Review of Convection and Magnetohydrodynamic Mixed Convection Heat Transfer Enhancement

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Abstract – *In this paper, we discuss about the recent research trends in heat transfer enhancement in convection mode by using two kinds of techniques: killing thermal boundary layer and using magnetohydrodynamic (MHD) mixed convection. We first give a glance of various techniques utilized by the researchers to properly utilize energy and heat in varying applications. Then we focus our study in heat transfer enhancement only. The entire discussion is divided into two categories based on the kinds of heat transfer enhancement as mentioned. We have presented the comparative study of related investigations along with the conclusion from them in the most understandable manner. This article opens a path for inclusive understanding of the phenomenon for future study, design and development of devices in convection heat transfer.*

Key Words: heat transfer, convection, magnetohydrodynamics

1. INTRODUCTION

Heat transfer is required for the exchange of thermal energy. Heat exchangers are used in several applications including cooling the engines of automobiles, in refrigeration cycle, air conditioning as well as in power plants. All of these utilize the phenomenon of heat transfer to take heat from one point to other. Sometimes, a hotter body is required to be cooled for its efficient operation while in some other application, one needs to transfer heat to generate power and transmit electricity, and efficient heat transfer is crucial to all those fields. However, there lies always a limit of heat transfer between two bodies. The limit exists due to the material properties, design as well as fluid flow parameters of the heat exchanger or transfer device. So, in the recent decade, many researchers around the world are concerned about this limit and are trying to eliminate this limit so that maximum amount of heat transfer is possible. If there is an infinite limit to the heat transfer phenomenon in a device, we can achieve greater thermal efficiency, optimize the geometry of heat exchanger and ultimately save energy.

In the scenario of present innovation in thermo-fluids engineering we can find a lot of researchers who have contributed to design, develop and test the devices related energy/thermal management and clean energy. Various techniques to attain efficient heat exchange [1-3], effective combustion [4-6], alternative fuels [7-10], efficient power generation [11-13] have been explored. And, all these have helped the present-day technology in thermo-fluids and energy sector to march ahead. In this paper, we concentrate on the heat transfer enhancement portion of the energy management technique. We have discussed about the recent advances in convection heat transfer enhancement which is required in various fields as discussed above. We have presented a review of those articles in the most understandable way. Based on our knowledge, this is one of the first articles in literature, to encompass a clear and understandable review in convection heat transfer enhancement and mixed magnetohydrodynamic (MHD) convection in a single paper.

2. DISCUSSION

We divide the discussion in the present article into two categories based on two different kinds of convection heat transfer enhancement: extra surface to kill thermal boundary layer and MHD mixed convection.

2.1 Extra surface to kill thermal boundary layer

In this technique, people the surface of heat transfer device or heat exchanger is modified. The modification can be done by using rough surface to increase friction for the flow or by using an extra device like coil or tape inside the exchanger which are typically called as insertions. Table -1 shows the comparative illustration of various researches carried out in this field. It also shows the final outcome/conclusion from the corresponding studies. The reason behind this insertion is to kill the thermal boundary layer which ultimately increases the limit of heat transfer.

Table -1: Various studies illustrating heat transfer enhancement using extra surface to kill thermal boundary layer

S. No.	Author(s)	Investigation	Conclusion
1	Sheikholeslami et al. [14]	Passive methods of heat transfer enhancement using swirl flow	Swirl device induce turbulence and vortex motion ultimately inducing a thinner boundary layer
2	Kareem et al. [15]	Review in corrugation for heat	Helically coiled corrugation has compound

		transfer enhancement	effect of curvatures as well as corrugation
3	Pethkool et al. [16]	Helical corrugation in heat exchanger	Heat transfer enhancement along with friction factor was studied experimentally and an empirical relation was established
4	García et al. [17]	Corrugated tubes, dimpled tubes and wire coils in heat transfer	Core flow rotation causes transition from laminar to tubulent flow, coil causes smooth transition to turbulent
5	Zimparov [18]	Combined single-start spirally corrugated tubes with a twisted tape	Benefits of using combined structures over smooth tubes, reduction in entropy generation
6	Elshafei et al. [19]	Heat transfer & pressure drop	Heat transfer enhancement achieved along with rise in pressure drop, channel spacing also affects pressure drop
7	Rainieri et al. [20]	Helically coiled wall corrugated tubes	In a given range of Re, both the curvature as well as the combination of curvature & corrugation enhance heat transfer
8	Naphon [21]	Channel with V corrugated upper and lower plates	Such design provides higher compactness
9	Gradeck et al. [22]	Local heat transfer analysis in corrugated channel	Heat transfer coefficient has strong sensitivity to convective effects at top of the corrugation only
10	Saha & Saha [23]	Integral helical rib roughness & fitted wavy strip	Up to a certain amount of wavy strip centre-clearance, the integral design performs better than individual
11	Bhattacharyya et al. [24]	Heat transfer enhancement & entropy generation of flow through a wavy channel	Combination of the low wave ratio and low diameter ratio shows promising heat transfer effect
12	Deb & Poudel [25]	Combined wire coil and wavy strip in a tube	Combined effect augments the heat transfer enhancement
13	Sharma et al. [26]	Twisted tape inserts in a tube	A new method to predict heat transfer coefficient with twisted tape inserts considering heat transfer augmentation due modified wall shear and temperature gradient
14	Agarwal & Rao [27]	Circular tubes with twisted tape inserts	Developed a correlation to predict isothermal friction factors and Nusselt number

2.2 Magnetohydrodynamic (MHD) mixed convection

In this type of procedure, magnetic field with certain strength is also applied in the heat transfer device with an aim of enhancing the heat transfer capability. Many of the research works in this area are carried out numerically using computational fluid dynamics rather than experimentally due to the ease of parametric variation and cost effectiveness. Generally, a lid-driven square cavity is considered with liquid filled inside it. Magnetic field is supplied across the cavity and the variation of heat transfer coefficient in terms of Nusselt number (Nu) is studied. Table -2 demonstrate various kinds of heat transfer enhancement techniques within MHD mixed convection using lid-driven cavity. Each kind of innovation has helped to understand the fundamental behind the phenomenon and to draw a strong conclusion for applying in the practical field.

Table -2: Studies associated with heat transfer enhancement technique using magnetohydrodynamic (MHD) mixed convection in a lid-driven cavity

S. No.	Author(s)	Investigation	Conclusion
1	Malleswaran & Sivasankaran [28]	MHD Mixed Convection in a Lid-driven Cavity with Corner Heaters	The magnetic field has greater effect on heat transfer rate with vertical heater than with horizontal one
2	Oztop et al. [29]	MHD mixed convection in a lid-driven cavity with corner heater	Size of heater and the magnetic field strength has a great effect on boundary layer thus dictates heat transfer rate
3	Selimefendigil & Oztop [30]	MHD mixed convection in a nanofluid filled lid-driven enclosure with a rotating cylinder	Presence of magnitic field minimizes the velocity field and thus convection; solid volume fraction of nanoparticle increases heat transfer
4	Deb et al. [31]	MHD convection in a lid-driven cavity with a heat conduction elliptical obstacle	Magnetic field offers damping effect on transport (convection) and suppress natural convection of heat
5	Pekmen & Tezer-Sezgin [32]	MHD flow in a lid-driven porous enclosure	Decrease in permeability of porous medium slows down the fluid flow
6	Hussain et al. [33]	MHD mixed convection and entropy generation in a lid-driven cavity with nanofluid flow	Total entropy generation adds up with rise in Reynolds number
7	Rashad et al. [34]	MHD mixed convection in a nanofluid-filled lid-driven cavity with partial-slip	Shortest length of source/sink give the maximum convective heat transfer; partial slip on walls alters the streamlines and isotherms ultimately decreases the convective heat transfer
8	Chatterjee [35]	MHD mixed convection in a lid-driven cavity with a heated source	Contribution of straight and semicircular sources towards heat transfer is more than towards the bulk fluid temperature
9	Rahman et al. [36]	MHD mixed convection in a lid-driven cavity with a heated semi-circular source	Direction of the moving lid has a great effect on flow field; lower Joule parameter decreases heat transfer
10	Sivasankaran et al. [37]	MHD mixed convection of Cu-water nanofluid in a lid-driven porous cavity with a partial slip	Nanoparticles properties as well as porosity of the medium affects the flow thus the convection heat transfer
11	Rahman & Alim [38]	MHD mixed convection in a lid-driven enclosure with a heat conducting circular cylinder with Joule heating	Hartmann number, Reynolds number and Richardson number have strong effects on the streamline and isotherm plots
12	Deb et al. [39]	MHD convection in a lid-driven cavity containing a	Size and orientation of the obstacle dictates isotherms as

		obstacle with different inclination	well as orientation thus alters heat transfer
13	Sajjadi et al. [40]	Lattice Boltzmann simulation of MHD mixed convection	Established a new lattice Boltzmann method to replicate the results of CFD; growth of magnetic field induces circulation and vortices on streamlines
14	Hasanpour et al. [41]	Prandtl effect on MHD flow in a lid-driven porous cavity	Rise in average Nusselt number by increasing Prandtl number; up to 28% increment in heat transfer enhancement by increasing Prandtl number

3. CONCLUSION

In this work, we show a comparative study of two different kinds of convection heat transfer enhancement techniques carried out with an aim of better thermal/energy/power management. We explored and presented the recent articles in the field of passive heat transfer enhancement using extra surface to kill the thermal boundary layer as well as the MHD mixed convection in a lid-driven cavity. Hereby, we are confident enough that this review article will help in planning for future design and development of heat exchangers in plethora of applications.

REFERENCES

[1] Arsenyeva, O. P., Tovazhnyansky, L. L., Kapustenko, P. O., & Khavin, G. L. (2011). Optimal design of plate-and-frame heat exchangers for efficient heat recovery in process industries. *Energy*, *36*(8), 4588-4598.
[2] Vasiliev, L. L. (2005). Heat pipes in modern heat exchangers. *Applied thermal engineering*, *25*(1), 1-19.
[3] Sunden, B. (2005, September). High temperature heat exchangers (HTHE). In *Proceedings of the 5th International Conference on Science, Engineering and Technology, VIT University, Vellore, India*.
[4] Babrauskas, V. (2006). Effective heat of combustion for flaming combustion of conifers. *Canadian Journal of Forest Research*, *36*(3), 659-663.
[5] Cartellieri, W., Chmela, F. G., Kapus, P. E., & Tatschl, R. M. (1994). Mechanisms leading to stable and efficient combustion in lean burn gas engines. In *Proceedings of International Symposium COMODIA*.
[6] Singh, S. (2001). *U.S. Patent No. 6,237,579*. Washington, DC: U.S. Patent and Trademark Office.
[7] Balat, M. (2005). Current alternative engine fuels. *Energy Sources*, *27*(6), 569-577.
[8] Murugesan, A., Umarani, C., Subramanian, R., & Nedunchezhian, N. (2009). Bio-diesel as an alternative fuel for diesel engines—a review. *Renewable and sustainable energy reviews*, *13*(3), 653-662.
[9] Poudel, S., & Deb, D. Study of Modified Internal Combustion Engine to Run with Ethanol. *International Journal of Engineering and Applied Sciences*, *4*(8).
[10] Gupta, K. K., Rehman, A., & Sarviya, R. M. (2010). Bio-fuels for the gas turbine: A review. *Renewable and Sustainable Energy Reviews*, *14*(9), 2946-2955.
[11] Farooque, M., & Maru, H. C. (2001). Fuel cells-the clean and efficient power generators. *Proceedings of the IEEE*, *89*(12), 1819-1829.
[12] Wang, J., Anthony, E. J., & Abanades, J. C. (2004). Clean and efficient use of petroleum coke for combustion and power generation. *Fuel*, *83*(10), 1341-1348.
[13] Andreycak, W. M. (2008). *U.S. Patent No. 7,375,994*. Washington, DC: U.S. Patent and Trademark Office.
[14] Sheikholeslami, M., Gorji-Bandpy, M., & Ganji, D. D. (2015). Review of heat transfer enhancement methods: Focus on passive methods using swirl flow devices. *Renewable and Sustainable Energy Reviews*, *49*, 444-469.
[15] Kareem, Z. S., Jaafar, M. M., Lazim, T. M., Abdullah, S., & Abdulwahid, A. F. (2015). Passive heat transfer enhancement review in corrugation. *Experimental Thermal and Fluid Science*, *68*, 22-38.
[16] Pethkool, S., Eiamsa-Ard, S., Kwankaomeng, S., & Promvonge, P. (2011). Turbulent heat transfer enhancement in a heat exchanger using helically corrugated tube. *International Communications in Heat and Mass Transfer*, *38*(3), 340-347.
[17] García, A., Solano, J. P., Vicente, P. G., & Viedma, A. (2012). The influence of artificial roughness shape on heat transfer enhancement: Corrugated tubes, dimpled tubes and wire coils. *Applied Thermal Engineering*, *35*, 196-201.
[18] Zimparov, V. (2002). Enhancement of heat transfer by a combination of a single-start spirally corrugated tubes with a twisted tape. *Experimental Thermal and Fluid Science*, *25*(7), 535-546.
[19] Elshafei, E. A. M., Awad, M. M., El-Negiry, E., & Ali, A. G. (2010). Heat transfer and pressure drop in corrugated channels. *Energy*, *35*(1), 101-110.
[20] Rainieri, S., Bozzoli, F., Cattani, L., & Pagliarini, G. (2013). Compound convective heat transfer enhancement in helically coiled wall corrugated tubes. *International Journal of Heat and Mass Transfer*, *59*, 353-362.
[21] Naphon, P. (2007). Heat transfer characteristics and pressure drop in channel with V corrugated upper and lower plates. *Energy conversion and management*, *48*(5), 1516-1524.

[22] Gradeck, M., Hoareau, B., & Lebouché, M. (2005). Local analysis of heat transfer inside corrugated channel. *International journal of heat and mass transfer*, *48*(10), 1909-1915.

[23] Saha, S., & Saha, S. K. (2013). Enhancement of heat transfer of laminar flow through a circular tube having integral helical rib roughness and fitted with wavy strip inserts. *Experimental Thermal and Fluid Science*, *50*, 107-113.

[24] Bhattacharyya, S., Chattopadhyay, H., Swami, A., & Uddin, M. K. (2016). Convective heat transfer enhancement and entropy generation of laminar flow of water through a wavy channel. *International Journal of heat and Technology*, *34*(4), 727-733.

[25] Deb, D., & Poudel, S. Investigation of Heat Transf Laminar Flow through Circ Combined Wire Coil and Wa.

[26] Sarma, P. K., Subramanyam, T., Kishore, P. S., Rao, V. D., & Kakac, S. (2003). Laminar convective heat transfer with twisted tape inserts in a tube. *International Journal of Thermal Sciences*, *42*(9), 821-828.

[27] Agarwal, S. K., & Rao, M. R. (1996). Heat transfer augmentation for the flow of a viscous liquid in circular tubes using twisted tape inserts. *International Journal of Heat and Mass Transfer*, *39*(17), 3547-3557.

[28] Malleswaran, A., & Sivasankaran, S. (2016). A Numerical Simulation on MHD Mixed Convection in a Lid-driven Cavity with Corner Heaters. *Journal of Applied Fluid Mechanics*, *9*(1).

[29] Oztop, H. F., Al-Salem, K., & Pop, I. (2011). MHD mixed convection in a lid-driven cavity with corner heater. *International Journal of Heat and Mass Transfer*, *54*(15-16), 3494-3504.

[30] Selimefendigil, F., & Öztop, H. F. (2014). Numerical study of MHD mixed convection in a nanofluid filled lid driven square enclosure with a rotating cylinder. *International Journal of Heat and Mass Transfer*, *78*, 741-754.

[31] Deb, D., Poudel, S., & Chakrabarti, A. (2017). Numerical Simulation of Hydromagnetic Convection in a Lid-driven Cavity Containing a Heat Conducting Elliptical Obstacle with Joule Heating. *International Journal of Engineering Research and Technology*, *6*(08).

[32] Pekmen, B., & Tezer-Sezgin, M. (2014). MHD flow and heat transfer in a lid-driven porous enclosure. *Computers & Fluids*, *89*, 191-199.

[33] Hussain, S., Mehmood, K., & Sagheer, M. (2016). MHD mixed convection and entropy generation of water–alumina nanofluid flow in a double lid driven cavity with discrete heating. *Journal of Magnetism and Magnetic Materials*, *419*, 140-155.

[34] Rashad, A. M., Ismael, M. A., Chamkha, A. J., & Mansour, M. A. (2016). MHD mixed convection of localized heat source/sink in a nanofluid-filled lid-driven square cavity with partial slip. *Journal of the Taiwan Institute of Chemical Engineers*, *68*, 173-186.

[35] Chatterjee, D. (2013). MHD mixed convection in a lid-driven cavity including a heated source. *Numerical Heat Transfer, Part A: Applications*, *64*(3), 235-254.

[36] Rahman, M. M., Öztop, H. F., Rahim, N. A., Saidur, R., & Al-Salem, K. (2011). MHD mixed convection with joule heating effect in a lid-driven cavity with a heated semi-circular source using the finite element technique. *Numerical Heat Transfer, Part A: Applications*, *60*(6), 543-560.

[37] Sivasankaran, S., Mansour, M. A., Rashad, A. M., & Bhuvaneswari, M. (2016). MHD mixed convection of Cu–water nanofluid in a two-sided lid-driven porous cavity with a partial slip. *Numerical Heat Transfer, Part A: Applications*, *70*(12), 1356-1370.

[38] Rahman, M. M., & Alim, M. A. (2010). MHD mixed convection flow in a vertical lid-driven square enclosure including a heat conducting horizontal circular cylinder with Joule heating. *Nonlinear Analysis: Modelling and Control*, *15*(2), 199-211.

[39] Deb, D., Poudel, S., & Chakrabarti, A. (2017). Numerical Simulation of Hydromagnetic Convection in a Lid-driven Cavity Containing a Heat Conducting Inclined Elliptical Obstacle with Joule Heating. *International Journal of Engineering Research and Technology*, *6*(10).

[40] Sajjadi, H., Gorji-Bandpy, M., Ganji, D. D., & Kefayati, G. R. (2012). Lattice Boltzmann simulation of MHD mixed convection in a two-sided lid-driven square cavity. *Heat Transfer—Asian Research*, *41*(2), 179-195.

[41] Hasanpour, A., Farhadi, M., Sedighi, K., & Ashorynejad, H. R. (2012). Numerical study of Prandtl effect on MHD flow at a lid-driven porous cavity. *International Journal for Numerical Methods in Fluids*, *70*(7), 886-898.