A REVIEW OF STUDYING EFFECT OF RIBS HEIGHT IN TWO –PHASE FLOW ON HEAT TRANSFER COEFFICIENT IN VERTICAL RIBBED DUCT

Shaimaa G. Hamza[1]
eng806.shyma.galab@student.uobabylon.edu.iq
[1]**Mechanical Engineering Department / Faculty of Engineering / University of Babylon, Iraq.**

Riyadh S. Al-Turaihi[2]
drriyadhalturaihi@yahoo.com
[2]**Mechanical Engineering Department / Faculty of Engineering / University of Babylon, Iraq.**

ABSTRACT

The effect of rib height on the heat transfer coefficient in two-phase flow in vertical ribbed ducts is reviewed. It consolidates and examines the experimental and numerical studies carried out on rib geometry, flow regimes, and fluid properties. The results indicate that increasing the rib height significantly enhances heat transfer coefficient with increased turbulence and fluid-surface interaction, but not at the expense of significant pressure drop. Optimizing rib height can enhance heat transfer efficiency and lessen energy losses. The role of rib attack angle and flow disturbance as well as the pressure losses associated with each in two-phase heat transfer enhancement are discussed. The energy efficiency and cooling performance can be further improved in the future by integrating ribs geometry variation with Nano fluid in multiphase conditions.

Keywords: Two-phase flow, Ribs height, Ribbed duct, Vertical channel, Pressure Drop.

NOMENCLATURE

HTC	Heat Transfer Coefficient
TPF	Two-Phase Flow
Rd	Ribbed duct
Rh	Rib height
Vc	Vertical channel
Nu	Nusselt number
Re	Reynolds number
Exp	Experimental

Received: July 16, 2025.
Accepted: March 29, 2026.

Num	Numerical
Turb	Turbulent
VG	Vortex Generator
PD	Pressure Drop

INTRODUCTION

In solar air heaters and turbine blade cooling systems, heat transfer in rib-roughened channels must be enhanced to improve energy efficiency (Mousa et al.2021). The performance of solar air heaters will improve considerably when rib geometries such as trapezoidal staggered ribs, rotating cylindrical turbulators, etc. are optimized (Gomaa et al. ,2025); (Wang et al. ,2023), Studies on different rib shapes, for example, triangular, W-shaped and hybrid rib shapes have shown increase in Nusselt Number value and decrease in pressure drop across the duct shapes (Jin et al. ,2024); (Nagayach et al. ,2023);(Zheng et al. ,2022). Spiral tubes and ribbed channels have shown improved heat transfer performance when used for energy and turbine application (Singh et al. ,2024) ;(Wolff,2022); (Zhu et al. ,2021). Modern experimental and numerical methods, particularly CFD simulation, Particle Image Velocimetry (PIV) and Laser induced fluorescence (LCT) are giving deeper insights on the structures of turbulent flows and on the rib induced vortex flow in stationary as well as rotating channels (Li et al.,2022). Moreover, studies have also been made on two-phase flow, boiling in ribbed channels and narrow ducts. In this phase distribution, local heat transfers and pressure drop interaction was studied. According to one source, it was found that better thermal performance could be achieved by geometric modification (Singh et al.,2023). This study evaluates additional improvements to the heat transfer and pressure loss trade-offs that can be achieved through optimum rib configuration in ribbed channel in view of the gains received with these ribs.In recent years, many researchers have worked on improving heat transfer in ribbed and structured channels under both single- and two-phase flow conditions. (Shen et al. ,2025) showed that heat transfer can be significantly enhanced in vertical tubes, especially when two-phase flow is involved.(Chen et al. ,2025) also emphasized that rib geometry has a clear impact on thermal and flow behavior in microchannels. The influence of mist/steam cooling in ribbed channels was examined by (Tamang et al., 2023) and (Tamang et al., 2025), who reported noticeable improvement in thermal performance due to the interaction between phases. In addition, (Hameed et al. ,2024) used CFD simulations to demonstrate that different rib configurations can considerably affect heat transfer in triangular ducts. Further optimization studies by (Yang et al. ,2023) and (Wang et al. ,2024) confirmed that adjusting structural parameters improves cooling efficiency. More recently, (Koveiti et al. ,2025) indicated that combining V-shaped ribs with nanofluids can further enhance heat transfer performance. (Kumar et al. ,2023) investigated the thermo-hydraulic performance of artificial ribs mounted in a rectangular duct, demonstrating notable enhancement in heat transfer accompanied by an expected increase in friction losses.

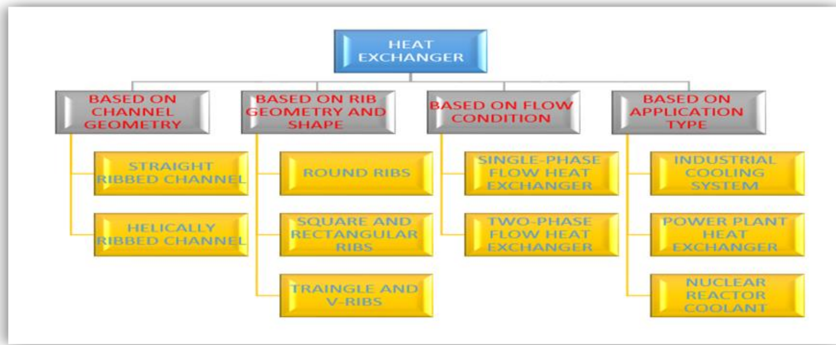

Fig. 1. A classification of heat transfers according to the influence of ribbed channel design. (The schematic was designed and prepared by the authors to illustrate the geometry used in the study).

KEY APPLICATIONS INCLUDE

- Power plants use ribbed ducts for their cooling systems. Moreover, such systems enhance the cooling in power generation units. Using ribbed ducts helps cool down the pipes and thermal system thereby improving the efficiency of the operation.

- The nuclear reactor needs to remove the heat effectively so that the temperature can be kept to a satisfactory level. Nuclear applications can benefit from the increased cooling efficiency brought by ribbed vertical channels under two-phase flow conditions.

- Ribbed designs boost heat conduction between various fluids inside heat exchangers. This aspect makes chemical industries' industrial processes more efficient while using less energy at exchangers.

- Ribbed ducts improve heat transfer in aircraft and spacecraft cooling applications. In such applications, operation optimization was encouraged by controlling two-phase flow to improve thermal performance.

ROLE OF RIB HEIGHT IN ENHANCING HEAT TRANSFER EFFICIENCYAIR-WATER TWO-PHASE FLOW IN VERTICAL RIBBED CHANNELS

The phenomenon of heat transfer due to the interaction of water and air flow in vertical ribbed channels is complex. These ribbed surfaces will enhance the thermal performance of the system. In a ribbed channel with vertical flow of air and water, the effect of the design and height of the rib on the performance of heat transfer has been studied under two phase situations for enhancement of heat transfer. The internal ribs from the vertical passages help improve cooling and thermal performance from the surface while also aiding in wetting between the liquid and solid. In some applications, it is important to control heat.

THE FACTORS AFFECTING HEAT TRANSFER ENHANCEMENT IN RIBBED CHANNELS

Geometric Parameters of Ribs

- **Rib Height**: A significant parameter that has a strong impact on heat transfer. Higher ribs increase airflow and heat change across the ribcage. Air moves in a unique way close to the edges. This causes more agitation of the fluid due to which a higher rate of heat transfer is achieved. However, increasing the rib height higher increases the pressure drop also. Thus, there exists an energy penalty associated with this enhancement. It is vital to identify the optimum rib height that enhances the heat transfer rate, while having low pressure loss.
- **Rib Shape and Orientation (Angle of Attack):**The square, triangular and V-shape of various ribs influence the flow structure in different ways. To add secondary flows to channels with rib patterns, features like V-ribs or angles are added. The thermal boundary layer gets broken up and there is an improvement in heat transfer. The angle of attack (the angle of the ribs with respect to the direction of flow) is also important, as certain angles yield stronger and more heat transfer-enhancing vortices but also higher pressure losses.
- **The distance (or pitch)** between the ribs will affect the flow path and turbulence characteristics of the fluid. The turbulence increases and wall interaction occurs more with lower pitch distances used in this design. However, a restriction that is too small can lead to excessive pressure drop. Just like that, the turbulence effect will be reduced if the pitch is very larger. Studies show a proper pitch will provide maximum heat transfer and good flow resistance.

Flow Conditions in Two-Phase Flow

- **Inlet Velocity and Flow Rate:** The fluid may interact with the ribbed channel differently depending on the inlet velocity profile and flow rate. Higher inlet velocities generally increase turbulence hence enhancing heat transfer But, an increase in the flow rate will also produce more frictional losses and higher energy costs. Make the inlet velocity optimum to get the most result. The involvement of two-phase flow i.e. mixing of air and water will get benefited from ribs. It will change the flow in a different manner. However, it will involve phases separately. It will get optimum heat transfer as the phases will function on ribs separately.
- **Two-Phase Flow Regime:** In two-phase flow, heat transfer is directly impacted by the arrangement of gas and liquid phases stratified versus slug. For instance, in a bubbly flow regime, when gas bubbles are located in the liquid, the heat transfer coefficient tends to be higher (Zhu et al. 2023).

Thermodynamic Properties and Performance Indicators

- **The heat transfer coefficient** is a good measure of thermal performance. Rib height, shape and flow rate are some factors that affect HTC. Higher HTC value indicates better heat transfer which means channel can remove heat from the fluid quicker. Research indicates that ribbed channels tend to have higher heat transfer coefficients (HTC) than smooth channels, as the ribs disrupt the thermal boundary layer in the channel fluid and promote mixing. One of the important challenges in channel design is to achieve high HTC at low pressure drop.
- **Pressure Drop (PD):** Heat transfer improvement must account for pressure drop. Ribs cause resistance to flow and create pressure drops leading to loss of energy to maintain flow rate.

Experimental and Numerical Approaches

Experimental investigations: Experimental tests on ribbed pipes take real-world quantitative measures of heat transfer rate, pressure drop as well as flow pattern under test conditions. Research shows how rib height and spacing affect heat transfer in designs used in industry and business. Experiments can illustrate complex effects that a simulation cannot recreate, such as turbulent structures or phase distribution in a two-phase flow process.

- The process of simulating Computational Fluid Dynamics or CFD in ribbed channels helps to know the heat transfer and flow behavior taking place (Akermann et al. 2024) A numerical study will enable the researchers to visualize and quantify the affect of different rib geometry, different flow rate and fluid property (Mahmoodi et al. 2022). CFD helps demonstrate the internal movement of fluids through an object so that you can discover the most effective design or operating conditions. Numerical studies can help in understanding the phase interaction behavior at lower (or higher) orders.

Practical Applications in Industry

- To prevent the overheating of both power-generating thermal power plants and nuclear reactors, ribbed channels are installed to remove heat from these areas. The ribs transfer heat more efficiently so as to cool the high temperature components better. The rib shape and flow condition have an essential effect on heat transfer in these applications, which is necessary for proper functioning and safety.
- Ribbed heat exchangers are used in chemical industry processes when phase changes or high thermal loads occur. All applications also include aerospace industry applications. Aerospace components and engine cooling uses cooling ribs channels in aerospace components and engines. In food processing and aerospace industries, high heat transfer applications may have ribbed channels because of the occurring two-phase flows. This seems to help in their effective operation (Parmar et al.2023).

CLASSIFICATION OF RIBBED CHANNEL TYPES FOR HEAT TRANSFER ENHANCEMENT

Based on Rib Shape

- **Square Ribs**: Square ribs are one of the most popular types of ribs. It causes a large amount of turbulence. They break down boundary layers and, therefore, heat transfer rates improve when they are used. Square ribs can cause a large pressure drop, and it may be necessary to balance this as well as required.
- **Triangular Ribs**: Triangular ribs affect flow differently compared to square ribs. Due to the lower pressure drop, a heat transfer enhancement occurs if they are used. People often use this design when a moderate enhancement will do, without much energy loss.
- **V-Ribs**: V-shaped ribs are positioned at an angle to the flow direction, allowing for the formation of secondary flows and increasing heat transfer and mixing. The vertex of the V-ribs can also face upstream or downstream. The former is called a forward-facing configuration and the latter a backward-facing configuration. This choice alters the flow through the device (Gajghate et al. 2023).
- **Round Ribs**: Usually such ribs help in smoother interaction n with the flow which in turn reduces turbulence and lowers pressure drop. Round ribs are ideal for applications where energy efficiency is important, although their heat transfer improvement is not as significant as that of square or triangular ribs.

Based on Rib Orientation

- **Transverse Ribs**: The ribs which cut across the flow are transverse ribs. This orientation creates significant turbulence, disrupts the boundary layer, and improves heat transfer greatly. However, transverse ribs usually lead to the highest pressure drop due to directly blocking the flow.
- **Inclined Ribs**: Inclined ribs are positioned at an angle to the flow direction instead of being completely transverse. This orientation decreases pressure drop from transverse type ribs and adds to turbulence. Heat transfer enhancement and energy efficiency often needs a compromise in the shape of inclined ribs.
- **Vortex-Generating Ribs**: For enhanced mixing, the ribs are designed to create small currents (vortices) within the flow. The designs of ribs generating vortices are usually complex and/or angled, which results in a higher design cost but much better thermal performance.

Based on Rib Arrangement

- **Continuous Ribs:** The ribs in this arrangement are uninterrupted along the surface of the channel. Continuous ribs give the flow a constant effect which can lead to stable turbulence levels in the channel. But, solid ribs can create high-pressure losses.

- **Interrupted Ribs:** The ribs in the channels are spaced with interruptions. The openings, or gaps, in the surface enable the flow to fix itself again after every rib causing a periodic disturbance in the boundary layer to enhance heat transfer. Heat transfer efficiency has improved across the use of interrupted ribs which drop continuous ribs.
- **Staggered Ribs**: The ribs on opposite channel walls are staggered or offset. The flow configuration creates turbulence because the flow patterns are asymmetric, which increases heat transfer. Staggered ribs work well in rectangular or square channels where reattachment and redistribution of the flow is possible.

Based on Channel Configuration and Surface Design

- **Helically Ribbed Channels**: Channels with helically aligned ribs help to swirl-up the flow for better turbulence and surface area interaction. Helically ribbed channels are particularly effective for applications requiring high heat transfer across the channel surface.
- **Serpentine Channels with Ribbed Surfaces**: Serpentine channels are made with bends/turns and often have ribbed surfaces for better fluid mixing. It is beneficial when there is fast heat removal required, where the flow direction changes and ribs team up to enhance turbulence.
- **Rotated Ribs**: The ribs that are located on the walls of the channel are rotated. Rotated ribs create complex turbulence patterns and are often employed in applications that require a trade-off between high heat transfer rates and controlled pressure drops.

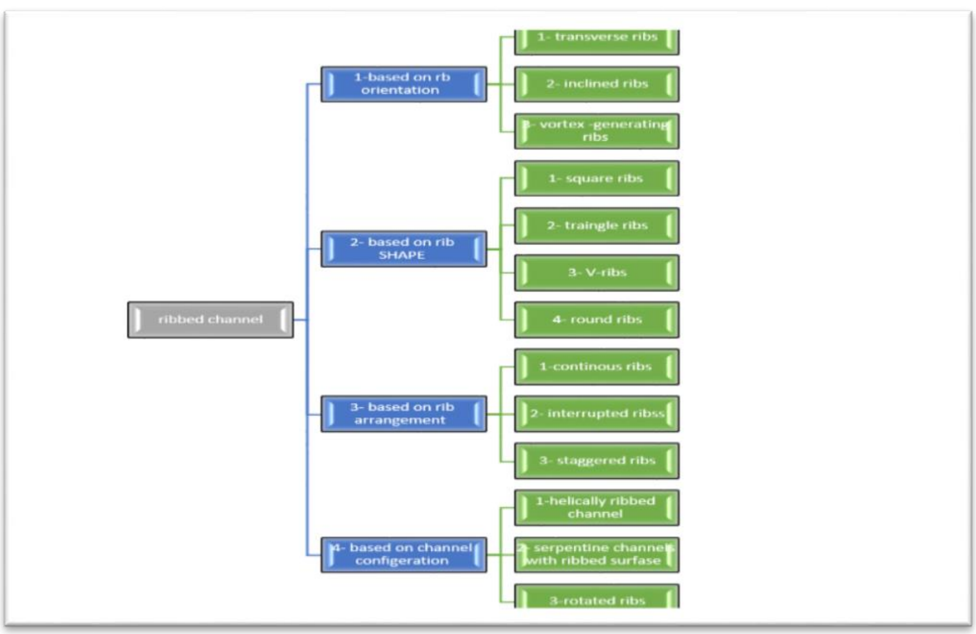

Fig. 2. Classification of ribbed channel**:** The schematic was designed and prepared by the authors to illustrate the geometry used in the study.

CHALLENGES AND LIMITATIONS IN RIBBED CHANNEL DESIGN

Many problems are being solved while designing ribbed channels for increased heat transfer. Getting the best rib shape is one of the main issues to get best heat transfer that does not incur high pressure drop. Raising rib heights and adding complex shapes can add turbulence and increase heat transfer coefficient, however, they will usually create more frictional losses and increase the energy costs. This increased heat transference and increased chance of pressure drop affects the overall efficiency of the system. The high thermal performance would lead to less efficiency due to a higher pump. Choosing a proper orientation and spacing (pitch) of the ribs presents a challenge. Narrow spaces between ribs can disturb boundary layers and improve mixing, but this leads to more flow resistance. But, more space between the rib will not obstruct the flow but will lessen the effect of turbulence. Figuring out the ideal ratio between pitch and height is very important because it helps us get most benefits from ribbed channel, but this depends on operating condition and flow regime.

CONCLUSIONS

The objective of this assessment is to compile the available raw investigations on two-phase flow heat transfer enhancement in vertical ribbed ducts. The review results indicated constantly rib heights result in the performance of heat transfer, which basically increases the very turbulence, improves further fluid-surface interaction, and in turn deflect boundary layer. In order to maximize the design flexibility of a heat sink, optimization allows it to undergo shape transformation. The analysis of a morphing 45-degree heat sink is done to determine the overall cooling performance. Writings also show that Rib shape – triangular, V-shaped and inclined rib impact generation of secondary flows, vortex structure and local heat transfer uniformity. Among these geometric features, our optimization can provide a well-balanced improvement in heat transfer and a low loss in hydraulic energy. A two-phase flow regime such as bubbly, churn or annular pattern alters the phase distribution and liquid-solid contact in a similar way. As a result, the heat transfer coefficient that can be achieved is affected. Both experimental studies and two-dimensional simulations suggested investigating the optimal rib design, in which rib height, pitch-to-height ratio and rib orientation have to be taken into account, along with the anticipated two-phase flow regime for reliable performance. In conclusion, the rib height, rib geometry, flow conditions and thermophysical properties together define the heat transfer characterization of ribbed vertical channels. Combining results from both experimental and numerical investigations gives a clearer picture of the mechanisms that enhance heat transfer with the ensuing penalties in terms of pressure drops. Once understood, it can be useful in designing ribbed-channel which are effective for power generation, chemical processing, aerospace cooling and nuclear applications thermal systems. This trend aligns well with earlier research highlighting the combined influence of rib geometry, flow regime, and advanced cooling techniques on thermal performance improvement.

PRACTICAL IMPLICATIONS

The ribbed channel design outcomes will benefit any industrial use possessing thermally dependent flow systems. Ribbed channels enhance cooling of condenser and cooler in a power generator. Cooling that's effective makes operations safe and inexpensive. Ribbed channels with optimization are eligible for use in chemical processing when critical nature of temperature gets involved in the reaction rates to ensure better temperature control, productivity and safety. The ribbed channels in an industrial cooling system can incorporate V-shaped or triangular ribs to promote good heat transfer with low flow resistance. Nuclear reactors require dependable and thermally efficient cooling systems. Ribbed channels can be used to handle elevated temperature & safety. This study will aid the understanding of an important heat transfer mechanism and provide useful measures to enhance energy efficiency in these important sectors**.**

RECOMMENDATIONS FOR FUTURE RESEARCH:

Further studies can focus on rib geometries and Nano-fluids interaction for enhancement in the effectiveness of heat transfer. Besides this, more general investigations on how rib geometry affects other two-phase flow patterns could yield helpful information on the optimization of ribbed channels for specific industrial applications.

REFERENCES

Akermann, K. and Renze, P., 'Numerical study of turbulent heat transfer and particle deposition in enhanced pipes with helical roughness', International Journal of Multiphase Flow, Vol.176, Article 104827, 2024. doi:10.1016/j.ijmultiphaseflow.2024.104827.

Chen, J., Xu, H., Li, D., Qu, J., Zhuravkov, M., Lapatsin, S. and Jiang, W., 'Comprehensive analysis of flow-heat transfer-thermodynamics in ribbed microchannel jet process with different structures', International Communications in Heat and Mass Transfer, Vol.169, Part A, Article 109593, 2025. doi: 10.1016/j. icheatmasstransfer. 2025. 109593.

Gajghate, S.S., Deshpande, O.P., Desai, A.U., Deshmukh, A.D., Kharade, S.U., Pal, S., Cardoso, E.M., Saha, B.B. and Bhaumik, S., 'Effect of Ribs Configurations on Heat Transfer Enhancement for W-Shaped Ribs in a Square Duct', Arabian Journal for Science and Engineering, Vol.48, pp. 12141–12160, 2023. doi: 10.1007/s13369-023-07662-7.

Gomaa, A., Mhrous, Y. and Abdelmagied, M.M., 'Investigation of the hydraulic and thermal characteristics of a double concentric tubes with an inner twisted spiral tube', Scientific Reports, Vol.15, Article 9301, 2025. doi: 10.1038/s41598-025-92043-3.

Hameed, M.H. and Mohammed, H.H., 'Assessment of heat transfer in a triangular duct with different configurations of ribs using computational fluid dynamics', Open Engineering, Vol.14, No.1, pp. 1-15, 2024. doi: 10.1515/eng-2022-0523.

Jin, C., Tao, L., Gu, S., Ju, Y. and Zhao, X., 'Experimental study on the flow pattern and local heat transfer characteristics of water flow boiling in a vertical upward narrow rectangular channel heated by steam', Applied Thermal Engineering, Vol.247, Article 123091, 2024. doi: 10.1016/j. applthermaleng.2024.123091.

Koveiti, A., Ali, A.B.M., Alhamdi, S.F.H., Akbari, O.A., Ahmadi, G., Salahshour, S. and Baghaei, Sh., 'Numerical simulation of laminar and two-phase flow and heat transfer of water-aluminum oxide nanofluid in microchannel with V-shaped ribs', Results in Engineering, Vol. 27, No. 1, Article 106062, 2025. doi:10.1016/j.rineng. 2025.106062.

Kumar, B.V., Kanna, P.R., Manikandan, G., Taler, D., Taler, J., Sobota, T. and Nowak-Ocłoń, M., 'Investigation of Thermo-Hydraulic Performances of Artificial Ribs Mounted in a Rectangular Duct', Energies, Vol. 16, No. 11, Article 4404, 2023. doi:10.3390/en16114404.

Li, H., Shi, J., You, R. and Tao, Z., 'Particle image velocimetry measurements of turbulent flows in rotating square ribbed ducts', Physics of Fluids, Vol. 34, No. 7, Article 075102, 2022. doi:10.1063/5.0097193.

Mahmoodi-Jezeh, S.V. and Wang, B.-C., 'Direct numerical simulation of turbulent duct flow with inclined or V-shaped ribs mounted on one wall', Journal of Fluid Mechanics, Vol. 932, Article A48, 2022. doi:10.1017/jfm.2021.1028.

Mousa, M.H., Miljkovic, N. and Nawaz, K., 'Review of heat transfer enhancement techniques for single phase flows', Renewable and Sustainable Energy Reviews, Vol.137, Article 110566, 2021. doi:10.1016/j.rser.2020.110566.

Nagayach, N.K., Sharma, K., Agrawal, Y. and Yadav, A.S., 'Revisiting the Effect of Rib Roughness on the Performance of Solar Air Heater', E3S Web of Conferences, Vol.430, Article 01264, 2023. doi:10.1051/e3sconf/202343001264.

Parmar, S.S.S., Beohar, G. and Gupta, S., 'Improving Gas Turbine Efficiency through Ribbed Channel Designs: A CFD-Based Study', International Journal for Research in Applied Science & Engineering Technology (IJRASET), Vol. 11, Issue VII, pp. 988–1000, 2023. doi:10.22214/ijraset.2023.54783.

Shen, J., Liu, Z., Huang, D., Huang, G., Li, W. and Shan, L., 'Enhanced single-phase and two-phase flow heat transfer in vertical tube', Applied Thermal Engineering, Vol. 280, Part 3, Article 128329, 2025. doi:10.1016/j.applthermaleng.2025.128329.

Singh, S., Suman, S., Mitra, S. and Kumar, M., ‘Optimization of a novel trapezoidal staggered ribs configuration for enhancement of a solar air heater performance using CFD’, Environmental Science and Pollution Research, Vol. 30, pp. 93582–93601, 2023. doi:10.1007/s11356-023-28978-9.

Singh, S., Suman, S., Mitra, S. and Kumar, M., ‘Thermo-hydraulic performance enhancement of a solar air heater using rotating cylindrical turbulators’, Applied Thermal Engineering, Vol. 236, Part C, Article 121748, 2024. doi:10.1016/j.applthermaleng.2023.121748.

Tamang, S. and Park, H., ‘Optimization of heat transfer in mist/steam cooled square channel with kink angled rib turbulator’, International Communications in Heat and Mass Transfer, Vol. 140, Article 106553, 2023. doi:10.1016/j.icheatmasstransfer.2022.106553.

Tamang, S. and Park, H., ‘Effects of Mist/Steam Flow on Heat Transfer Performance for Rib Turbulated Channel’, Heat Transfer Engineering, 2025. doi:10.1080/01457632.2025.2480903.

Wang, J., Deng, X., Jia, D., Lei, J. and Xie, G., ‘Numerical investigation on effects of rib shapes on oscillating flow and heat transfer in heat exchanger channels’, Thermal Science and Engineering Progress, Vol. 42, Article 101919, 2023. doi:10.1016/j.tsep.2023.101919.

Wang, Y.-B., Yan, K.-C., Wang, C.-X., Wang, S.-Y., Zhang, B.-X., Yang, Y.-R. and Wang, X.-D., ‘Optimization study on fluid flow and heat transfer in a rectangular channel with cross-scale ribs for turbine blade internal cooling’, Physics of Fluids, Vol. 36, No. 12, Article 125109, 2024. doi:10.1063/5.0238508.

Wolff, J., Development of Experimental Methodology to Determine the Heat Transfer of Additively Manufactured Airfoil Channels in a High-Speed Linear Cascade Rig (Master Thesis), The Pennsylvania State University, 2022.

Yang, X., Hu, J., Fan, Y., Min, C. and Wang, K., ‘Enhanced heat dissipation of ribbed channels based on the coupling optimization of multiple structural parameters’, Applied Thermal Engineering, Vol. 235, Article 121362, 2023. doi:10.1016/j.applthermaleng.2023.121362.

Zheng, S.-F., Liu, G.-Q., Lian, W.-K., Yang, Y.-R., Gao, S.-R., Sunden, B. and Wang, X.-D., ‘Fluid flow and heat transfer in a rectangular ribbed channel with a hierarchical design for turbine blade internal cooling’, Applied Thermal Engineering, Vol. 217, Article 119183, 2022. doi:10.1016/j.applthermaleng.2022.119183.

Zhu, Q., Wang, G., Schlegel, J.P., Yan, Y., Yang, X., Liu, Y., Ishii, M. and Buchanan Jr., J.R., ‘Experimental study of two-phase flow structure in churn-turbulent to annular flows’, Experimental Thermal and Fluid Science, Vol. 129, Article 110397, 2021. doi:10.1016/j.expthermflusci.2021.110397.

Zhu, X., Wang, Z., Xu, C. and Wang, N., ‘Experimental Investigations and Numerical Studies of Two-Phase Countercurrent Flow Limitation in a Pressurized Water Reactor: A Review’, Energies, Vol. 16, No. 3, Article 1487, 2023. doi:10.3390/en16031487.