JETIR.ORG ISSN: 2349-5162 | ESTD Year : 2014 | Monthly Issue
JOURNAL OF EMERGING TECHNOLOGIES AND INNOVATIVE RESEARCH (JETIR)
An International Scholarly Open Access, Peer-reviewed, Refereed Journal

RECENT ADVANCES IN HEAT AND MASS TRANSPORT OF MHD FLUID FLOW IN WAVY CHANNELS AND CORRUGATED SURFACES

Dineshkumar S[1], Panneerselvi R[2] and Sumathi K[2*]

[1]Department of Mathematics, Dr. N.G.P. Institute of Technology, Coimbatore 641 048, Tamilnadu, India

Mail id: dineshsaravananmaths@gmail.com

[2,2*]Department of Mathematics, PSGR Krishnammal College for Women, Coimbatore 641004, Tamilnadu, India

Mail id: panneerselvir09@gmail.com, sumathik@psgrkcw.ac.in / sumathiarunmath@gmail.com

Abstract: Heat and mass transfer in wavy channels, corrugated surfaces, and porous plates plays a vital role in all fields of engineering because of its significance in thermal engineering, energy systems, and industrial transport applications. The present review summarizes recent analytical, numerical, and experimental studies pertaining to convective transport under the influence of radiation, Hall current, magnetic field, viscous dissipation, porous medium interaction in Newtonian and non-Newtonian fluids. Earlier investigations mainly focused on convection in vertical wavy channels and corrugated ducts, whereas recent studies emphasized entropy generation, nanofluid transport, Casson fluid flow, and thermal visualization in complex cavity configurations. The review further highlights the role of micropolar, couple-stress, and viscoelastic fluids in regulating transport behaviour in porous channels. Comparative observations indicate that wall corrugation enhances local heat transfer rates, while magnetic field effects generally suppress momentum transport because of Lorentz force resistance.

Key words: *Magnetohydrodynamics (MHD), Heat and Mass Transfer, Wavy Channels, Corrugated Surfaces. Porous Media. Thermal Radiation*

I. INTRODUCTION

Mass and heat transmission through convection in wavy channels, corrugated surfaces and porous geometries have garnered a lot of interest because of their applications in heat exchangers of small sizes, geothermal applications, electronic cooling, chemical processing units, pipelines for petroleum transportation, physiological fluid dynamics, and even nuclear reactors. Compared with conventional flat channels, wavy and irregular geometries enhance thermal transport by disturbing the boundary layer structure and generating secondary flow circulation. The interaction of magnetic field, thermal radiation, porous medium resistance, viscous dissipation, Hall current, and chemical reaction further complicates the transport mechanism and strongly influences momentum, thermal, and concentration boundary layers. Consequently, analytical, numerical, and experimental investigations on convective transport through corrugated channels have increased considerably over the past few decades.

Early investigations mainly concentrated on heat transmission and convection in vertical wavy surfaces and corrugated ducts. Vajravelu and Sastri (1978, 1980) established the fundamental behaviour considering natural convection in channels with vertical waves, while studies by Amano *et al.* (1987), Asako and Faghri (1987), and Moulic and Yao (1989) demonstrated the influence of wall corrugation on thermal transport and pressure characteristics. Later investigations incorporated magnetohydrodynamic effects, porous medium interaction, radiation, Hall current, and non-Newtonian fluid behaviour to simulate realistic engineering systems. Recent studies by Satya Narayana (2015), Dogonchi *et al.* (2021), Ahmad *et al.* (2022), and Mohammed Hirpho (2021) emphasized entropy generation, nanofluid transport, Casson fluid behaviour, and thermal visualization in complex wavy cavities. The present review summarizes the major developments in transport processes of non-Newtonian, viscous, electrically conducting fluid subject to the influence of heat and mass concentration across wavy channels, porous geometries, and non-uniform cavities.

II. HEAT AND MASS TRANSFER IN CORRUGATED SURFACES AND WAVY CHANNELS

Heat transfer through corrugated and wavy geometries significantly modifies the hydrodynamic and thermal boundary layers. Compared with smooth channels, corrugated surfaces generate periodic disturbance in the flow field, enhance fluid mixing and consequently improve thermal transport characteristics. Early experimental investigations by Ali and Ramadhyani (1992)

demonstrated that corrugated channels compared to flat channels offer greater convective heat transfer rates because of repeated boundary layer interruption and recirculation effects. Amano (1985), who quantitatively examined laminar and turbulent transport in periodically corrugated wall channels, obtained similar findings and showed that wall waviness intensifies turbulence generation and thermal mixing. Kishinami *et al*. (1990) examined the thermal behaviour at the convex and concave elements of the wavy surface, providing valuable insights into how surface geometry affects local heat transfer rates. Molla and Hossain (2007), investigated radiation effects and thermal diffusion along vertical wavy surfaces. The study by Jang *et al*. (2003) further showed that the simultaneous movement of mass and heat along vertical wavy walls enhances convective transport because of coupled thermal and concentration gradients.

Porous medium interaction introduces additional complexity into convective transport through corrugated channels. Tiwari and Singh (2010) demonstrated that permeability and wall waviness jointly regulate velocity and temperature distributions inside vertical channels. Increasing wall amplitude enhanced local heat transfer rates because of intensified secondary circulation near the corrugated surfaces. Kabir *et al.* (2013b) focused on the influence of viscous dissipation within MHD natural convection over a vertical wavy surface. It offers a theoretical analysis emphasizing how viscous heating affects the boundary layer characteristics and heat transfer rates under magnetic fields and surface waviness. Umavathi and Marudappa Shekar (2015) investigated unsteady flow in the interaction of a parallel plate consisting of porous and fluid layers with a wavy plate. Their analysis indicated that conductivity ratio and porous resistance substantially affect momentum transport and thermal boundary layer development.

Travelling thermal waves and viscous dissipation effects have also received considerable attention in wavy channel transport studies. Vajravelu and Debnath (1986) established the convective heat transfer caused by travelling thermal waves. Later Sakthikala *et al*. (2020) revealed that travelling thermal waves considerably modify temperature distribution and concentration boundary layers inside vertical wavy channels. Similarly, Jitesh Babu *et al*. (2012) demonstrated that viscous dissipation increases internal thermal energy and consequently enhances temperature profiles throughout horizontal wavy channels. These investigations collectively confirm that wall corrugation, porous interaction, travelling thermal waves, and the nature of convective heat and mass transfer in geometrical non-uniformities is greatly affected by viscosity. Arunachalam *et al.* (2021a) analysed steady electrically conducting viscous incompressible fluid between a long vertical wavy wall and a parallel flat plate in the presence of a transverse magnetic field regime.

III. MAGNETOHYDRODYNAMIC FLOW AND RADIATION EFFECTS

Magnetohydrodynamic transport through wavy and porous geometries has become an important area of thermal engineering because magnetic field interaction strongly modifies momentum and thermal transport characteristics. The use of magnetic field produces fluid motion and alters boundary layer development, while thermal radiation significantly influences energy transport in high-temperature systems. The effects of radiation absorption, chemical reaction, Hall current, and porous medium on heat and mass transport produces highly coupled transport behaviour in non-uniform channels and corrugated geometries.

EFFECT OF HALL CURRENT AND CHEMICAL REACTION

In magnetohydrodynamic channel flows, Hall current and chemical reaction effects have a major impact on the characteristics of heat and mass transmission. Viswanath Reddy *et al.* (2013) analysed chemically reactive convective transport under the influence of Hall current and heat radiation in a vertical wavy channel. Their perturbation analysis demonstrated that Hall current weakens magnetic damping and consequently accelerates fluid motion inside the channel. The interaction between magnetic field and wall waviness produces substantial changes in the distribution of concentration, temperature and velocity.

Alam and Sattar (2000) analysed unsteady free convection heat and mass transfer flow with hall current, viscous dissipation and Joule heating. A similar behaviour was reported by Gireesha and Mahanthesh (2013) for convective boundary conditions and radiating viscoelastic fluid flow in non-uniform channels. Their study showed that Hall current enhances momentum transport, whereas chemical reaction suppresses concentration profiles significantly. Skin friction and heat transmission characteristics were changed throughout the channel by the interaction of radiation, Hall current and viscoelasticity. Reddy *et al*. (2013) investigated the combined effects of chemical reactions, thermal radiation, and Hall currents on convective heat and mass transfer within a vertical wavy channel. The authors developed a comprehensive mathematical model that incorporates these complex phenomena to analyse their impact on velocity, temperature, and concentration profiles.

Dulal Pal and Babulal Talukdar (2013) investigated the combined effects of Hall current and thermal radiation on magnetohydrodynamic (MHD) convective heat and mass transfer within a rotating porous channel subject to chemical reactions. Peristaltic transport under Hall and ion-slip effects was investigated by Abo-Eldahab *et al.* (2010). Their analysis demonstrated that Hall current modifies pressure rise and pumping features of fluid movement under pair stress in asymmetric channels. Similar observations were obtained by Asghar *et al*. (2014), who showed that Hall and ion-slip currents considerably influence thermal transport and streamline formation during peristaltic motion with Ohmic heating.

Chemical reaction effects in porous irregular geometries were further examined by Devika *et al*. (2013). Their analytical investigation revealed that stronger chemical reaction parameters reduce concentration levels and alter mass transfer rates substantially. The study confirmed that reactive species transport in corrugated porous channels is highly sensitive to magnetic interaction and diffusion mechanisms. Hall current and Ion slip effect on steady laminar flow of an electrically conducting, viscous fluid in irregular channel subject to convective boundary condition has been investigated by Arunachalam *et al.* (2021b).

RADIATION AND POROUS MEDIUM INTERACTION

Thermal radiation and porous medium interaction strongly affect convective transport through wavy channels and corrugated geometries. The influence of porous medium resistance on mixed convection was investigated by Kumar and Gupta (2012) through comparative analysis of micropolar and Newtonian fluids. Their results showed that permeability considerably modifies momentum transport and thermal diffusion inside vertical porous channels. Micropolar fluids exhibited stronger rotational effects and higher resistance to flow compared with Newtonian fluids.

MHD convective flow across a porous horizontal channel was studied and observed by Raju *et al*. (2014) and showed that increasing Hartmann number suppresses velocity profiles, while buoyancy and permeability enhance thermal transport. Similar conclusions were reported by Hung *et al.* (2013), where wall waviness and porous medium interaction significantly altered streamline circulation and thermal boundary layer formation in micropolar mixed convection.

Fasogbon (2010) demonstrated that heat and mass transmission via free convection in irregular channels is strongly affected by wall corrugation and porous medium resistance. These studies collectively indicate that radiation and porous interaction significantly regulate momentum, thermal, and concentration transport in magnetohydrodynamic convection systems. Likewise, radiative transport in porous corrugated channels was further examined by Fasogbon (2018). This analytical study revealed that viscous dissipation and radiation considerably increase temperature profiles throughout the channel. Narmadha and her collaborators (2024, 2025a, b) carried out a numerical analysis of heat and mass transfer in magnetohydrodynamic hybrid nanofluid flow over a variable thickness sheet.

IV. NON-NEWTONIAN AND CONVECTIVE TRANSPORT IN POROUS CHANNELS AND CAVITIES

Non-Newtonian transport through porous channels and wavy cavities has become an important area of thermal and fluid engineering because many industrial and physiological fluids do not obey Newtonian constitutive relations. Fluids such as Casson, micropolar, viscoelastic, and couple-stress fluids exhibit complex rheological behaviour that significantly modifies momentum diffusion, thermal transport, and boundary layer development. In addition, cavity geometry, wall waviness, porous medium interaction, and buoyancy forces strongly influence streamline formation and heat transfer characteristics. Consequently, several analytical and numerical investigations have focused on understanding the combined influence of non-Newtonian rheology and convective transport in irregular geometries.

CASSON, MICROPOLAR AND COUPLE-STRESS FLUID FLOW

The transport characteristics of Casson fluids in permeable and asymmetric channels were analysed by Srinivas *et al*. (2014). Their study demonstrated that permeability significantly alters pressure rise and streamline distribution during peristaltic transport. Casson fluid behaviour modified pumping efficiency and trapping phenomena considerably when compared with Newtonian flow systems. Similar observations were reported by Rami Reddy *et al*. (2010). The effect of magnetic field on peristaltic fluid flow of an electrically conducting fluid in an inclined asymmetric channel was taken into consideration. Their analysis revealed that magnetic damping suppresses fluid motion and reduces pumping efficiency because of Lorentz force resistance.

The influence of couple-stress fluid behaviour on convective transport was investigated by Muthuraj *et al*. (2013). Their analysis showed that viscous dissipation substantially increases fluid temperature because of internal heat generation. Couple-stress parameters altered boundary layer thickness and modified shear stress distribution near the corrugated walls. The interaction between magnetic field and porous medium resistance produced significant changes in velocity and thermal transport behaviour inside the channel.

Experimental investigations on non-Newtonian transport through corrugated geometries were reported by Dodson *et al*. (1971). They examined flows of Newtonian and Non-Newtonian fluids in corrugated pipes. Their observations confirmed that geometric irregularity considerably affects pressure drop and flow resistance, particularly for highly viscous fluids. These studies collectively demonstrate that rheological behaviour, permeability, and wall waviness strongly regulate convective transport in non-Newtonian flow systems.

WAVY CAVITIES: ENTROPY GENERATION AND MIXED CONVECTION

Mixed convection and entropy production in irregular cavities have attracted significant interest because cavity geometry strongly affects heat transfer enhancement and thermal irreversibility. Dullien and Azzam (1973) presented an experimental investigation into the flow behaviour in capillary tubes with periodic variations in diameter. This study addresses the fundamental relationship between flow rate and pressure gradient in such non-uniform geometries, which are relevant in many chemical and process engineering applications. Kelly and Pal (1978) showed that periodic thermal boundary conditions significantly affect resonant convection behaviour in wavy geometries. These investigations collectively indicate that entropy generation, buoyancy interaction, and cavity modulation play dominant roles in controlling thermal transport and convection performance in irregular enclosures.

Antonio Barletta (1998), presented an in-depth analysis of heat transfer phenomena involving laminar mixed convection within a vertical channel. The study notably incorporated the effects of viscous dissipation, which is crucial for accurately modelling energy transfer in fluid flows where viscous heating impacts temperature distribution. Asako *et al.* (1988) investigated the thermal and fluid dynamic behaviour of flow through corrugated ducts featuring rounded corners. This study was crucial for improving the design of heat exchangers and duct systems where enhanced heat transfer efficiency and manageable pressure loss are key considerations. Azzam and Dullien (1977), presented a detailed numerical study of fluid flow through tubes exhibiting periodic step changes in diameter. This geometric configuration is significant in many industrial processes where flow behaviour in non-uniform conduits affects pressure drop and mixing efficiency.

Fasogbon (2007) developed a mathematical model to analyse the influence of magnetic fields on fluid flow within channels featuring corrugated walls. The author highlighted how the channel's geometric corrugations, combined with magnetic effects, alter velocity profiles and potentially improve flow control. Molla *et al.* (2007) investigated the natural convection heat transfer characteristics along a vertical surface with a complex wavy geometry subjected to a uniform heat flux. The authors developed a theoretical model to analyse the intricate flow and thermal fields induced by the combined effects of surface waviness and uniform thermal loading. Kabir *et al.* (2013a) investigated the combined effects of viscous dissipation, heat generation, and magnetohydrodynamic (MHD) natural convection along a vertical wavy surface. The study models the complex interaction between fluid flow, thermal energy, and electromagnetic forces, emphasizing how viscous heating modifies temperature and velocity

profiles. The incorporation of a wavy surface adds practical relevance by simulating real-world surface irregularities that influence heat transfer.

Kabir *et al.* (2015) extended the analysis of natural convection along vertical wavy surfaces by further exploring the simultaneous impact of viscous dissipation and internal heat generation without the magnetic field influence. Disu and Dada (2017) explored the complex interaction of radiative magnetohydrodynamic (MHD) flow within a porous medium confined between two vertical wavy walls. The study incorporates the effects of Reynold's model viscosity, which introduces a variable viscosity dependent on flow conditions, enhancing the realism of the fluid behaviour under varying shear rates. Panneerselvi and Subashree (2017) presented a detailed study of steady fluid flow influenced by an inclined magnetic field between a flat wall and a long wavy wall, considering slip conditions at the walls and the Soret effect. Sakthikala *et al.* (2020) explored heat and mass transfer in convective flow between vertical wavy channels influenced by thermal radiation and travelling thermal waves. The authors focused on the dynamic effects of thermal waves moving along the surface, which induce complex transient behaviours in the flow and thermal fields.

V. CONCLUSION

In this review, major theoretical, numerical, and experimental investigations dealing with heat and mass transfer in channels with wavy surfaces, porous medium, cavities with irregular shapes under the presence of radiation, magnetics field, Hall currents, chemical reaction, viscous dissipation, and non-Newtonian flow were presented. Particular attention was given to magnetohydrodynamic transport, porous medium interaction, Casson and micropolar fluid flow, entropy generation, and mixed convection phenomena in wavy geometries. The reviewed studies collectively demonstrated the significant role of wall corrugation and multi physics interaction in regulating transport characteristics in advanced thermal systems.

The above-mentioned recent investigations highlight the following:

- Wall waviness and corrugated geometries considerably enhance convective heat transfer by disturbing thermal boundary layers and strengthening secondary circulation inside channels and cavities.
- Magnetic field effects generally suppress fluid motion because of Lorentz force resistance, thereby reducing axial velocity and modifying momentum transport characteristics in magnetohydrodynamic flows.
- Thermal radiation significantly intensifies temperature distribution and increases thermal boundary layer thickness, particularly in high-temperature porous convection systems.
- In reactive MHD channel flows, Hall current and ion-slip effects reduce magnetic damping, which improves momentum transport and heat transfer properties.
- Porous medium permeability strongly influences flow resistance, thermal diffusion, and concentration distribution, indicating its importance in regulating coupled heat and mass transfer processes.
- Non-Newtonian fluids, including couple-stress, Casson, micropolar, and viscoelastic fluids exhibit substantially different transport characteristics compared with Newtonian fluids because of rotational interaction, yield stress behaviour, and microstructural effects.
- Mixed convection and entropy production in wavy cavities are highly sensitive to cavity geometry, nanoparticle concentration, buoyancy force, and wall amplitude, emphasizing the importance of geometric optimization in thermal engineering applications.

REFERENCES

[1]. Abo-Eldahab E. M., Barakat E. I. and Nowar K. I., "Effects of Hall and Ionslip currents on peristaltic transport of a couple stress fluid," *International Journal of Applied Mathematics and Physics*, Vol. 2(2), pp. 145–157, 2010.

[2]. Ahmad, H., Mahmood, R., Hafeez, M. B., Hussain Majeed, A., Askar, S., & Shahzad, H. "Thermal visualization of Ostwald-de Waele liquid in wavy trapezoidal cavity: Effect of undulation and amplitude," *Case Studies in Thermal Engineering*, Vol. *29*, 101698, 2022.

[3]. Alam M. M. and Sattar M. A., "Unsteady free convection and mass transfer flow in a rotating system with Hall currents, viscous dissipation and Joule heating," *Journal of Energy Heat and Mass Transfer*, Vol. 22, pp. 31–39, 2000.

[4]. Ali M. M. and Ramadhyani S., "Experimental convective heat transfer in corrugated channels," *Experimental Heat Transfer*, Vol. 5, pp. 175–193, 1992.

[5]. Amano R. S., "A numerical study of laminar and turbulent heat transfer in a periodically corrugated wall channel," *ASME Journal of Heat Transfer*, Vol. 107, pp. 564–569, 1985.

[6]. Amano R. S., Bagherlee A., Smith R. J. and Niess T. G., "Turbulent heat transfer in corrugated wall channels with and without fins," *ASME Journal of Heat Transfer*, Vol. 109, pp. 62–67, 1987.

[7]. Antonio Barletta, "Laminar mixed convection with viscous dissipation in a vertical channel," *International Journal of Heat and Mass Transfer*, Vol. 41, pp. 3501–3513, 1998.

[8]. Arunachalam T., Sakthikala R., and Panneerselvi R., "Effect of Hall Current on Convective Porous Flows Between a long Vertical Wavy Wall and a Parallel Flat Plate", Journal of Information and Computational Science, Vol.11(1), pp. 418-430, 2021.

[9]. Arunachalam T., Sakthikala R., and Panneerselvi R., "Ion Slip Effect on a Convective Porous Flow Between a Long Vertical Wavy Wall and a Parallel Flat Plate", The International journal of analytical and experimental modal analysis, Vol. 13(2), pp. 910-924, 2021.

[10]. Asako Y. and Faghri M., "Finite-volume solutions for laminar flow and heat transfer in a corrugated duct," *ASME Journal of Heat Transfer*, Vol. 109, pp. 627–634, 1987.

[11]. Asako Y., Nakamura H. and Faghri M., "Heat transfer and pressure drop characteristics in a corrugated duct with rounded corners," *International Journal of Heat and Mass Transfer*, Vol. 31, pp. 1237–1245, 1988.

[12]. Asghar S., Hussain Q., Hayat T. and Alsaadi F., "Hall and ion slip effect on peristaltic flow and heat transfer analysis with Ohmic heating," *Applied Mathematics and Mechanics*, Vol. 35, pp. 1–16, 2014.

[13]. Azzam I. S. and Dullien F. A. L., "Flow in tubes with periodic step changes in diameter: a numerical solution," *Chemical Engineering Science*, Vol. 32, pp. 1445–1455, 1977.

[14]. Devika B., Narayana P. V. S. and Venkataramana S., "Chemical reaction effects on MHD free convection flow in an irregular channel with porous medium," *International Journal of Mathematical Archive*, Vol. 4(4), pp. 282–295, 2013.

[15]. Disu A. B. and Dada M. S., "Reynold's model viscosity on radiative MHD flow in a porous medium between two vertical wavy walls," *J. Taibah Univ. Sci.*, Vol. 11(1), 2017.

[16]. Dodson A. G., Townsend P. and Walters K., "On the flow of Newtonian and non-Newtonian liquids through corrugated pipes," *Rheologica Acta*, Vol. 10, pp. 508–516, 1971.

[17]. Dogonchi, A. S., Sadeghi, M. S., Ghodrat, M., Chamkha, A. J., Elmasry, Y., & Alsulami, R. "Natural convection and entropy generation of a nanoliquid in a crown wavy cavity: Effect of thermo-physical parameters and cavity shape," *Case Studies in Thermal Engineering*, Vol. 27, 101208, 2021.

[18]. Dulal Pal and Babulal Talukdar, "Influence of Hall Current and Thermal Radiation on MHD Convective Heat and Mass Transfer in a Rotating Porous Channel with Chemical Reaction," *International Journal of Engineering Mathematics*, pp. 1–13, 2013.

[19]. Dullien F. A. L. and Azzam M. I. S., "Flow rate-pressure gradient measurements in periodically non-uniform capillary tubes," *AIChE Journal*, Vol. 19, pp. 222–229, 1973.

[20]. Fasogbon P. F., "Analytical studies of heat and mass transfer by free convection in a two-dimensional irregular channel," *International Journal of Applied Mathematics and Mechanics*, Vol. 6(4), pp. 17–37, 2010.

[21]. Fasogbon P. F., "Magnetic and Viscous Dissipation Effects on Convection-Radiation in Corrugated Channel with Porous Medium and Uniform Heat Flux," *International Journal of Science and Research*, Vol. 7(8), pp. 841–848, 2018.

[22]. Fasogbon P. F., "MHD flows in corrugated channel," *International Journal of Pure and Applied Mathematics*, Vol. 20(2), pp. 137–147, 2007.

[23]. Gireesha B. J. and Mahanthesh B., "Perturbation Solution for Radiating Viscoelastic Fluid Flow and Heat Transfer with Convective Boundary Condition in Nonuniform Channel with Hall Current and Chemical Reaction," *International Scholarly Research Notices*, Vol. 2013, Issue 1, pp. 1-10, 2013.

[24]. Hung, C.I., Chen, C.K., and Tsai, T.H., "Mixed convection of micropolar fluids in a vertical wavy channel saturated with porous media", *International Journal of Thermal Sciences*, Vol. 67, pp. 124–132, 2013.

[25]. Jang J. H., Yan W. M. and Liu H. C., "Natural Convection Heat and Mass Transfer along a Vertical Wavy Surface," *International Journal of Heat and Mass Transfer*, Vol. 46, Issue 6, pp. 1075–1083, 2003.

[26]. Jitesh Babu P., Sugunamma V. and Prasada Rao D. R. V., "Effect of dissipation on convective heat transfer flow in a horizontal wavy channel with traveling thermal waves," *International Journal of Mathematical Archive*, Vol. 3(10), pp. 3836–3847, 2012.

[27]. Kabir K. H., Alim M. A. and Andallah L. S., "Effects of Viscous Dissipation on MHD Natural Convection Flow along a Vertical Wavy Surface with Heat Generation," *American Journal of Computational Mathematics*, Vol. 3, pp. 91–98, 2013a.

[28]. Kabir K. H., Alim M. A., Andallah L. S. and Saika Mahjabin, "Combined effects of viscous dissipation and heat generation on natural convection flow along a vertical wavy surface," *Journal of Mechanical Engineering*, Vol. 45(1), pp. 24–31, 2015.

[29]. Kazi H. Kabir, Md. A. Alim and Laek S. Andallah, "Effects of viscous dissipation on MHD natural convection flow along a vertical wavy surface," *Journal of Theoretical and Applied Physics*, Vol. 7, pp. 1–8, 2013b.

[30]. Kelly R. E. and Pal D., "Thermal convection with spatially periodic boundary conditions: resonant wavelength excitation," *Journal of Fluid Mechanics*, Vol. 86, pp. 433–456, 1978.

[31]. Kishinami K., Saito H. and Tokura I., "An experimental study on natural convective heat transfer from a vertical wavy surface heated at convex/concave elements," *Experimental Thermal and Fluid Science*, Vol. 3, pp. 305–315, 1990.

[32]. Kumar, & Gupta, S., "MHD free-convective flow of micropolar and Newtonian fluids through porous medium in a vertical channel", *Mechanica*, Vol. 47(2), pp. 277–291, 2012.

[33]. Mohammed Hirpho, "Mixed convection of Casson fluid in a differentially heated bottom wavy wall," *Heliyon*, Vol. 7(6), 2021.

[34]. Molla M. M. and Hossain M. A., "Radiation effect on mixed convection laminar flow along a vertical wavy surface," *International Journal of Thermal Sciences*, Vol. 46, pp. 926–935, 2007.

[35]. Molla M. M., Hossain M. A. and Yao L. S., "Natural convection flow along a vertical complex wavy surface with uniform heat flux," *ASME Journal of Heat Transfer*, Vol. 129, pp. 1403–1407, 2007.

[36]. Moulic S. G. and Yao L. S., "Mixed convection along a wavy surface," *ASME Journal of Heat Transfer*, Vol. 111, pp. 974–979, 1989.

[37]. Muthuraj, R., Srinivas, S., and Selvi, R. K., "Heat and mass transfer effects on MHD flow of a couple-stress fluid in a horizontal wavy channel with viscous dissipation and porous medium," *Heat Transfer—Asian Research*, Vol. 42(5), 403–423, 2013.

[38]. Narmatha M., Rohith Roshan A. and Sumathi K, "Numerical investigation of melting heat transfer in magnetohydrodynamic flow of hybrid nanofluid (SWCNTs + Ag + Gasoline) over a non-uniform stretching sheet", Journal of Computational Analysis and Application, Vol. 33(5), pp. 884-897, 2024.

[39]. Narmatha M., Rohith Roshan A., Muthu Mekala N. and Sumathi K., "Numerical analysis of heat and mass transfer in magnetohydrodynamic hybrid Nanofluid (SWCNTs + Ag + Gasoline) flow over a variable thickness sheet with melting heat effects", Tuijin Jishu/Journal of Propulsion Technology, Vol. 46(3), pp. 168-184, 2025.

[40]. Narmatha M., Sumathi K., and Panneerselvi R., "Influence of Hall Effect and Radiation on Melting Heat Transfer of Magnetohydrodynamic Hybrid Nanofluid Flow over a Sheet with Variable Thickness", International Research Journal of Multidisciplinary Scope, Vol. 6(1), pp. 1225-1238, 2025.

[41]. Panneerselvi R. and Subashree, D., "Influence of Inclined magnetic field and wall slip conditions on steady flow between a parallel flat wall and a long wavy wall with Soret effect", Indian Journal of Scientific Research, Vol.13(1), pp. 307-315, 2017.

[42]. Raju, K. V. S., Reddy, T. S., Raju, M. C., Narayana, P. V. S., and Venkataramana, S, "MHD convective flow through porous medium in a horizontal channel with insulated and impermeable bottom walls in the presence of viscous dissipation and Joule heating," *Ain Shams Engineering Journal*, Vol. 5(2), pp. 543–551, 2014.

[43]. Rami Reddy G, Satya Narayana, P. V, and Venkataramana S, "Peristaltic transport of a conducting fluid in an Inclined asymmetric channel," *Applied Mathematical Sciences*, Vol. 4, pp. 1729 – 1741, 2010.

[44]. Reddy, G. V., Ramana Reddy, K. V., and Bhaskar Reddy, N, Effect of chemical reaction and radiation on convective heat and mass transfer flow in vertical wavy channel with Hall effects. *International Journal of Mathematical Archive*, Vol. 4(1), 173–186, 2013.

[45]. Sakthikala R., Sumathi K. and Arunachalam T., "Heat and Mass Transfer with Radiation in a Convective Flow Between Vertical Wavy Channels due to Travelling Thermal Waves," *Turkish Journal of Computer and Mathematics Education*, Vol. 12(1), 2020.

[46]. Satya Narayana, P. V., Effects of variable permeability and radiation absorption on magnetohydrodynamic (MHD) mixed convection flow in a vertical wavy channel with travelling thermal waves. *Propulsion and Power Research*, Vol. 4(3), 150–160, 2015.

[47]. Srinivas A.N.S, Hemadri Reddy R, Srinivas S, Sreenadh S, "Peristaltic transport of Casson fluid in a permeable channel," *International Journal of Pure and Applied Mathematics*, Vol. 90, pp. 11-24, 2014.

[48]. Tiwari AK and Singh AK, "Natural convection heat transfer in a porous medium between vertical wavy wall and flat wall", **Zeitschrift für Naturforschung A**, Vol. 39(7), pp. 800-810, 2010.

[49]. Umavathi J C. and Marudappa Shekar, "Unsteady Mixed Convective Flow Confined between Vertical Wavy Wall and Parallel Flat Wall Filled with Porous and Fluid Layer," *Heat Transfer Engineering*, Vol. 36(1), pp. 1-20, 2015.

[50]. Vajravelu K. and Debnath L., "Non-linear study of convective heat transfer and fluid flows induced by travelling thermal waves," *Acta Mechanica*, Vol. 59, pp. 233–249, 1986.

[51]. Vajravelu K. and Sastri K. S., "Free convective heat transfer in a viscous incompressible fluid confined between a long vertical wavy wall and a parallel flat wall," *Journal of Fluid Mechanics*, Vol. 86(2), pp. 365–383, 1978.

[52]. Vajravelu K. and Sastri K. S., "Natural convective heat transfer in vertical wavy channels," *International Journal of Heat and Mass Transfer*, Vol. 23, pp. 408–411, 1980.