances convection, while the rise in Darcy number causes a decrease in local Nusselt number. Heat transfer and entropy generation vary with changes in the power-law index and Darcy number. Ashorynejad and Hoseinpour [60] investigate the impact of different nanofluids on entropy generation in natural convection within a porous cavity. The study uses the lattice Boltzmann method to analyse the effects of various porosities, Darcy numbers, and volume fractions of nanofluids. The nanofluids consist of water as the base fluid and nanoparticles such as Al_2O_3, TiO_2, and CuO. The research reveals that higher porosity leads to increased total entropy generation due to the rise in fluid friction. The study also shows that CuO–water has a more significant effect on heat transfer, while the average Nusselt number decreases slightly with increased volume fractions of TiO_2–water. Nanofluids are found to reduce heat loss and entropy generation, with smaller nanoparticle sizes leading to a reduction in heat transfer rate. The results also demonstrate that the size of the nanoparticles has a considerable influence on the average Nusselt number and entropy generation.

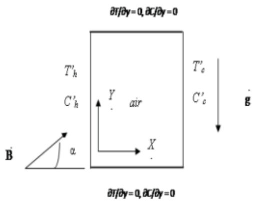
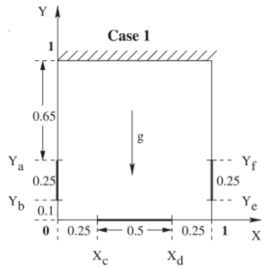
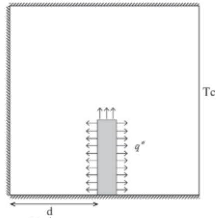
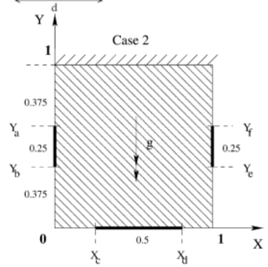
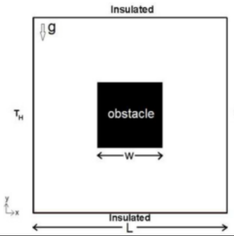
The utilisation of an inclined or tilted cavity in the investigation of natural convection has been observed to significantly influence the fluid flow and heat transfer properties within the system. The inclination angle impacts the direction and strength of the fluid motion, consequently affecting the rate of heat transfer and entropy generation within the system. A study by Said *et al.,* [61] on double-diffusive convection was observed within a two-dimensional inclined cavity filled with an air-CO_2 binary gas mixture. The study found that the buoyancy ratio (N) and the inclination angles significantly control entropy production within the system. The results showed that, except for N = –1.0, the entropy production increased substantially under turbulent regimes. Li *et al.,* [62] studied free convective heat transfer in alumina-water nanofluid in a square cavity with an inclination angle of γ relative to the horizon. The study also examined radiation heat transfer and entropy generation in the cavity. A hot circular baffle was placed in the cavity and exposed to a constant horizontal magnetic field. The study found that as the Ra increased from 10^3 to 10^6, the heat transfer rate (HTR) increased by 4.5 times, and the generated entropy also increased. The aspect ratio was found to have a significant impact on HTR and generated entropy. The Bejan number decreased with an increase in Rad and increased at low and high Rayleigh numbers while increasing the baffle size, respectively. As the Ha was amplified, the average Nu and generated entropy reduced by 45% and 35%, respectively, while the Bejan number increased. The maximum entropy was developed at a cavity inclination angle of 0°, whereas the maximum Bejan number was observed at a cavity inclination angle of 60°. The study also found that entropy generation increased with nanoparticle volume fraction and radiation parameters. Tasnim *et al.,* [63] studied the natural convective flow and heat transfer of TiO2-water nanofluid in a tilted square enclosure with solid elements that generate and conduct heat. The study found that incorporating nanofluid did not significantly impact entropy, but the base fluid (water) had lower entropy. Additionally, the thermal performance criteria (TPC) were more inadequate for water than nanofluid. The study also found that lower Hartmann numbers resulted in lower TPC but higher entropy and Nusselt numbers. Furthermore, higher Joule heating parameters at a constant Hartmann number resulted in lower TPC, entropy, and Nusselt number. Ikram *et al.,* [64] analysed the thermodynamic characteristics of a two-fluid system (Al_2O_3-water and CuO-water nanofluids) with a heat-conducting partition wall of varying surface roughness and constant geometric orientation. The research revealed that the Rayleigh number and inclination angle impact entropy generation in the inclined two-fluid system. Specifically, as the Rayleigh number increases, there is a significant improvement in entropy generation due to two factors: thermal irreversibility and flow frictional losses. Thermal irreversibility is caused by finite thermal stratification between the wall and adjacent fluid, while flow frictional losses are caused by viscous dissipation. Higher Rayleigh numbers show a more significant temperature difference between the flowing fluid and the heated wall, increasing thermal irreversibility. A higher Rayleigh number also results in stronger convection currents, intensifying shear stress between adjacent fluid layers and forming local eddy vortices, contributing to viscous dissipation. Overall, the increase in these two factors justifies increasing entropy generation with the Rayleigh number. Interestingly, the research found that the surface roughness of the partition wall had no significant effect on overall entropy generation. In contrast, the development of the inclined cavity only became visible at higher Rayleigh numbers. The study by Kefayati [65] analyzes the effects of different parameters on entropy generation and heat and mass transfer in an inclined cavity with natural convection and Bingham fluid. The parameters studied include Rayleigh number, Bingham number, Lewis number, Dufour parameter, Soret parameter, inclined angle, and Buoyancy ratio. The study shows that changes in these parameters affect entropy generation due to heat transfer, fluid friction, and mass transfer, leading to changes in the total entropy generation and average Bejan number. The study also employs the Finite Difference Lattice Boltzmann Method (FDLBM) for numerical simulations to understand the behaviour of these parameters.

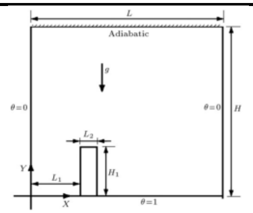
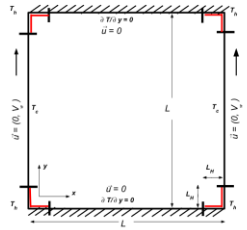
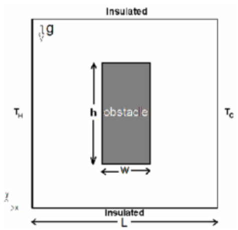
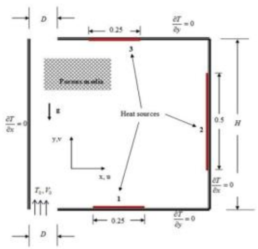
The discussion on the phenomenon of natural convection above has shown its essential role in facilitating heat transfer through fluid movement. The studies highlight the impact of different factors such as heat transfer capacity, fluid friction, inclination angles, adiabatic obstacles, Rayleigh number, Prandtl number, relaxation time, aspect ratio, and Hartmann number on thermal behaviours and fluid flow characteristics. The use of porous medium and inclined or tilted cavities in studying natural convection has also been discussed, emphasising their significant impact on the process. Overall, the discovery provides valuable insights into the thermal behaviour of fluids within different geometries and highlights the importance of considering various factors in the study of natural convection for designing efficient heat transfer equipment and minimising irreversibility within enclosures.

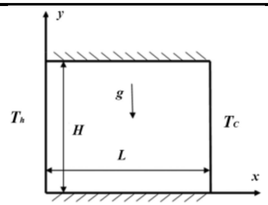
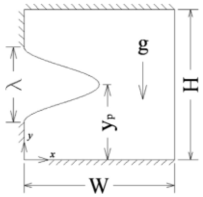
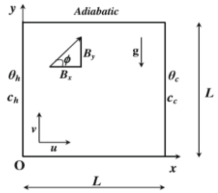
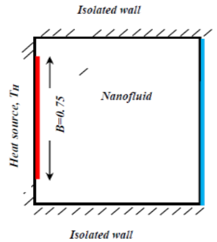
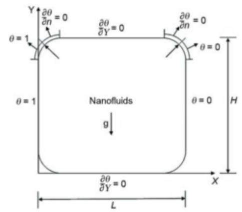
Table 1
Summary of review in rectangular cavities

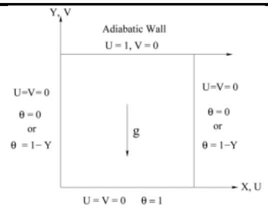
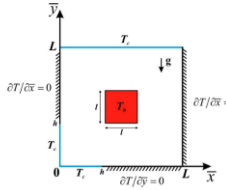
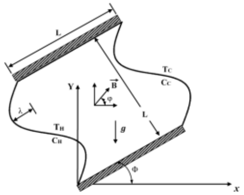
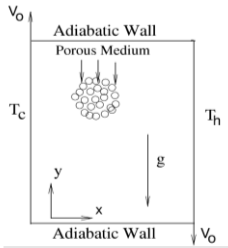
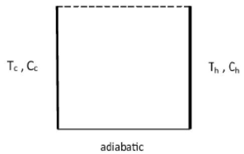
Ref.	Author (year)	Type of Convection	Geometry Description	Shape of Cavity	Type of Fluid	Results and Remarks
[10]	Shuja *et al.*,	Natural convection	Square enclosure, two sides partially opened (inlet and outlet), square heated block		Air or water	The orientation of a solid body's surfaces facing the inlet and exit of a cavity affects its heat transfer. The highest entropy is generated when the body is at the cavity centre, resulting in the lowest irreversibility ratio
[50]	Mahmud and Fraser	Natural convection	Square enclosure, vibrating sinusoidally, porous media		Fluid, Prandtl number, Pr = 1.0	The study emphasises the role of entropy generation in fluid flow and heat transfer and investigates its impact on thermal column temperature, Rayleigh number, and nanoparticle volume fraction. At high Rayleigh numbers, the heat transfer mechanism significantly increases the total entropy generation compared to the volume fraction
[7]	Erbay *et al.*,	Natural convection	Closed square enclosure, partially heated side wall		Newtonian fluid	The study determines the main irreversibility locations and their effects on entropy generation. Results suggest that energy loss initiates entropy generation in the upper corner of the heated side wall
[11]	Ilis *et al.*,	Natural convection	Square enclosure, vertical walls of the cavities are at different constant temperatures		Air with Pr = 0.70	The study analyses local entropy generation from heat transfer and fluid friction, total entropy generation and average Bejan number. Findings offer insights into entropy behaviour in different cavity geometries, useful for optimising heat transfer systems and reducing irreversibilities

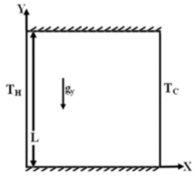
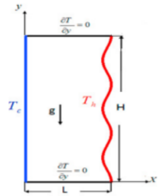
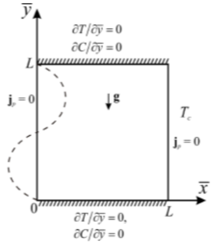
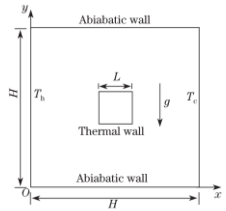
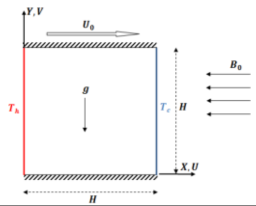
[6]	Soleimani *et al.*,	Natural convection	Closed cavity		Newtonian fluid	This study uses the Local RBF-DQ method to examine entropy generation in natural convection and its variations for different Rayleigh numbers. Results demonstrate the method's accuracy and flexibility in simulating fluid mechanics and heat transfer problems
[8]	Delavar *et al.*,	Natural convection	Closed cavity, heater (hot wall) is located on the right-side wall		Fluid (Pr = 0.71)	The study has demonstrated the significant role of entropy generation in the research. It is one of the factors that is influenced by the placement of the heater, which further affects the flow pattern and temperature fields in the enclosure
[9]	Magherbi *et al.,*	Natural convection	Closed cavity, evanescent magnetic field		Newtonian Fluid (Prandtl number of 0·71)	The research investigated the effect of an externally evanescent magnetic field on total entropy generation in a fluid enclosed in a square cavity. Entropy generation was found to be a critical factor in the investigation
[12]	Bouabid *et al.,*	Natural convection	Tilted square enclosure		Air	Analysing entropy generation in an inclined rectangular cavity filled with air is critical in determining heat transfer and fluid friction. The study demonstrates that entropy generation depends on various parameters and exhibits distinct behaviours based on the thermal Grashof number
[90]	Bouabid *et al.,*	Double diffusive natural & thermosolutal convection	Closed cavity, oriented magnetic field		Air and gas-diffusing species	Entropy generation is essential in the research as it determines the impact of heat and mass transfer, fluid friction, and magnetic effect on the system. The amount of entropy generated can provide insight into the efficiency of the system and the effectiveness of different parameters in reducing it

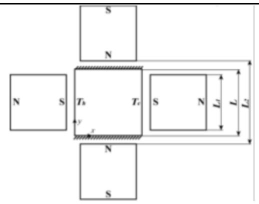
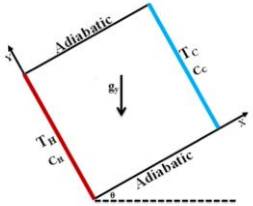
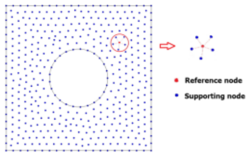
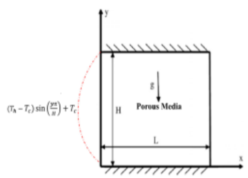
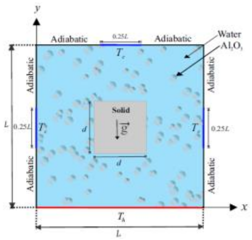
[91]	Hidouri *et al.*,	Thermosolutal convection	Closed cavity, oriented magnetic field		Binary perfect gas mixture	Entropy generation due to heat and mass transfer, fluid friction, and magnetic effect has been determined for laminar flow through numerical simulations using a Control Volume Finite-Element Method
[16]	Kaluri and Basak	Natural convection	Closed cavity, partially heated wall		Newtonian and incompressible fluid	The study looks at entropy generation in square cavities with distributed heated sources during natural convection. Heat transfer irreversibility dominates the conduction phase, while fluid friction irreversibility dominates the convection phase, except for low Prandtl number fluids based on the heating configuration
[49]	Shahi *et al.,*	Natural convection	Closed cavity, protruded heat source in the centre representing fins or heat sinks		Water and copper nanofluid	The study examines entropy generation with a protruded heat source in a square cavity. It concludes that adding copper nanoparticles to the base fluid increases heat transfer while also increasing viscous dissipation, ultimately resulting in a decrease in local entropy generation
[57]	Kaluri and Basak	Natural convection	Closed cavity, porous medium, multiple heat sources		Different types of fluids - molten metals, air / gaseous substances, aqueous solutions, olive/engine oils	The study shows how distributed heating reduces entropy generation and local entropy intensity in square cavities. It also highlights the importance of optimising thermal processes for material processing applications by considering heat transfer irreversibility and fluid friction irreversibility at different Darcy numbers
[27]	Sheikhzadeh *et al.*,	Natural convection	Closed cavity, central square obstacle, the left and right vertical walls are hot and cold		Pure water or Cu-water nanofluid	Cu-water nanofluid increases entropy generation at high Rayleigh numbers. Increasing obstacle dimensions increases entropy generation and decreases the Bejan number. At low Rayleigh numbers, increasing obstacle dimensions significantly increases the Nusselt number compared to entropy generation

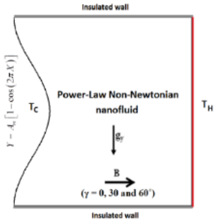
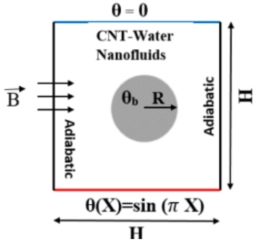
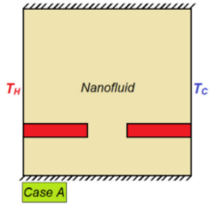
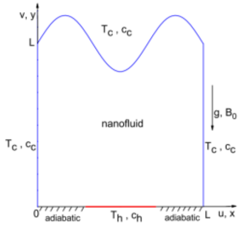
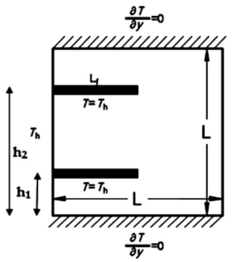
[28]	Khorasanizadeh *et al*.,	Natural convection	Square enclosure, conductive baffle embedded on bottom hot wall		Cu-water nanofluid	The study investigated the impact of the Rayleigh number, the position of the conductive baffle, and the volume fraction of nanoparticles on entropy generation and Bejan number. The findings suggest that the effect of volume fraction and position of the baffle on entropy generation and Bejan number varies with Rayleigh number, and a constant irreversibility factor cannot be assumed with the change of Ra and ϕ
[88]	Ovando-Chacon *et al*.,	Mixed convection	Closed cavity, four corners maintained at hot temperature, central parts are cold, vertical walls move upward		Incompressible fluid	This study analyses entropy generation in a heated square cavity with mixed convection. Increasing the Richardson number intensifies fluid friction inside the cavity and temperature gradients at the vertical walls and central low part, leading to more intense entropy generation
[26]	Sheikhzadeh and Nikfar	Natural convection	Closed cavity, centred adiabatic rectangular obstacle		Water or nanofluid (Cu-water)	Nanofluid increases flow strength, Nusselt number, and entropy generation while decreasing the Bejan number, especially at high Rayleigh numbers. The viscose entropy generation is more significant and dominant in total entropy generation. Maximum entropy generation occurred at an aspect ratio of 1/3 and 3, while minimum entropy generation occurred at an aspect ratio of 1 and 1/2
[72]	Maougal and Bessaih	Mixed convection	Vented cavity, bottom and upper slot for flow enters and out, the left vertical wall is adiabatic with three discrete heat sources		Fluid saturated porous medium	The study investigated a mixed flow's irreversibility and heat transfer properties in a square cavity heated by heat sources. The research findings correlated with entropy generation, Nusselt, and Bejan numbers

[23]	Alipanah *et al.*,	Natural convection	Closed cavity, insulated and impermeable horizontal walls, differentially heated vertical wall		Al_2O_3–water nanofluid	The study investigates the entropy generation of Al_2O_3–water nanofluid in a square cavity for natural convection heat transfer. It finds that adding nanoparticles increases entropy generation, with a more pronounced effect at higher Rayleigh numbers
[36]	Cho	Natural convection	Closed cavity, partially heated wavy wall		Nanofluid consisting of Al_2O_3–water	Increasing nanoparticle volume fraction increases the mean Nusselt number and decreases total entropy. Increasing the amplitude and wavelength of the wavy surface reduces the mean Nusselt number and increases the total entropy
[15]	Bouabid and Brahim	MHD double-diffusive natural convection	Square enclosure, magnetic field		Binary fluid	The investigated results showed that the different values of the involved parameters of the problem, including the Soret parameter, Thermal Grashof number, Hartmann number, and buoyancy ratio, notably influence the flow field and entropy generation
[19]	Bouchoucha and Bessaïh	Natural convection	Closed cavity, heated left vertical wall (heat source)		Base fluid and spherical solid nanoparticles (Cu, Ag, Al_2O_3 and TiO_2)	The research found that the maximum total entropy generation ratio occurs at a low Rayleigh number for different values of solid volume fraction
[29]	Salari *et al.*,	Natural convection	Square enclosure, different circular corners, and different aspect-ratio		Cu-water nanofluid	The study found that entropy generation increases with Rayleigh number, irreversibility coefficient, aspect ratio, or solid volume fraction and decreases with corner radius. Reducing Rayleigh number is the best way to minimise entropy generation

[71]	Roy *et al.*,	Mixed convection	Closed cavity, bottom wall is heated uniformly, left side wall is heated linearly, right side wall is cold		Incompressible fluid	This study examines entropy generation in mixed convection in a cavity under different thermal conditions. It studies the effects of variables like Prandtl number, Reynolds number, and Grashof number on fluid flow, heat transfer, and entropy generation, highlighting the dominance of thermal and fluid friction irreversibilities
[17]	Sheremet *et al.*,	Natural convection	Closed cavity, hot centred square block, cooled top wall and left bottom corner		Cu-water nanofluid	This study examines entropy generation in a nanofluid in a square cavity with a hot solid block. Increasing the Rayleigh number enhances convective flow and reduces the average Bejan number. Nanoparticles decrease convective flow and increase entropy generation, while a larger solid block size reduces heat transfer rate and increases entropy generation
[34]	Hussain	Double-diffusive MHD natural convection	Tilted square enclosure, wavy wall, porous medium,		Electrically conducting fluid (Pr = 0.024) saturated with a porous medium	The research investigates the entropy generation in double-diffusive MHD natural convection in a tilted sinusoidal corrugated porous enclosure. The results show that the entropy generations due to the magnetic field when the enclosure is subjected to the horizontal magnetic field are higher than the corresponding values when it is subjected to the vertical magnetic field
[85]	Pandit *et al.*,	Mixed convection	Square enclosure with porous media, vertical lids are differentially heated and moving with the same velocities		Fluid with Prandtl number 0.7	This paper compares local entropy generation distributions using velocity and temperature values. The results are consistent and accurate even with variations in critical parameters. The study shows that the fourth-order compact and Padé schemes are efficient and effective
[92]	Arbin *et al.*,	Double-Diffusive Marangoni Convection	Open cavity, both verticals' walls are differentially-heated and -salted		Newtonian Fluid	The study found that entropy generation increased as the Marangoni number increased, while heat and mass transfer patterns remained similar

[59]	Kefayati	Natural convection	Closed cavity, porosity medium, differentially heated walls		Non-Newtonian nanofluid	This study examines entropy generation in the natural convection of non-Newtonian nanofluids within a porous cavity. The addition of nanoparticles and Darcy number significantly enhances entropy generation. Power-law index and Darcy number variations affect the behaviour of entropy generation
[13]	Morsli *et al.*,	Natural convection	Closed rectangular cavity, wavy hot wall		Air with Pr = 0.70	Rectangular cavities were studied for entropy generation. Higher aspect ratios and Rayleigh numbers increased total entropy generation. Fluid friction irreversibility was the dominant factor. The study provides insights for minimising entropy in rectangular cavities
[18]	Sheremet *et al.*,	Natural convection	Closed cavity, sinusoidal temperature distribution		Water & solid nanoparticles	The study analysed heat transfer and entropy generation in a nanofluid-filled square cavity. The results showed that higher temperature amplitude and wave number increased average entropy generation. However, for low Rayleigh numbers, an increase in these parameters led to a decrease in the average Bejan number
[25]	Xiong *et al.*,	Natural convection	Closed cavity, thermal square column, the left wall is hot, the right wall is cold		SiO_2-water nanofluid	The study found that thermal column temperature affects Nusselt number and total entropy generation, while nanoparticle volume fraction has little effect on Nusselt number. Optimal entropy generation occurs at T = 0.5 for all Rayleigh number values
[39]	Oueslati and Ben-Beya	MHD natural convection	Closed cavity, uniform magnetic field		Liquid metal	The study found that enhancing the Richardson number increases entropy generation rates within the cavity, especially for relatively high values. Contrarily, the Hartmann parameter declined the heat transfer rate for all liquid metals considered

[41]	Shi *et al.*,	Natural convection	Square enclosure, four permanent magnets which generate a magnetic field		Newtonian fluid	A study investigated natural convection and entropy generation of air in a 2D square enclosure with a magnetic quadrupole field. Results indicate that increasing the magnetic force number leads to higher entropy generation and a lower average Bejan number. These findings could aid in controlling natural convection and reducing system irreversibility in engineering applications
[65]	Kefayati	Double-diffisive natural convection	Inclined cavity, left wall has higher temperature and concentration, right wall has lower temperature and concentration		Bingham fluid	The study found that various parameters significantly affect heat and mass transfer and the average Bejan number of double-diffusive natural convection of Bingham fluid in an inclined cavity. Changes in these parameters lead to variations in total entropy generation and local entropy generation due to heat transfer, fluid friction, and mass transfer
[89]	Wang *et al.*,	Mixed convection	Closed cavity, rotating circular cylinder		Air (Prandtl number is fixed at 0.71)	The findings show that total entropy generation increases with the irreversibility distribution ratio and Reynolds number while the Bejan number decreases. The region around the cylinder experiences the highest local entropy generation due to viscous solid effects and a high thermal gradient
[60]	Ashorynejad and Hoseinpour	Natural convection	Closed cavity, porous medium, temperature at the left boundary varies sinusoidally		Nanofluids consist of water as the base fluid and nanoparticles (Al_2O_3, TiO_2, and CuO)	The study found that nanofluids can reduce entropy generation and improve temperature gradient and average Nusselt number in natural convection within a porous cavity. Higher volume fractions of nanofluids are more effective, and smaller nanoparticle size decreases the heat transfer rate
[24]	Alsabery *et al.*,	Natural convection	Enclosed cavity with a concentric solid insert, hot bottom wall, and isothermal cold sources along the top and side walls		Water-based nanofluids with Al_2O_3 nanoparticles	The study discovered that the nanofluid square cavity with a solid insert and different temperature distributions generated significant entropy. The findings indicated that the inner solid's thermal conductivity ratio and size play a crucial role in enhancing heat transfer and the Bejan number within the cavity

[31]	Hatami	Natural convection	Wavy wall square enclosure, the left wavy-walled is cold and hot wall in the right flat wall		Fe_3O_4 nanoparticles with the base fluid are considered as a power-law non-Newtonian nanofluid	This study found that nanoparticle volume fraction, shape, and wavy surface amplitude affect entropy generation in a square cavity filled with non-Newtonian nanofluids. Increasing nanoparticle volume fraction decreases entropy generation, while brick-shaped nanoparticles produce the most entropy
[38]	Belhaj and Ben-Beya	MHD natural convection	Closed cavity with circular cylinder placed in the centre, heated sinusoidally from below		Water-based nanofluids containing nanoparticles of Carbone Nanotubes (CNT)	The study found that including an isothermal block and increasing the magnetic field strength significantly reduce entropy generation and improve system performance. A cold block inside the cavity decreased entropy generation by 30%. A hot block did not significantly affect average entropy generation due to the thermal gradient
[47]	Rahimi *et al.*,	Natural convection	Closed cavity, internal active fins with hot temperature		CuO–water nanofluid	The study shows how Rayleigh numbers and solid volume fractions affect entropy generation in a CuO-water nanofluid-filled square cavity. It concludes that the Rayleigh number has a direct relationship, while solid volume fraction has a reverse relationship with entropy generation
[35]	Parveen and Mahapatra	Double-diffusive natural convection	Square enclosure, wavy-walled cavity, centre heater, uniform vertical magnetic field		Water-based Al_2O_3 nanofluid	The study explores entropy generation in natural convection of Al_2O_3 nanofluid under various conditions. Results show that entropy generation is influenced by parameters such as Rayleigh and Hartmann numbers, buoyancy ratio, and nanoparticle volume fraction
[45]	Al-Kouz *et al.*,	Natural convection	Square enclosure, equipped with two solid fins at the hot wall		Air-Al_2O_3 nanofluid	The study analysed entropy generation for 2-D air-Al_2O_3 nanofluid flow in a cavity with fins. It found that Kn has an inverse effect on entropy generation, while ϕ and Ra increase it. A correlation model was proposed, and an optimisation technique was used to minimise entropy generation

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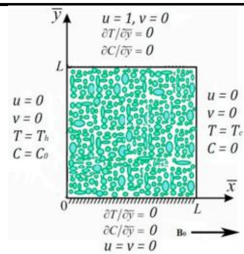
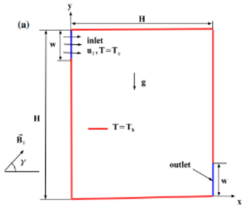
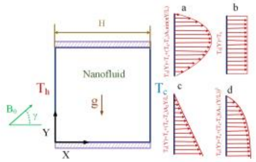
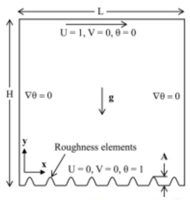
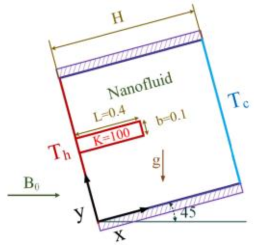
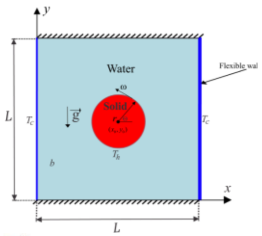
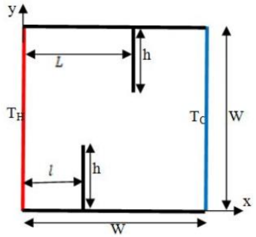
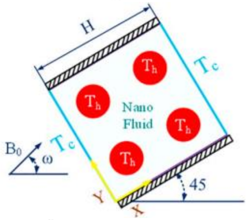
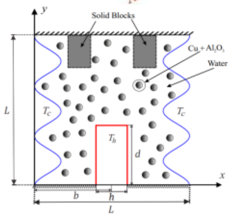
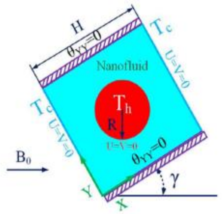
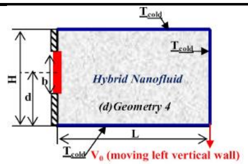
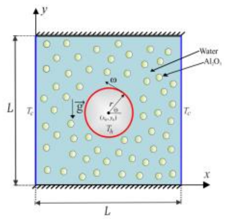
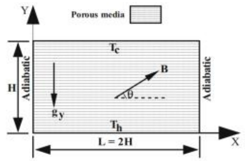
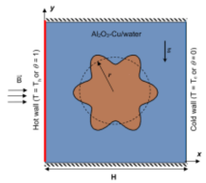
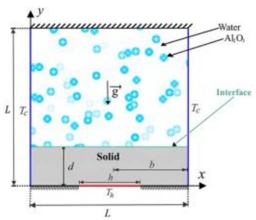
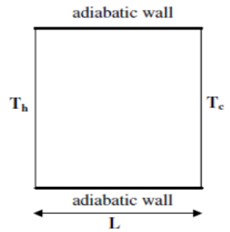
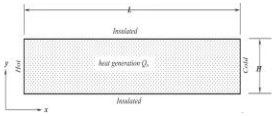
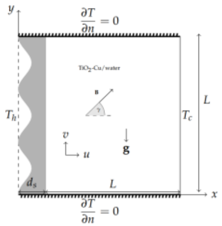
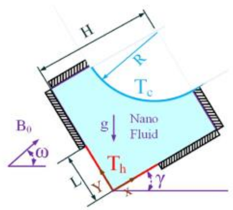
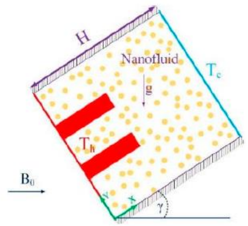
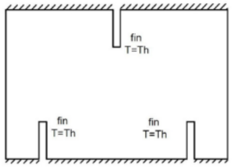
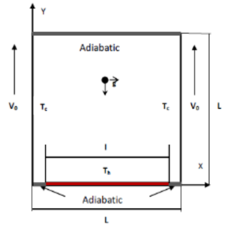
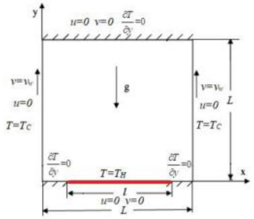
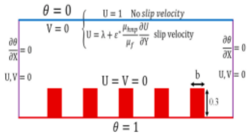
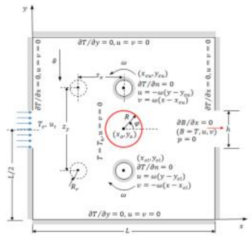
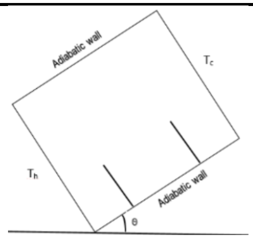
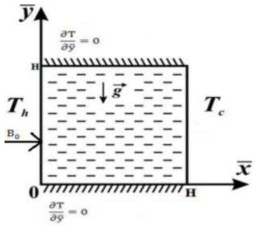
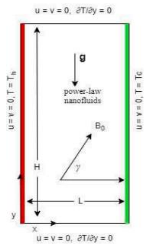
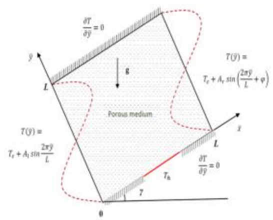
[51]	Goqo *et al.*,	Natural convection	Closed cavity, porous medium, heating on the left vertical surface		Nanofluid	The research found that entropy generation increases with increasing Rayleigh number and primarily depends on the Brownian motion parameter
[76]	Selimefendigil and Oztop	Mixed convection	Vented cavity with inlet and outlet ports, magnetic field		CuO-water nanofluid	The overall entropy generation rate first decreases and then increases with increasing Hartmann numbers and incorporating nanoparticles increases the overall entropy generation
[77]	Hajatzadeh Pordanjani *et al.*,	Mixed convection	Closed cavity, magnetic field, differentially heated walls		Water-Al_2O_3 nanofluid	The study found that increasing the Rayleigh number leads to higher temperature, Nusselt number, and total entropy generation. The study also shows that magnetic field strength, angle, and volume per cent of nanoparticles affect entropy generation and heat transfer rate
[87]	Ting *et al.*,	Mixed convection	Closed cavity, roughness element on bottom surface, top boundary moving		Water-Al_2O_3 nanofluid	The study shows that surface roughness reduces heat transfer and increases entropy generation in mixed convection of nanofluids. However, adding nanoparticles in the base fluid increases heat transfer while minimising entropy generation
[48]	Alnaqi *et al.*,	Natural convection	Diagonal square cavity with conductor fin, magnetic field and radiation		Water-based nanofluids	This study analyzes the effect of different parameters on entropy generation. The results show that increasing the Rayleigh and decreasing the Hartmann numbers lead to higher Nusselt numbers and total entropy generation.

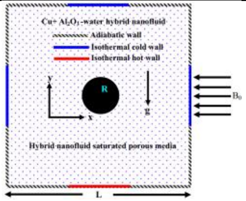
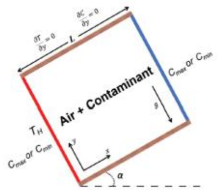
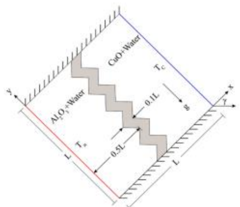
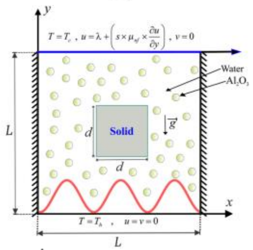
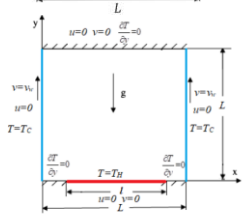
[83]	Alsabery *et al.*,	Mixed convection	Closed cavity, central rotating solid cylinder, vertical walls are cold		Viscous incompressible Newtonian fluid (water)	The study shows that the global entropy generation rate increases with the counter-clockwise rotation of the hot cylinder and lower elastic modulus. The Bejan number is low in the parametric range. Local and average Nusselt numbers increase with Rayleigh number increment, with a secondary peak in local Nusselt numbers for lower Rayleigh numbers
[4]	Baliti *et al.*,	Natural convection	Closed cavity with a heated left plate, two adiabatic obstacles fixed at the horizontal walls		Viscous fluid (Air, Prandtl number of 0.71)	The research found that entropy generation is higher at locations with large temperature gradients
[30]	Li *et al.*,	Natural convection	Oblique square enclosure, four pipes at specific distances		water/alumina nanofluid	The research found that the entropy generation decreases by 25% in the absence of radiation and by 29% in the presence of it
[32]	Alsabery *et al.*,	Natural convection	Closed cavity, wavy walls, hot-half partition, prominent isothermal heater at the bottom, and solid blocks at the top		Cu-Al_2O_3-water hybrid nanofluids	Hybrid nanofluids containing Cu-Al_2O_3-water show better heat transfer than simple nanofluids, especially at low Rayleigh numbers. Altering the cavity's geometry has different effects on entropy generation and Bejan number, and the global entropy generation for Cu-Al_2O_3-water hybrid nanofluid falls between Cu-water and Al_2O_3-water nanofluids
[62]	Li *et al.,*	Natural convection	Square enclosure, tilted cavity, constant horizontal magnetic field, circular baffle in the middle		Al_2O_3/water nanofluid	The research investigated the entropy generation in a square cavity with a tilted and magnetised Al_2O_3/water nanofluid and found that increasing the Rayleigh number amplified the entropy generation while increasing the Hartmann number reduced it

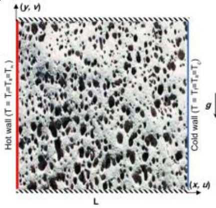
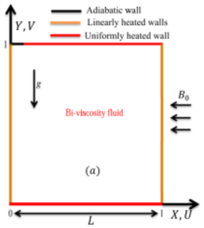
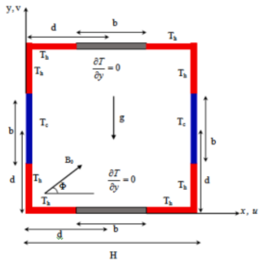
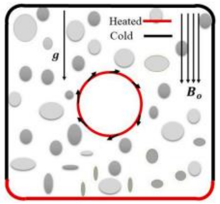
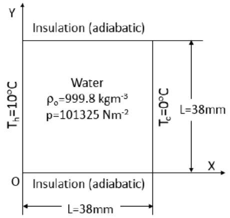
[79]	Zeghbid and Bessaih	Mixed convection	Closed cavity, heat source installed on the left vertical walls, movable wall		Al_2O_3-Cu/water hybrid nanofluid	The research finding is that entropy generation decreases with the increase of relevant parameters such as the Richardson and Reynolds numbers. Incorporating an Al_2O_3-Cu/water hybrid nanofluid in the primary fluid improves indoor cavities' high heat transfer rate
[86]	Alsabery *et al.*,	Mixed convection	Square enclosure, central rotating circular cylinder		Al_2O_3/water nanofluid	The study investigates the impact of various parameters on entropy generation in the system. It explores factors such as heat transfer irreversibility, nanofluid friction irreversibility, nanoparticle volume fraction, rotational velocity, and local Nusselt number in relation to rotating cylinder radius
[93]	Ahmed Himika *et al.,*	Rayleigh–Bénard convection	Closed cavity, porous media, magnetic field		Electrically conducting water	The research found that entropy generation occurs due to the irreversibility of the fluid friction, temperature gradient, and magnetic field effects
[43]	Tayebi and Chamkha	Natural convection	Closed cavity, wavy solid block, magnetic field, left wall is hot wall, right wall is cold wall		Al_2O_3-Cu/water hybrid nanofluid	This study examines the impact of magnetic field and thermal conductivity ratio on entropy generation in a square cavity with a conducting wavy solid block. The addition of hybrid nanoparticles and thermal conductivity ratio significantly affects heat transfer rate, entropy generation, fluid friction, magnetic effects, and average Bejan number
[21]	Ishak *et al.,*	Natural convection	Square cavity, bottom heat source, solid wall placed at the bottom, vertical walls at low temperatures		Al_2O_3-water nanofluid	This study analyses heat transfer and fluid flow in a cavity filled with Al_2O_3-water nanofluid. The results provide insights for reducing entropy generation in thermal processing applications by considering factors such as thermal conductivity and wall thickness

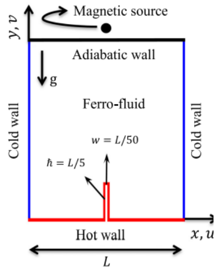
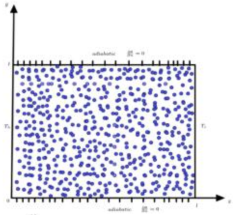
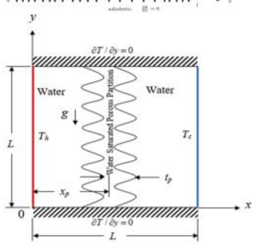
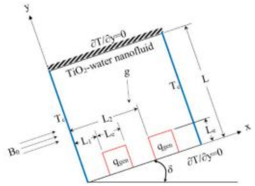
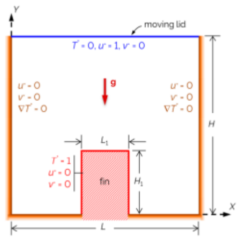
[5]	Boudebous and Ferroudj	Unsteady natural convection	Closed cavity, vertical sides maintained at different temperatures		Fluid (based on Prandtl number)	The researchers proposed a new approach to calculate entropy generation for unsteady natural convection in a square cavity with vertical sides. This approach provides direct access to the entropy generation value by considering the exact values of thermophysical properties of the fluid
[14]	El-Maghlany	Natural convection	Closed rectangular cavity, differentially heated walls		Water (Pr = 6.2)	The study analysed enclosures with different aspect ratios and heat generation rates in natural convection heat transfer mode. The numerical results were used to select a suitable aspect ratio of the cooling enclosure for minimum entropy generation
[33]	Geridonmez and Oztop	Conjugate natural convection	Closed cavity, solid block attached to the left wall, uniform inclined magnetic field		TiO_2-Cu nanoparticles with base fluid water	The study investigated the two-dimensional, time-independent conjugate natural convection flow and entropy generation in a uniform inclined magnetic field. The total entropy generation increases with the increase in Ra and kr, but it decreases with Ha values
[37]	Zhang *et al.*,	Natural convection	Inclined enclosure, oblique magnetic field, L-shaped heat source, low temperature quarter-circular arc-shaped fin		Steady, laminar, incompressible, and Newtonian Al_2O_3-water nanofluid	The study found that a perpendicular magnetic field at high Rayleigh numbers resulted in the highest entropy generation rates. The Bejan number was at its minimum for a 15° magnetic field at these Rayleigh numbers. Magnetic field variation can cause a 34% change in entropy generation
[46]	Khetib *et al.*,	Natural convection	Inclined enclosure, two fins with the same wall temperature		Al_2O_3-water nanofluid	The research found that increasing the Hartmann number from 0 to 40 reduced entropy generation by 33.8%

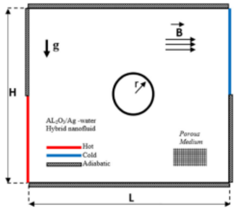
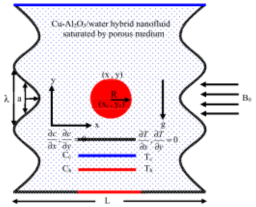
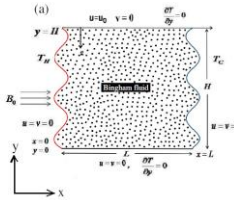
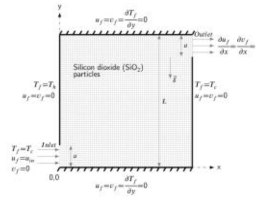
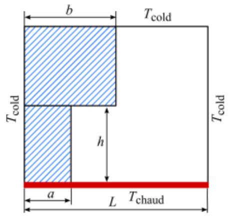
[53]	Sadeghi *et al.*,	Natural convection	Closed cavity, three fins attached to the insulated wall, and porous media		CuO-water nanoliquid	Nanoparticles decrease entropy while a magnetic field increases it. Entropy is directly related to the Grashof number and inversely related to volume fraction. This highlights the significance of entropy generation in energy system optimisation
[66]	Ferroudj *et al.*,	Mixed convection	Closed cavity, middle of the lower wall is heated, side walls move upwardly with a specified velocity		Fluid (Prandtl number, Pr = 0.0212, 0.71 and 6.35)	The study found that both the irreversibility distribution ratio and Prandtl number have a significant effect on the total entropy generation, with an increase in both resulting in an increase in total entropy generation
[67]	Ferroudj *et al.*,	Mixed convection	Closed cavity, partially heated from below with moving cooled vertical sidewalls.		Mercury (Pr = 0.0251), air (Pr = 0.7296) and water (Pr = 6.263)	The study found that the Prandtl number significantly impacts the entropy generation, with the total average entropy generation being significantly higher for mercury and water compared to air. The highest average Nusselt numbers were observed for water, while mercury had the lowest
[69]	El-Shorbagy *et al.*,	Mixed convection	Vertical cavity with a size of L × 3L, heat sink with five fins		Hybrid nanofluid (HNFs) of $Al_2O_3/CuO–H_2O$	The study found that dispersing a 3% volume fraction of hybrid nanoparticles (NPs) at a 1:1 ratio to the water resulted in an increase of 6.59% in entropy generation (S_{gen})
[81]	Hamzah *et al.*,	Mixed convection	Vented cavity, heated cylinder placed between two oppositely rotating cylinders		Newtonian incompressible fluid	The results indicate that the spatial location and rotational speed of the rotating cylinders have a significant influence on the heat transfer and entropy generation within the cavity

[3]	Oyewola *et al*.,	Natural convection	Closed cavity at different inclination angles, two adiabatic obstacles inside the cavity, left wall (heated) and right wall (cooled)		Air with Prandtl number of 0.71	The study found that heat transfer and fluid friction irreversibilities, temperature gradient, and irreversibility distribution influence entropy generation in a cavity. Adiabatic obstacles influence thermal behaviour and entropy generation. No specific quantitative results or trends were provided
[20]	Reddy *et al*.,	Natural convection	Closed square chamber, magnetic field in x-axis direction		Water – MWCNTs-based radiative nanofluid	Adding MWCNTs to the base fluid increases the total entropy generation and decreases with lower heat transport and vortex velocity
[42]	Rahman *et al*.,	Natural convection	Closed rectangular cavity, differentially heated walls, uniform magnetic field		Cu-water nanofluid	The study analysed entropy generation in a rectangular enclosure with non-Newtonian nanofluid, finding that the Nusselt number increased with magnetic angle. Still, the Bejan number varied with the Rayleigh number and power-law index. The study offers insights into nanofluid entropy generation under magnetic fields
[58]	Cimpean and Pop	Natural convection	Inclined closed cavity, sinusoidal temperature distribution on the side walls, porous medium		Base fluid and nanoparticles	This study explores entropy generation in a square-inclined cavity filled with a porous media saturated by a nanofluid. The results demonstrate significant changes in fluid flow, heat and mass transfer characteristics, and entropy generation under different conditions, with potential applications in electronic device optimisation and cooling processes

[55]	Akhter *et al.*,	Natural convection	Square enclosure, partially heated at the bottom, heat conductive circular solid cylinder at the centre, partially cooled at vertical and top walls		Cu-Al_2O_3/water hybrid nanofluid	The study found that local entropy generation is strongly influenced by the buoyancy parameter, magnetic field strength, amount of hybrid nanoparticles, and cavity permeability
[61]	Said *et al.*,	Double-diffusive natural convection	Closed and inclined cavity, left and right vertical walls are differentially heated, turbulent regime		Air-CO_2 binary gas mixture	The study analysed and discussed the effect of buoyancy ratio (N), thermal Rayleigh number (Ra), and inclination angle (α) on entropy generation rate and found that these parameters considerably affect both the heat and mass transfer performances of the system
[64]	Ikram *et al.*,	Conjugate natural convection	Square enclosure, heat conducting partition wall of variable surface roughness		Al_2O_3-water and CuO-water nanofluids	The study examines the effect of system inclination on thermodynamic characteristics and finds that the average entropy generation is significantly affected by the change of Rayleigh number and inclination angle, being highest at a critical angle of system inclination for each Rayleigh number
[80]	Alsabery *et al.,*	Mixed convection	Square enclosure, wavy isothermal heater, solid inner body installed in the centre		Aluminium oxide (Al_2O_3) nanofluid	The study found that partial slip is more effective in reducing entropy generation when friction irreversibilities govern the cavity. The flow circulation changes the trend in the middle of the cavity around the solid block, leading to a decrease in isentropic lines at the dense sections
[84]	Ferroudj *et al.*,	Mixed convection	Closed cavity, heat source is located at the centre of the bottom wall, side walls moving		Water (different Prandtl numbers)	The research investigated entropy generation for mixed convection inside a water-filled square cavity and found that the average entropy generation decreases with an increase in both Richardson and Prandtl numbers

[56]	Tayebi	Double-diffusive natural convection	Square enclosure, porous media		Fluid-saturated porous structure	This study examines the impact of local thermal non-equilibrium (LTNE) on heat exchange and entropy generation in porous media. As the system shifts from LTNE to local thermal equilibrium, thermal irreversibility in both phases becomes more similar
[78]	Iftikhar *et al.*,	Mixed convective	Closed cavity, linearly and uniformly heated wall, magnetic field		Non-Newtonian fluid (bi-viscosity fluid)	The study analysed entropy generation in the mixed convective flow of a non-Newtonian fluid in a square cavity. It found that increasing the bi-viscosity parameter increases fluid velocity, energy transfer rate, and entropy generation. However, increasing the Hartmann number decreases velocity and temperature while increasing entropy generation
[44]	Reddy *et al.*,	Natural convection	Closed cavity, isotropic porous medium, left and right sides are cooled, remaining portions are hot, inclined magnetic field		Cu-water nanofluid	The study found that increasing nanoparticle volume fraction reduces global entropy generation and enhances the Darcy numbers. The average Nusselt number decreases with the increase of volume fraction in the Hartmann number. Moreover, the total entropy generation also increases with the increase in the volume fraction of the nanoparticles
[82]	Rehman *et al.*,	Mixed convection	Fillet square cavity, rotating heated cylinder, magnetic fields, bottom wall is heated		Magnetised ferric oxide-water nanofluid (ferrofluid)	The study on magnetised ferric oxide-water nanofluid in a fillet square cavity shows that increasing the Darcy number and porosity leads to higher entropy generation. Meanwhile, a higher volume fraction of ferro-particles and their angular velocity result in a rise in the average Nusselt number and a decrease in both viscous and thermal entropy
[2]	Luan *et al.*,	Natural convection	Square enclosure (38 mm)		Water at a pressure of 101325 Nm^{2-}	The research investigates the entropy generation and heat transfer of water density inversion region in a square cavity with different relative positions of hot and cold walls. The results indicate that the Nusselt number of case 1 is higher than cases 2 and 3, and entropy generation by fluid friction is negligible

[40]	Iftikhar *et al.*,	Natural convection	Closed cavity, heated bottom surface with heated fin attached to the bottom surface		Ferrofluid	Higher magnetic numbers resulted in lower entropy generation, while increasing ferroparticle concentrations led to the opposite effect. Non-uniform magnetic fields suspended convection flow and contributed to heat transfer entropy generation. In general, higher magnetic numbers and lower ferroparticle concentrations reduced entropy generation
[52]	Charreh *et al.*,	Transient natural convection	Closed cavity, porous medium		Non-Darcy porous media	The simulation results suggest that the top right wall and base of the heated wall are where entropy is most generated. Additionally, the study found that as the Forschheimer resistance increases, the flow rate, heat transfer, and entropy production reduce
[54]	Javed *et al.*,	Natural convection	Square enclosure, corrugated porous partition, left and right walls are differentially heated		Water and a water-saturated	Entropy analysis improves thermal design, and porous partition boosts heat transfer but increases entropy. Lower partition thickness, and higher amplitude/frequency enhance heat transfer. Porous partition increases average Nusselt number by up to 565% at higher Rayleigh numbers
[63]	Tasnim *et al.*,	MHD conjugate natural convection	Tilted square enclosure, square shape heater at the bottom wall, constant magnetic field		TiO_2-water nanofluid	Higher Rayleigh numbers and nanoparticle volume fractions lead to more entropy generation in both configurations. The configuration with closer heat-generating elements exhibits higher entropy generation. Nanofluids in natural convective flow generate higher entropy, especially with closely positioned heat-generating elements
[68]	Mountrichas *et al.*,	Mixed convection	Square enclosure, moving top wall, and a rectangular fin at the bottom		CuO-water nanofluid	The study found that using nanofluids instead of conventional heat transfer fluids can minimise entropy generation while improving heat transfer rates

[73]	Abdelhak *et al.*,	Mixed convection	Closed cavity with a cylinder installed inside, porous medium, hot wall (left)		Al_2O_3-Ag/water (hybrid nanofluid)	Applying a magnetic field can effectively adjust the heat transfer rate. The study found that entropy generation improves, with the third case being an exception. The third cavity produces the most entropy with a higher Rayleigh number, average Nusselt number, and entropy production
[74]	Akhter *et al.*,	Hydromagnetic double-diffusive mixed convection	Wavy enclosure, porous medium, solid cylindrical rotating heat source, partially heated bottom wall		Cu–Al_2O_3/water hybrid nanofluid	The study found that the entropy generation components were affected significantly by higher values of physical parameters. The Bejan number was found to decline for all influential parameters studied
[75]	Hossain *et al.*,	MHD Mixed convection	Wavy enclosure		Bingham Nanofluid (Al_2O_3-water nanofluids)	It was found that the total entropy generation $(E_s)_t$ is reduced by raising the Hartmann number (Ha), but $(E_s)_t$ rises with the augmentation of nanoparticle volume fraction (ϕ) and Reynolds number (Re)
[70]	Çiçek and Baytaş	Mixed convection	Vented square cavity, inlet at bottom left, outlet at top right		Silicon dioxide (SiO_2) particles	The study demonstrates that the presence of particles leads to increased entropy generation due to heat transfer exchange between particles and fluid, as well as frictional forces, highlighting the importance of considering irreversibilities stemming from particle presence in thermal system design and optimisation
[22]	Bouchoucha *et al.*,	Natural convection	Closed cavity, vertical and top horizontal walls are cold, bottom wall is hot, left body wall filled with nanofluid		Al_2O_3/water nanofluid	Adding nanoparticles in a nano-fluid-filled enclosure with a stepped wall reduces entropy generation and improves heat transfer by reducing temperature gradients. It also increases friction losses due to increased nano-fluid viscosity, leading to higher entropy generation, except when the Rayleigh number is 104

4. Entropy generation in Mixed Convective Heat Transfer

Mixed convection refers to fluid flow resulting from the combination of buoyancy forces and forced flow. This phenomenon occurs in various scenarios, including heating and cooling systems, industrial processes, and electronic devices. In the following discussion, several studies are discussed, which delve into fluid flow, heat transfer, and entropy generation in mixed convection scenarios. The authors analyse how variables like Prandtl and Richardson numbers, as well as solid nanoparticle concentration, can impact heat transfer and entropy generation. The implications of these findings are far-reaching, with potential applications in areas such as energy conversion and storage, electronic devices, and improving the efficiency of solar collectors and nuclear power plants.

Ferroudj *et al.,* [66] conducted a numerical study on entropy generation in laminar mixed convection within a square fluid-filled cavity. The preliminary results show that entropy creation increases with an increase in the Prandtl number due to a rise in velocity gradients and the irreversibility distribution ratio. An increase in the Prandtl number leads to total entropy mainly due to temperature gradients, as confirmed by the values of the Bejan number, which are more significant than 0.5. Additionally, the irreversibility distribution ratio on the entropy generation in the cavity affects the Prandtl number of 0.0212, 0.71, and 6.35. Another study by Ferroudj *et al.,* [67] has delved into fluid flow, heat transfer, and entropy generation in a water-filled square cavity under mixed convection. The study found that the flow patterns and thermal field exhibit significant changes as the Richardson and Prandtl numbers increase. Interestingly, the results demonstrate that, regardless of the Prandtl number, the heat transfer and entropy generation patterns are symmetric for low Ri. However, these patterns become more complex and asymmetric with increasing Ri. Additionally, the study found that the entropy production decreases as the Richardson and Prandtl numbers increase. Notably, the average Bejan number is consistently close to one, indicating that the contribution of thermal irreversibility to total entropy generation is much more significant than fluid friction irreversibility. Mountrichas *et al.,* [68] conducted a study analysing the impact of a nanofluid on heat transfer and entropy generation within a confined cavity. The findings revealed that the type of entropy generation mode present was contingent upon the geometric makeup of the rectangular fin located at the cavity's base. In cases where the aspect ratio was higher, the inertial forces between particles were the primary cause of entropy generation. Understanding the root cause of entropy generation is crucial for minimising energy waste, thereby increasing system efficiency and reducing energy consumption. The results showed that CuO-nanoparticle concentration could improve conduction and convection heat transfer while lowering entropy generation. This finding has promising implications for various applications, including electronic devices, energy conversion and storage, and improving efficiency in solar collectors and nuclear power plants. A study by El-Shorbagy *et al.,* [69] utilised numerical simulations to investigate the mixed convection of a hybrid nanofluid (HNFs) consisting of Al_2O_3/CuO-H_2O on a primary heat sink (HS). The findings revealed that incorporating a 3% volume fraction of hybrid nanoparticles (NPs) at a 1:1 ratio with water significantly boosted heat transfer and entropy generation (S_{gen}) by 2.78% and 6.59%, respectively. Additionally, it was demonstrated that the use of CuO NPs had a more significant impact on enhancing heat transfer than Al_2O_3 NPs. Çiçek and Baytaş [70] discuss a numerical investigation of mixed convection and entropy generation in a vented square cavity, focusing on particle behaviours and transportation. The research emphasises the importance of minimising entropy generation (EGM) in thermal system design and optimisation. It also explores the impact of mixed convection on particle deposition and removal and the forces that act on these particles. The study reveals that the presence of particles leads to an increase in entropy generation due to heat transfer and frictional forces. This highlights the crucial role of considering irreversibilities caused by particles when designing and optimising thermal systems to achieve optimal efficiency. Roy *et al.*, [71] present a detailed entropy generation analysis during mixed convection in a square cavity under various thermal boundary conditions. It investigates the impact of parameters such as Prandtl number, Reynolds number, and Grashof number on fluid flow, heat transfer, and entropy generation, revealing the dominance of thermal and fluid friction irreversibilities within the system. The study also examines the distribution of streamlines, local entropy generation due to fluid friction, isotherms, entropy generation due to heat transfer, total entropy generation maps, and Bejan number contours for different cases, providing insights into the complex interplay between fluid flow, heat transfer, and entropy generation under varying parameters.

Maougal and Bessaih [72] conducted a numerical investigation on the heat transfer properties and irreversibility of a steady laminar mixed flow in a square cavity. The cavity was filled with a saturated porous medium and heated by discrete heat sources. The findings showed that increasing the Reynolds and Prandtl numbers improved heat transfer and led to lower entropy production. Introducing the porous medium resulted in even better heat transfer and lower entropy production, which aligns with the Entropy Generation Minimization (EGM) principle. The study also revealed a relationship between Da, Re, Pr, Bejan number, and entropy generation rate. The study observed a positive correlation between the entropy generation rate and the irreversibility distribution ratio. Additionally, it identified an aspect ratio at which both entropy generation and heat transfer reached their maximum values. The study concluded that the physical system must be stable for this value, and the EGM principle does not apply to this case. Abdelhak *et al.,* [73] studied heat exchanges and general entropy within a square-shaped cavity. By altering the temperature of the walls in four cases filled with a hybrid nano liquid (Al_2O_3-Ag/water) and installing a cylinder within, they measured the impact of Rayleigh number (Ra), Hartman number (Ha), and Darcy number (Da) on heat transmission and entropy production. Results showed that the volume concentration of solid nanoparticles had minimal impact on entropy generation and heat transfer, especially at high Rayleigh numbers (Ra). Improved entropy generation and thermal performance were observed with higher Ra and solid volume fraction (ϕ) values but decreased with increasing Ha. The third cavity had the best entropy production, followed by the second. The fourth cavity continued to produce poor and unstimulated entropy. Akhter *et al.,* [74] studied hydromagnetic double-diffusive mixed convection in a wavy porous cavity filled with a hybrid nanofluid with a rotating heat source. The study observed a significant increase in the strength of flow circulation, heat transfer, and particle transmission within the cavity with increasing cylinder rotating velocity and Darcy number. The flow velocity, heat transfer, and particle transmission significantly increase with each increment in the porosity of the cavity. The study revealed that the patterns of streamlined circulation, isotherms, isoconcentration, and isentropic contour distributions exhibited remarkable similarity across all physical parameters. Moreover, fluid flow velocity, heat transferring, and particle moving rate declined remarkably with increasing magnetic field strength. The optimum heat transfer rate for maximum hybrid nanoparticles amalgamating in the base fluid is recorded. Heat transfer irreversibility becomes dominant in entropy generation at lower values of rotation velocity of the cylindrical solid heat source, Darcy number, cavity porosity, and Hartmann number than that of fluid friction irreversibly.

Hossain *et al.,* [75] examine the effects of magneto-hydrodynamic (MHD) mixed convection flow and entropy formation of non-Newtonian Bingham fluid in a lid-driven wavy square cavity filled with nanofluid. The results indicate that the overall entropy production rises significantly as the Reynolds number (Re) increases. Specifically, when Re increases from 10 to 100, 100 to 200, and 200 to 400 at Ha = 10 and ϕ = 0.04, the overall entropy production increases by 61.85%, 30.51%, and 31.93%, respectively. The total entropy production decreases as Hartmann number (Ha) increases, reducing 7.9%, 8.2%, and 8.3% as Ha grows from 0 to 20. However, when ϕ = 0, the entropy production caused by the magnetic field is zero. On the other hand, the overall entropy production increases with an additional 2% and 4% of nanofluid in the system. A study by Selimefendigil and Oztop [76] explored the behaviour of CuO-water nanofluid in a cavity with inlet and outlet ports under the influence of a uniform inclined magnetic field. The study found that different parts of the computational domain contribute differently to the overall entropy generation, depending on changes in Hartmann number. Interestingly, the overall entropy generation decreases and increases as the Hartmann number changes from Ha = 0 to Ha = 50. While there were only slight changes in the entropy generation rate as the magnetic field inclination angle varied, the entropy generation rate did increase with higher solid particle volume fraction due to the increased effects of fluid friction and heat transfer irreversibility. Hajatzadeh Pordanjani *et al.,* [77] studied entropy generation in a square cavity filled with water-Al_2O_3 nanofluid and subjected to a magnetic field. The study indicates that increasing the Rayleigh number leads to higher temperature, Nusselt number, and total entropy generation, while the Bejan number decreases. The study also reveals that the strength and angle of the magnetic field and the volume per cent of nanoparticles impact entropy generation and heat transfer rate. Additionally, the researchers discuss the influence of the Hartmann number on entropy generation, showing that it affects the velocity gradient and heat transfer rate, ultimately impacting total entropy generation. The study also highlights the importance of thermal entropy in total entropy generation and its significant role in areas with high heat transfer rates. Furthermore, the research demonstrates the relationship between entropy generation, fluid friction entropy, and magnetic field entropy and how changes in these parameters affect total entropy generation. Iftikhar *et al.*, [78] use the Galerkin finite element method to analyse energy transport and entropy generation due to the influence of various flow control parameters such as bi-viscosity, Prandtl, Richardson, Reynolds, and Grashof numbers. The results show that increasing the bi-viscosity parameter increases fluid velocity, energy transfer rate, and entropy generation. The study also explores the influences of magnetic field and Richardson number on the flow and entropy generation. The findings provide insights into the thermal performance of the system and the dominant factors affecting entropy generation.

In a study by Zeghbid and Bessaih [79], square cavities were filled with Al_2O_3-Cu/water hybrid nanofluid and subjected to heat sources on the left vertical wall. The researchers investigated various boundary conditions and analysed the second law of energy efficiency based on thermodynamics. The findings suggest that modifications to the boundary conditions, Richardson, and Reynolds numbers can impact the system's heat transfer rate and total entropy generation. Interestingly, the addition of hybrid nanoparticles seemed to enhance the efficiency of the thermal system by decreasing entropy generation and increasing the heat transfer rate. Alsabery *et al.,* [80] investigated the heat transfer and fluid flow of Al_2O_3/water nanofluid inside a square cavity with a solid circular cylinder. The results showed that the nanoparticle loading and the angular rotational velocity for upper radius values of the rotating cylinder influence the global entropy generation. It was found that the stationary cylinder has dominant heat transfer irreversibility, while the generated entropy is mainly caused by nanofluid friction irreversibility for a rotating cylinder. Hamzah *et al.*, [81] investigate the effect of entropy generation in the context of hydrothermal behaviour and heat transfer within a vented cavity containing a centrally heated cylinder between two oppositely rotating cylinders. The study focuses on the impact of various parameters such as Reynolds number, Grashof number, and angular rotational speeds on entropy generation. The results demonstrate that changing the position of counter-rotating cylinders significantly influences hydrothermal behaviour and entropy generation within the cavity. The study also highlights the influence of the Reynolds number on entropy generation, with the optimal thermal performance criterion achieved at low Reynolds numbers over a range of angular rotational speeds. Additionally, the study emphasises the role of entropy generation in evaluating the system's thermal performance under the given conditions. Rehman *et al*., [82] investigated the behaviour of a magnetised ferric oxide-water nanofluid in a fillet square cavity, mainly focusing on the impact of various parameters such as Hartmann number, angular velocity, and volume fraction on the flow behaviour and entropy generation. The findings indicate that entropy generation increases with the Darcy number and is correlated with the porosity of the nanofluids. The study also reveals that increasing the volume fraction of ferro-particles and their angular velocity raises the average Nusselt number and lowers both viscous and thermal entropy. Additionally, the impact of entropy on the average Nusselt number and the behaviour of magnetic irreversibility about the Hartmann number and volume fraction of ferrofluid particles are analysed. Alsabery *et al*., [83] discuss the fluid-structure interaction analysis of entropy generation and mixed convection inside a cavity with a flexible right wall and a heated rotating cylinder. The results show that the highest values of the average Nusselt number are obtained for the counter-clockwise rotation of the hot cylinder and when the flexible wall is moving with a lower elastic modulus. The global entropy generation rate rises with the counter-clockwise rotation of the hot cylinder and for lower adjustable modulus values. Still, the Bejan number achieves very low values in the parametric range of interest. Local and average Nusselt numbers augment with Rayleigh number increment, and a secondary peak in the local Nusselt number is established for lower values of Rayleigh number.

A study by Ferroudj *et al*., [84] explored the effects of mixed convection, heat transfer, and entropy generation in a square cavity partially heated from below with a moving cooled vertical sidewall. The study revealed that the Prandtl number significantly influenced the velocity and temperature fields, which affected the entropy generation. The study also found that the dominant irreversibilities were caused by heat transfer. In contrast, fluid friction irreversibilities played a minor role in the overall entropy generation, regardless of the Prandtl and Richardson numbers. The research showed that the bottom cavity wall was the most crucial location for entropy generation, with peak values observed at the lower left or right corner (x=0; x=1) and both ends of the heat source (x=0.1; x=0.9). Interestingly, the average total entropy generation decreased with an increase in the Richardson number. Moreover, the research suggested that mercury (Pr=0.0251) and water (Pr=6.263) were the best options for heat transfer processes, as they had the highest entropy generation compared to air (Pr=0.7296). Pandit *et al*., [85] examined the entropy generation analysis in mixed convective flow within a two-sided lid-driven enclosure filled with fluid-saturated porous medium. The findings revealed that case I for Ri = 100 exhibited the lowest entropy generation for local heat transfer and fluid friction among all three cases analysed. A study by Alsabery *et al*., [86] examined the impact of partial slip on the upper surface of a lid-driven wavy cavity containing an internal conductive solid body filled with aluminium oxide nanofluid. The study found that partial slip is more effective when friction irreversibilities govern the cavity. The global entropy generation (GEG) was found to consist of both friction and heat transfer irreversibilities. Additionally, the heated wavy wall increased local entropy generation due to the high-temperature gradient and small thickness of the thermal boundary layer on the crests of the undulations. Ting *et al*., [87] examine how factors like roughness elements, nanoparticle concentrations, Reynolds numbers, and Rayleigh numbers affect entropy generation. The study concludes that roughness elements and nanoparticle concentrations significantly impact entropy generation and Bejan number. Additionally, increasing Reynolds and Rayleigh numbers enhances the average Nusselt number and total entropy generation but reduces the average Bejan number. Ovando-Chacon *et al*., [88] discuss a numerical study of entropy generation due to mixed convection in a two-dimensional square cavity with heated corners. The findings show that increasing the Richardson number intensifies entropy generation by fluid friction inside the cavity due to vortex formation at the central part of the cavity. The entropy generation by heat transfer becomes more intense at the vertical walls and the main low part of the cavity due to stronger temperature gradients in these regions. The study also includes mesh convergence analysis and velocity profiles at different positions within the cavity. The study conducted by Wang *et al.*, [89] analyses entropy generation in the context of mixed convection flow induced by a rotating circular cylinder in a square enclosure. The study investigates the impact of several parameters, such as the Reynolds number, Richardson number, and irreversibility distribution ratio, on entropy generation. The study observes that the total entropy generation increases with the irreversibility distribution ratio and Reynolds number, while the Bejan number decreases with these parameters. The study also highlights the influence of flow patterns on entropy generation due to heat transfer and fluid friction. The results indicate that the maximum local entropy generation occurs around the rotating cylinder, with a high thermal gradient and strong viscous effects. Moreover, the distribution of isotherms and flow patterns affected by the Richardson and Reynolds numbers significantly impact entropy generation and Bejan numbers.

The information presented above can be used to better understand how fluids flow and heat are transferred in different mixed convection scenarios. This understanding can help researchers and engineers design more efficient heating and cooling systems, electronic devices, and industrial processes by optimising heat transfer and reducing energy waste caused by entropy generation. The studies' findings can also be applied to develop new materials and technologies to enhance the efficiency of solar collectors and nuclear power plants. Ultimately, this information can significantly improve the energy efficiency of various systems and processes.

5. Entropy Generation in Other Convective Heat Transfer

Entropy generation is a topic of study in various types of convection, apart from natural and mixed convection. However, the study of entropy generation using other types of convection, such as thermosolutal or Marangoni, has received less attention from researchers. The following discussion will discuss the importance of studying heat transfer using different types of convection, and some recent studies in this field will be highlighted.

A numerical study by Bouabid *et al.,* [90] analysed the entropy generation in natural and thermosolutal convection in a square air-filled cavity exposed to an inclined magnetic field. The study found that total entropy generation increases at high thermal Grashof number and buoyancy ratio in the cooperative case. At a low thermal Grashof number, entropy generation increases initially, reaches a peak, and then asymptotically decreases. However, at a high thermal Grashof number, entropy generation oscillates towards a steady state value. The impact of heat transfer on entropy generation is the most significant, followed by mass transfer. Additionally, the magnetic effect is stronger than the friction effect. A study by Hidouri *et al.,* [91] examined entropy generation in a square cavity during thermosolutal convection, considering magnetic and radiation effects. The results showed that increasing the Hartmann and radiation parameters decreased the Nusselt number, while the magnetic effect acted as a resistance to the flow. The entropy generation grew with radiation but fell with the Hartmann number. The minimum total entropy generation was observed when $N = -1$. Additionally, the maximum Nusselt and Sherwood numbers and total entropy generation were kept at an inclination angle of 80 degrees. The presence of radiation resulted in more vertical and parallel isothermal lines and a monocellular flow structure.

In another study, Arbin *et al.,* [92] conducted a numerical study on double-diffusive Marangoni convection in an open-top square cavity filled with aqueous solution. In this study, both vertical walls were differentially heated and salted. The effect of surface tension was analysed as it influenced the fluid path, temperature, concentration, and entropy generation. The study found that the irreversibility of entropy generation increases at a higher value of Ma, as indicated by the Bejan number. Ahmed Himika *et al.,* [93] analysed the impact of various inclination angles of an applied magnetic field on Rayleigh-Bénard convection in a porous medium. The researchers found that the influence of the Hartmann number is inversely related to several factors, including local entropy generation from fluid friction (SF), local entropy generation from temperature gradient (ST), local entropy (SS), and local Bejan number (Be). Conversely, the Hartmann number's impact is directly proportional to local entropy generation resulting from the magnetic field effect (SM).

To summarise, researching entropy generation in different forms of convection is crucial when studying heat transfer. The article concludes that comprehending entropy generation in various types of convection can aid in creating energy systems that are more effective and environmentally friendly.

6. Recommendations for Future Studies

Based on the information provided in the document, there are several potential areas for future research related to entropy generation in convective heat transfer. Here are some suggestions

i. Investigation of different types of convection: While natural and mixed convection have been extensively studied, there is relatively little research on other forms of convection, such as thermosolutal and Marangoni convection. Future studies can focus on understanding the entropy generation and heat transfer characteristics in these types of convection and their impact on energy systems.
ii. Exploration of complex geometries: The document mentions using wavy walls, inclined or tilted cavities, and cavities with obstacles or fins in natural convection studies. Further research can delve into the effects of these complex geometries on fluid flow, heat transfer, and entropy generation. Understanding the behaviour of fluids in such geometries can provide insights into optimising heat transfer equipment and improving energy system efficiency.
iii. Investigation of nanofluids and hybrid nanofluids: Nanofluids and hybrid nanofluids have shown promise in enhancing heat transfer and reducing entropy generation. Future research can focus on exploring different types of nanoparticles, their concentrations, and their effects on heat transfer and entropy generation in various convection scenarios. Additionally, combining different nanoparticles in hybrid nanofluids can be further investigated to optimise their performance.
iv. Study of magnetic field effects: The influence of magnetic fields on natural and mixed convection has been studied, but there is still room for further research. Future studies can explore the effects of different magnetic field strengths, angles, and orientations on fluid flow, heat transfer, and entropy generation. Understanding the behaviour of fluids under the influence of magnetic fields can lead to the development of more efficient energy systems.
v. Investigation of non-Newtonian fluids: The document briefly mentions the study of non-Newtonian fluids in the context of entropy generation. Future research can focus on understanding the behaviour of non-Newtonian fluids in convective heat transfer processes and their impact on entropy generation. This can provide valuable insights into optimising heat transfer in systems involving non-Newtonian fluids, such as in industrial processes or biomedical applications.
vi. Studying entropy generation in open cavities: While the document primarily focuses on entropy generation in closed square cavities, there is relatively less research on entropy generation in open cavities. Open cavities present additional complexities due to the

interaction with the external environment, which can influence fluid flow, heat transfer, and entropy generation. Future research can explore the relationship between cavity geometry, internal flow, and the external environment regarding entropy generation.

These are just a few potential areas for future research based on the information provided in the study. Further exploration in these areas can contribute to advancing the understanding of entropy generation in convective heat transfer and lead to the development of more efficient and sustainable energy systems.

7. Conclusions

The information above highlights the practical applications of research findings on entropy generation in square cavities across various industrial contexts. Engineers can leverage these insights to optimise the design of heating and cooling systems in buildings or industrial processes, resulting in energy-efficient systems that minimise waste and improve efficiency. For instance, the research findings can be applied to enhance cooling solutions for electronic components, addressing the critical concern of heat dissipation in electronic devices. Additionally, in automotive applications, implementing square cavities with obstacles or fins in radiators or heat exchangers can improve convective heat transfer, thereby enhancing the overall efficiency of vehicle cooling systems. Moreover, these research findings play a pivotal role in guiding the design of industrial processes involving heat transfer in enclosures or cavities. This has implications for energy-intensive industries such as chemical, food processing, and power generation, where improved efficiency through minimised entropy generation is crucial. Furthermore, the research serves as a foundation for the development of new materials and technologies. By understanding the influence of various parameters—such as Rayleigh number, Prandtl number, magnetic field, and nanoparticle volume fraction—engineers can innovate materials, like nanofluids with specific nanoparticle properties, to significantly improve heat transfer performance.

In summary, optimising heat transfer and reducing energy waste, attributed to entropy generation, has been discussed considering factors like nanoparticle concentration, magnetic field angle, fin angle, and solid nanoparticle concentration. Achieving maximum energy efficiency also requires identifying the ideal system configuration, thereby minimising entropy creation and increasing heat transfer rates. This involves careful consideration of design and operation parameters alongside the integration of cutting-edge materials and technologies. Therefore, understanding fluid behaviour in various convection scenarios provides valuable insights and potential solutions for advancing energy systems, improving efficiency, and reducing energy waste.

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References

[1] Bejan, Adrian. "Discipline in thermodynamics." *Energies* 13, no. 10 (2020): 2487. https://doi.org/10.3390/en13102487
[2] Thanh, Luan Nguyen, Phu Nguyen Minh, and Ha Nguyen Minh. "Entropy Generation, Heat Transfer of Water Near Density Inversion Region with Relative Positions of Hot and Cold Walls: Numerical Analysis." *CFD Letters* 15, no. 5 (2023): 42-53. https://doi.org/10.37934/cfdl.15.5.4253
[3] Oyewola, Olanrewaju, and Samuel Afolabi. "EXAMINATION OF CONVECTIVE HEAT TRANSFER AND ENTROPY GENERATION BY TWO ADIABATIC OBSTACLES INSIDE A CAVITY AT DIFFERENT INCLINATION ANGLES." *Frontiers in Heat and Mass Transfer (FHMT)* 19 (2022). https://doi.org/10.5098/hmt.19.20

[4] Baliti, Jamal, Mohamed Hssikou, Youssef Elguennouni, Ahmed Moussaoui, and Mohammed Alaoui. "Heat transfer and entropy generation for natural convection by adiabatic obstacles inside a cavity heated on the left side." *FME Transactions* 48, no. 4 (2020): 825-832. https://doi.org/10.5937/fme2004825b.

[5] Boudebous, Saadoun, and Nawal Ferroudj. "New approach to compute accurately the entropy generation due to natural convection in a square cavity." In *E3S Web of Conferences*, vol. 321, p. 04020. EDP Sciences, 2021. https://doi.org/10.1051/e3sconf/202132104020

[6] Soleimani, Soheil, A. Qajarjazi, H. Bararnia, Amin Barari, and G. Domairry. "Entropy generation due to natural convection in a partially heated cavity by local RBF-DQ method." *Meccanica* 46 (2011): 1023-1033. https://doi.org/10.1007/s11012-010-9358-0

[7] Berrin Erbay, L., Zekeriya Altaç, and Birsen Sülüş. "Entropy generation in a square enclosure with partial heating from a vertical lateral wall." *Heat and mass transfer* 40, no. 12 (2004): 909-918. https://doi.org/10.1007/s00231-003-0497-x

[8] Aghajani, Delavar Mojtaba, Mousa Farhadi, and Kurosh Sedighi. "Effect of discrete heater at the vertical wall of the cavity over the heat transfer and entropy generation using LBM." *Thermal Science* 15, no. 2 (2011): 423-435. https://doi.org/10.2298/tsci1102423a

[9] Magherbi, Mourad, Atef El Jery, Nejib Hidouri, and Ammar Ben Brahim. "Evanescent magnetic field effects on entropy generation at the onset of natural convection." *Sadhana* 35, no. 2 (2010): 163-176.https://doi.org/10.1007/s12046-010-0021-1

[10] Shuja, S. Z., B. S. Yilbas, and M. O. Budair. "Natural convection in a square cavity with a heat generating body: entropy consideration." *Heat and mass transfer* 36, no. 4 (2000): 343-350. https://doi.org/10.1007/s002310000075

[11] Ilis, Gamze Gediz, Moghtada Mobedi, and Bengt Sunden. "Effect of aspect ratio on entropy generation in a rectangular cavity with differentially heated vertical walls." *International Communications in Heat and Mass Transfer* 35, no. 6 (2008): 696-703. https://doi.org/10.1016/j.icheatmasstransfer.2008.02.002

[12] Bouabid, Mounir, Mourad Magherbi, Nejib Hidouri, and Ammar Ben Brahim. "Entropy generation at natural convection in an inclined rectangular cavity." *Entropy* 13, no. 5 (2011): 1020-1033. https://doi.org/10.3390/e13051020

[13] Morsli, Souad, Amina Sabeur, and Mohammed El Ganaoui. "Influence of aspect ratio on the natural convection and entropy generation in rectangular cavities with wavy-wall." *Energy Procedia* 139 (2017): 29-36. https://doi.org/10.1016/j.egypro.2017.11.168

[14] El-Maghlany, Wael M. "Isentropic contours of natural convection heat generated enclosures." *Alexandria Engineering Journal* 60, no. 2 (2021): 2149-2154. https://doi.org/10.1016/j.aej.2020.12.004

[15] Bouabid, Mounir, and Ammar Ben Brahim. "Soret effect on entropy generation at magneto double-diffusive convection in an air filled square medium." In *IREC2015 The Sixth International Renewable Energy Congress*, pp. 1-6. IEEE, 2015. https://doi.org/10.1109/IREC.2015.7110874

[16] Kaluri, Ram Satish, and Tanmay Basak. "Analysis of entropy generation for distributed heating in processing of materials by thermal convection." *International Journal of Heat and Mass Transfer* 54, no. 11-12 (2011): 2578-2594. https://doi.org/10.1016/j.ijheatmasstransfer.2011.02.003

[17] Sheremet, Mikhail A., Hakan F. Oztop, Ioan Pop, and Nidal Abu-Hamdeh. "Analysis of entropy generation in natural convection of nanofluid inside a square cavity having hot solid block: Tiwari and Das' model." *Entropy* 18, no. 1 (2015): 9. https://doi.org/10.3390/e18010009

[18] Sheremet, Mikhail A., Teodor Grosan, and Ioan Pop. "Natural convection and entropy generation in a square cavity with variable temperature side walls filled with a nanofluid: Buongiorno's mathematical model." *Entropy* 19, no. 7 (2017): 337.https://doi.org/10.3390/e19070337

[19] Bessaih, Rachid. "NATURAL CONVECTION AND ENTROPY GENERATION OF NANOFLUIDS IN A SQUARE CAVITY." *International Journal of Heat & Technology* 33, no. 4 (2015). https://doi.org/10.18280/ijht.330401

[20] Reddy, P. Sudarsana, P. Sreedevi, and V. Nageswara Reddy. "Entropy generation and heat transfer analysis of magnetic nanofluid flow inside a square cavity filled with carbon nanotubes." *Chemical Thermodynamics and Thermal Analysis* 6 (2022): 100045. https://doi.org/10.1016/j.ctta.2022.100045

[21] Ishak, Muhamad Safwan, Ammar I. Alsabery, A. Chamkha, and Ishak Hashim. "Effect of finite wall thickness on entropy generation and natural convection in a nanofluid-filled partially heated square cavity." *International Journal of Numerical Methods for Heat & Fluid Flow* 30, no. 3 (2020): 1518-1546. https://doi.org/10.1108/HFF-06-2019-0505

[22] OZTOP, Hakan F., Rachid BESSAÏH, and ABU-HAMDEH Nidal. "Entropy production due to conjugate natural convection in a nanofluid-filled enclosure with a stepped wall." *Engineering Transactions* 71, no. 2 (2023): 161-183. https://doi.org/10.24423/EngTrans.2032.20230517

[23] Alipanah, M., A. A. Ranjbar, E. Farnad, and F. Alipanah. "Entropy generation of natural convection heat transfer in a square cavity using Al2O3–water nanofluid." *Heat Transfer—Asian Research* 44, no. 7 (2015): 641656. https://doi.org/10.1002/htj.21141

[24] Alsabery, Ammar I., Muhamad Safwan Ishak, Ali J. Chamkha, and Ishak Hashim. "Entropy generation analysis and natural convection in a nanofluid-filled square cavity with a concentric solid insert and different temperature distributions." *Entropy* 20, no. 5 (2018): 336. https://doi.org/10.3390/e20050336

[25] Xiong, Xiaopeng, Sheng Chen, and Bo Yang. "Natural convection of SiO2-water nanofluid in square cavity with thermal square column." *Applied Mathematics and Mechanics* 38, no. 4 (2017): 585-602. https://doi.org/10.1007/s10483-017-2183-6

[26] Sheikhzadeh, G. A., and M. Nikfar. "Aspect ratio effects of an adiabatic rectangular obstacle on natural convection and entropy generation of a nanofluid in an enclosure." *Journal of Mechanical Science and Technology* 27 (2013): 3495-3504. https://doi.org/10.1007/s12206-013-0875-3

[27] Sheikhzadeh, Ghanbar Ali, Majid Nikfar, and A. Fattahi. "Numerical study of natural convection and entropy generation of Cu-water nanofluid around an obstacle in a cavity." *Journal of mechanical science and technology* 26 (2012): 3347-3356. https://doi.org/10.1007/s12206-012-0805-9

[28] Khorasanizadeh, H., J. Amani, and M. J. S. I. Nikfar. "Numerical investigation of Cu-water nanofluid natural convection and entropy generation within a cavity with an embedded conductive baffle." *Scientia Iranica* 19, no. 6 (2012): 1996-2003. https://doi.org/10.1016/j.scient.2012.07.018

[29] Salari, Mahmoud, Ali Mohammadtabar, and Mohammad Mohammadtabar. "Effects of circular corners and aspect-ratio on entropy generation due to natural convection of nanofluid flows in rectangular cavities." *Thermal Science* 19, no. 5 (2015): 1621-1632.https://doi.org/10.2298/tsci130201034s

[30] Li, Zhixiong, Ahmed Kadhim Hussein, Obai Younis, Sara Rostami, and Wei He. "Effect of alumina nano-powder on the natural convection of water under the influence of a magnetic field in a cavity and optimization using RMS: Using empirical correlations for the thermal conductivity and a sensitivity analysis." *International Communications in Heat and Mass Transfer* 112 (2020): 104497. https://doi.org/10.1016/j.icheatmasstransfer.2020.104497

[31] Li, Zhixiong, Ahmed Kadhim Hussein, Obai Younis, Sara Rostami, and Wei He. "Effect of alumina nano-powder on the natural convection of water under the influence of a magnetic field in a cavity and optimization using RMS: Using empirical correlations for the thermal conductivity and a sensitivity analysis." *International Communications in Heat and Mass Transfer* 112 (2020): 104497. https://doi.org/10.18280/ijht.360215

[32] Alsabery, Ammar I., Ishak Hashim, Ahmad Hajjar, Mohammad Ghalambaz, Sohail Nadeem, and Mohsen Saffari Pour. "Entropy generation and natural convection flow of hybrid nanofluids in a partially divided wavy cavity including solid blocks." *Energies* 13, no. 11 (2020): 2942. https://doi.org/10.3390/en13112942

[33] Geridonmez, Bengisen Pekmen, and Hakan F. Oztop. "Entropy generation due to magneto-convection of a hybrid nanofluid in the presence of a wavy conducting wall." *Mathematics* 10, no. 24 (2022): 4663.https://doi.org/10.3390/math10244663

[34] Hussain, Salam Hadi. "Analysis of heatlines and entropy generation during double-diffusive MHD natural convection within a tilted sinusoidal corrugated porous enclosure." *Engineering science and technology, an international journal* 19, no. 2 (2016): 926-945. https://doi.org/10.1016/j.jestch.2015.12.001

[35] Parveen, Rujda, and T. R. Mahapatra. "Numerical simulation of MHD double diffusive natural convection and entropy generation in a wavy enclosure filled with nanofluid with discrete heating." *Heliyon* 5, no. 9 (2019). https://doi.org/10.1016/j.heliyon.2019.e02496

[36] Cho, Ching-Chang. "Heat transfer and entropy generation of natural convection in nanofluid-filled square cavity with partially-heated wavy surface." *International Journal of Heat and mass transfer* 77 (2014): 818-827. https://doi.org/10.1016/j.ijheatmasstransfer.2014.05.063

[37] Zhang, Xiao-Hong, Tareq Saeed, Ebrahem A. Algehyne, M. A. El-Shorbagy, Adel M. El-Refaey, and Muhammad Ibrahim. "Effect of L-shaped heat source and magnetic field on heat transfer and irreversibilities in nanofluid-filled oblique complex enclosure." *Scientific Reports* 11, no. 1 (2021): 16458. https://doi.org/10.1038/s41598-021-95803-z

[38] Belhaj, Soufien, and Brahim Ben-Beya. "Magnetoconvection and entropy generation of nanofluid in an enclosure with an isothermal block: Performance evaluation criteria analysis." *Journal of Thermal Science and Technology* 13, no. 1 (2018): JTST0019-JTS0019. https://doi.org/10.1299/jtst.2018jtst0019

[39] Oueslati, Fakher, and Brahim Ben-Beya. "Magnetoconvection and irreversibility phenomena within a lid driven cavity filled with liquid metal under magnetic field." *Frontiers in Heat and Mass Transfer (FHMT)* 8 (2017).https://doi.org/10.5098/hmt.8.38

[40] Iftikhar, Babar, Muhammad Arshad Siddiqui, and Tariq Javed. "Dynamics of magnetohydrodynamic and ferrohydrodynamic natural convection flow of ferrofluid inside an enclosure under non-uniform magnetic field." *Alexandria Engineering Journal* 66 (2023): 523-536. https://doi.org/10.1016/j.aej.2022.11.011

[41] Shi, Er, Yecong He, Xiaoqin Sun, and Changwei Jiang. "Entropy generation and natural convection of air under a magnetic quadrupole field in a square enclosure." *Energy Procedia* 105 (2017): 5073-5078. https://doi.org/10.1016/j.egypro.2017.03.1027
[42] Rahman, Aimon, Didarul A. Redwan, Sharaban Thohura, Md Kamrujjaman, and Md Mamun Molla. "Natural convection and entropy generation of non-Newtonian nanofluids with different angles of external magnetic field using GPU accelerated MRT-LBM." *Case Studies in Thermal Engineering* 30 (2022): 101769. https://doi.org/10.1016/j.csite.2022.101769
[43] Tayebi, Tahar, and Ali J. Chamkha. "Entropy generation analysis during MHD natural convection flow of hybrid nanofluid in a square cavity containing a corrugated conducting block." *International Journal of Numerical Methods for Heat & Fluid Flow* 30, no. 3 (2019): 1115-1136. https://doi.org/10.1108/HFF-04-2019-0350
[44] Reddy, P. Bala Anki, T. Salah, Shaik Jakeer, M. A. Mansour, and A. M. Rashad. "Entropy generation due to magneto-natural convection in a square enclosure with heated corners saturated porous medium using Cu/water nanofluid." *Chinese Journal of Physics* 77 (2022): 1863-1884. https://doi.org/10.1016/j.cjph.2022.01.012
[45] Al-Kouz, Wael, Ahmad Al-Muhtady, Wahib Owhaib, Sameer Al-Dahidi, Montasir Hader, and Rama Abu-Alghanam. "Entropy generation optimization for rarified nanofluid flows in a square cavity with two fins at the hot wall." *Entropy* 21, no. 2 (2019): 103. https://doi.org/10.3390/e21020103
[46] Khetib, Yacine, Ahmad Aziz Alahmadi, Ali Alzaed, Hamidreza Azimy, Mohsen Sharifpur, and Goshtasp Cheraghian. "Effect of straight, inclined and curved fins on natural convection and entropy generation of a nanofluid in a square cavity influenced by a magnetic field." *Processes* 9, no. 8 (2021): 1339. https://doi.org/10.3390/pr9081339
[47] Rahimi, Alireza, Mohammad Sepehr, Milad Janghorban Lariche, Abbas Kasaeipoor, Emad Hasani Malekshah, and Lioua Kolsi. "Entropy generation analysis and heatline visualization of free convection in nanofluid (KKL model-based)-filled cavity including internal active fins using lattice Boltzmann method." *Computers & Mathematics with Applications* 75, no. 5 (2018): 1814-1830. https://doi.org/10.1016/j.camwa.2017.12.008
[48] Alnaqi, Abdulwahab A., Saeed Aghakhani, Ahmad Hajatzadeh Pordanjani, Reza Bakhtiari, Amin Asadi, and Minh-Duc Tran. "Effects of magnetic field on the convective heat transfer rate and entropy generation of a nanofluid in an inclined square cavity equipped with a conductor fin: Considering the radiation effect." *International Journal of Heat and Mass Transfer* 133 (2019): 256-267. https://doi.org/10.1016/j.ijheatmasstransfer.2018.12.110
[49] Shahi, Mina, Amir Houshang Mahmoudi, and Abbas Honarbakhsh Raouf. "Entropy generation due to natural convection cooling of a nanofluid." *International Communications in Heat and Mass Transfer* 38, no. 7 (2011): 972-983. https://doi.org/10.1016/j.icheatmasstransfer.2011.04.008
[50] Mahmud, Shohel, and Roydon Andrew Fraser. "Vibrational effect on entropy generation in a square porous cavity." *Entropy* 5, no. 5 (2003): 366-376. https://doi.org/10.3390/e5050366
[51] Goqo, Sicelo P., Hiranmoy Mondal, Precious Sibanda, and Sandile S. Motsa. "A multivariate spectral quasilinearisation method for entropy generation in a square cavity filled with porous medium saturated by nanofluid." *Case Studies in Thermal Engineering* 14 (2019): 100415. https://doi.org/10.1016/j.csite.2019.100415
[52] Charreh, D., and M. Saleem. "Entropy generation and natural convection analyses in a non-darcy porous square cavity with thermal radiation and viscous dissipation." *Results in Physics* 52 (2023): 106874. https://doi.org/10.1016/j.rinp.2023.106874
[53] Sadeghi, Mohamad Sadegh, A. S. Dogonchi, M. Ghodrat, Ali J. Chamkha, Hesham Alhumade, and Nader Karimi. "Natural convection of CuO-water nanofluid in a conventional oil/water separator cavity: Application to combined-cycle power plants." *Journal of the Taiwan Institute of Chemical Engineers* 124 (2021): 307-319.https://doi.org/10.1016/j.jtice.2021.03.031
[54] Javed, Sakib, Niloy Deb, and Sumon Saha. "Natural convection and entropy generation inside a square chamber divided by a corrugated porous partition." *Results in Engineering* 18 (2023): 101053. https://doi.org/10.1016/j.rineng.2023.101053
[55] Akhter, Rowsanara, Mohammad Mokaddes Ali, and M. A. Alim. "Entropy generation due to hydromagnetic buoyancy-driven hybrid-nanofluid flow in partially heated porous cavity containing heat conductive obstacle." *Alexandria Engineering Journal* 62 (2023): 17-45. https://doi.org/10.1016/j.aej.2022.07.005
[56] Tayebi, Tahar. "Analysis of the local non-equilibria on the heat transfer and entropy generation during thermal natural convection in a non-Darcy porous medium." *International Communications in Heat and Mass Transfer* 135 (2022): 106133. https://doi.org/10.1016/j.icheatmasstransfer.2022.106133
[57] Kaluri, Ram Satish, and Tanmay Basak. "Entropy generation due to natural convection in discretely heated porous square cavities." *Energy* 36, no. 8 (2011): 5065-5080. https://doi.org/10.1016/j.energy.2011.06.001
[58] Cimpean, Dalia Sabina, and Ioan Pop. "Entropy generation of a nanofluid in a porous cavity with sinusoidal temperature at the walls and a heat source bellow." *International Journal of Numerical Methods for Heat & Fluid Flow* 32, no. 1 (2022): 23-40. https://doi.org/10.1108/HFF-10-2020-0654

[59] Kefayati, G. H. R. "Heat transfer and entropy generation of natural convection on non-Newtonian nanofluids in a porous cavity." *Powder technology* 299 (2016): 127-149. https://doi.org/10.1016/j.powtec.2016.05.032

[60] Ashorynejad, Hamid Reza, and B. Hoseinpour. "Investigation of different nanofluids effect on entropy generation on natural convection in a porous cavity." *European Journal of Mechanics-B/Fluids* 62 (2017): 86-93. https://doi.org/10.1016/j.euromechflu.2016.11.016

[61] Said, Khaled, and A. Q. Sabeur. "Turbulent double-diffusive natural convection and entropy generation within an inclined square cavity." *Fluid Dynamics and Materials Processing* 18, no. 6 (2022): 1621-1629. https://doi.org/10.32604/fdmp.2022.022220

[62] Li, Zhixiong, Ahmed Kadhim Hussein, Obai Younis, Masoud Afrand, and Shizhe Feng. "Natural convection and entropy generation of a nanofluid around a circular baffle inside an inclined square cavity under thermal radiation and magnetic field effects." *International Communications in Heat and Mass Transfer* 116 (2020): 104650. https://doi.org/10.1016/j.icheatmasstransfer.2020.104650

[63] Tasnim, Sadia, Anamica Mitra, Hriti Saha, Md Quamrul Islam, and Sumon Saha. "MHD conjugate natural convection and entropy generation of a nanofluid filled square enclosure with multiple heat-generating elements in the presence of Joule heating." *Results in Engineering* 17 (2023): 100993. https://doi.org/10.1016/j.rineng.2023.100993

[64] Ikram, Maruf M., Shadman S. Priam, and Sumon Saha. "Thermo-fluid characteristics and second law analysis of an inclined two-fluid system with variable surface roughness." *Case Studies in Thermal Engineering* 37 (2022): 102270. https://doi.org/10.1016/j.csite.2022.102270

[65] Kefayati, G. H. R. "Double-diffusive natural convection and entropy generation of Bingham fluid in an inclined cavity." *International Journal of Heat and Mass Transfer* 116 (2018): 762-812. https://doi.org/10.1016/j.ijheatmasstransfer.2017.09.065

[66] Ferroudj, Nawal, and Hasan Köten. "Numerical Simulation of Prandtl number effect on entropy generation in a square cavity." *Journal of Thermal Engineering* 7, no. 4 (2021): 1016-1029. https://doi.org/10.18186/thermal.931364

[67] Ferroudj, Nawal, Hasan Koten, Sacia Kachi, and Saadoun Boudebous. "Prandtl number effects on the entropy generation during the transient mixed convection in a square cavity heated from below." *Periodica Polytechnica Mechanical Engineering* 65, no. 4 (2021): 310-325. https://doi.org/10.3311/PPme.17563

[68] Mountrichas, Periklis, Wendi Zhao, Mehtab Singh Randeva, and Prodip K. Das. "Entropy Generation of CuO-Water Nanofluid in a Cavity with an Intruded Rectangular Fin." *Energies* 16, no. 2 (2023): 912. https://doi.org/10.3390/en16020912

[69] El-Shorbagy, M. A., Ebrahem A. Algehyne, Muhammad Ibrahim, Vakkar Ali, and Rasool Kalbasi. "Effect of fin thickness on mixed convection of hybrid nanofluid exposed to magnetic field-Enhancement of heat sink efficiency." *Case Studies in Thermal Engineering* 26 (2021): 101037. https://doi.org/10.1016/j.csite.2021.101037

[70] Çiçek, Oktay, and A. Cihat Baytaş. "A numerical investigation of the particle behaviors and entropy generation in mixed convection inside a vented enclosure." *International Journal of Thermal Sciences* 185 (2023): 108058. https://doi.org/10.1016/j.ijthermalsci.2022.108058

[71] Roy, Monisha, Tanmay Basak, S. Roy, and I. Pop. "Analysis of entropy generation for mixed convection in a square cavity for various thermal boundary conditions." *Numerical Heat Transfer, Part A: Applications* 68, no. 1 (2015): 44-74.https://doi.org/10.1080/10407782.2014.955352

[72] Maougal, A., and R. Bessaïh. "Heat transfer and entropy analysis for mixed convection in discretely heated porous square cavity." *Fluid Dyn. Mater. Process* 9, no. 1 (2013): 35-58. https://doi.org/10.3970/fdmp.2013.009.035

[73] Abdelhak, Roubi, Fares Redouane, Wasim Jamshed, Mohamed R. Eid, Kamel Guedri, M. Israr Ur Rehman, and Sayed M. El Din. "Analysis of water conveying aluminum oxide/silver nanoparticles due to mixed convection through four square cavity's variable hot (cold) walled." *Ain Shams Engineering Journal* 14, no. 9 (2023): 102072. https://doi.org/10.1016/j.asej.2022.102072

[74] Akhter, Rowsanara, Mohammad Mokaddes Ali, and Md Abdul Alim. "Magnetic field impact on double diffusive mixed convective hybrid-nanofluid flow and irreversibility in porous cavity with vertical wavy walls and rotating solid cylinder." *Results in Engineering* 19 (2023): 101292. https://doi.org/10.1016/j.rineng.2023.101292

[75] Hossain, Amzad, Md Mamun Molla, Md Kamrujjaman, Muhammad Mohebujjaman, and Suvash C. Saha. "MHD mixed convection of non-Newtonian Bingham nanofluid in a wavy enclosure with temperature-dependent thermophysical properties: a sensitivity analysis by response surface methodology." *Energies* 16, no. 11 (2023): 4408. https://doi.org/10.3390/en16114408

[76] Selimefendigil, Fatih, and Hakan F. Oztop. "Mixed convection and entropy generation of nanofluid flow in a vented cavity under the influence of inclined magnetic field." *Microsystem Technologies* 25, no. 12 (2019): 4427-4438. https://doi.org/10.1007/s00542-019-04350-1

[77] Pordanjani, Ahmad Hajatzadeh, Saeed Aghakhani, Abdulwahab A. Alnaqi, and Masoud Afrand. "Effect of alumina nano-powder on the convection and the entropy generation of water inside an inclined square cavity subjected to a magnetic field: uniform and non-uniform temperature boundary conditions." *International Journal of Mechanical Sciences* 152 (2019): 99-117. https://doi.org/10.1016/j.ijmecsci.2018.12.030

[78] Iftikhar, Babar, Tariq Javed, and Muhammad Arshad Siddiqu. "Entropy generation analysis during MHD mixed convection flow of non-Newtonian fluid saturated inside the square cavity." *Journal of Computational Science* 66 (2023): 101907. https://doi.org/10.1016/j.jocs.2022.101907

[79] Zeghbid, Ilhem, and Rachid Bessaih. "Numerical simulation of boundary conditions effect on heat transfer and entropy generation in a square cavity filled with Al2O3-Cu-water hybrid nanofluid." In *Defect and Diffusion Forum*, vol. 406, pp. 98-109. Trans Tech Publications Ltd, 2021. https://doi.org/10.17654/hm019010155

[80] Alsabery, Ammar I., Mohammad H. Yazdi, Ali S. Abosinnee, Ishak Hashim, and Evgeny Solomin. "Impact of partial slip condition on mixed convection of nanofluid within lid-driven wavy cavity and solid inner body." *Propulsion and Power Research* 11, no. 4 (2022): 544-564. https://doi.org/10.1016/j.jppr.2022.09.001.

[81] Hamzah, Hudhaifa, Cetin Canpolat, Laith M. Jasim, and Besir Sahin. "Hydrothermal index and entropy generation of a heated cylinder placed between two oppositely rotating cylinders in a vented cavity." *International Journal of Mechanical Sciences* 201 (2021): 106465.https://doi.org/10.1016/j.ijmecsci.2021.106465

[82] Rehman, Nusrat, Rashid Mahmood, Afraz Hussain Majeed, Khalil Ur Rehman, and Wasfi Shatanawi. "Finite element analysis on entropy generation in MHD Iron (III) Oxide-Water NanoFluid equipped in partially heated fillet cavity." *Journal of Magnetism and Magnetic Materials* 565 (2023): 170269. https://doi.org/10.1016/j.jmmm.2022.170269

[83] Alsabery, A. I., F. Selimefendigil, I. Hashim, A. J. Chamkha, and M. Ghalambaz. "Fluid-structure interaction analysis of entropy generation and mixed convection inside a cavity with flexible right wall and heated rotating cylinder." *International journal of heat and mass transfer* 140 (2019): 331-345. https://doi.org/10.1016/j.ijheatmasstransfer.2019.06.003

[84] Ferroudj, Nawal, Hasan KÖTEN, and Saadoun Boudebous. "Mixed Convection Heat Transfer and Entropy Generation in a Water-filled Square Cavity Partially Heated from Below: The Effects of Richardson and Prandtl Numbers." *Journal of Applied and Computational Mechanics* 8, no. 1 (2022): 282-297. https://doi.org/10.22055/jacm.2021.38614.3259

[85] Pandit, Swapan K., Anirban Chattopadhyay, and Hakan F. Oztop. "A fourth order compact scheme for heat transfer problem in porous media." *Computers & Mathematics with Applications* 71, no. 3 (2016): 805-832. https://doi.org/10.1016/j.camwa.2015.12.037

[86] Alsabery, Ammar I., Engin Gedik, Ali J. Chamkha, and Ishak Hashim. "Impacts of heated rotating inner cylinder and two-phase nanofluid model on entropy generation and mixed convection in a square cavity." *Heat and Mass Transfer* 56, no. 1 (2020): 321-338. https://doi.org/10.1007/s00231-019-02698-8

[87] Ting, Kevin, Aloke K. Mozumder, and Prodip K. Das. "Effect of surface roughness on heat transfer and entropy generation of mixed convection in nanofluid." *Physics of Fluids* 31, no. 9 (2019).https://doi.org/10.1063/1.5111104

[88] Ovando-Chacon, G. E., S. L. Ovando-Chacon, and J. C. Prince-Avelino. "Entropy generation due to mixed convection in an enclosure with heated corners." *International journal of heat and mass transfer* 55, no. 4 (2012): 695-700. https://doi.org/10.1016/j.ijheatmasstransfer.2011.10.041

[89] Wang, Tongsheng, Zhu Huang, and Guang Xi. "Entropy generation for mixed convection in a square cavity containing a rotating circular cylinder using a local radial basis function method." *International Journal of Heat and Mass Transfer* 106 (2017): 1063-1073. https://doi.org/10.1016/j.ijheatmasstransfer.2016.10.082

[90] Bouabid, Mounir, Nejib Hidouri, Mourad Magherbi, and Ammar Ben Brahim. "Analysis of the magnetic field effect on entropy generation at thermosolutal convection in a square cavity." *Entropy* 13, no. 5 (2011): 1034-1054.https://doi.org/10.3390/e13051034

[91] Hidouri, Nejib, Mounir Bouabid, Mourad Magherbi, and Ammar Ben Brahim. "Effects of radiation heat transfer on entropy generation at thermosolutal convection in a square cavity subjected to a magnetic field." *Entropy* 13, no. 12 (2011): 1992-2012.https://doi.org/10.3390/e13121992

[92] Arbin, Norazam, Nur Suhailayani Suhaimi, and Ishak Hashim. "Simulation on double-diffusive Marangoni convection with the presence of entropy generation." *Indian Journal of Science and Technology* (2016). https://doi.org/10.17485/ijst/2016/v9i31/97817

[93] Himika, Taasnim Ahmed, Sheikh Hassan, Md Farhad Hasan, and Md Mamun Molla. "Lattice Boltzmann simulation of MHD Rayleigh–Bénard convection in porous media." *Arabian Journal for Science and Engineering* 45, no. 11 (2020): 9527-9547. https://doi.org/10.1007/s13369-020-04812-z