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A Literature Survey on Different Refrigerants Based on Condensation Heat Transfer Correlations

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Abstract*—The increasing emphasis on energy-efficient and environmentally sustainable refrigeration systems has led to extensive research on alternative refrigerants and condensation heat transfer characteristics. This review paper presents a comprehensive survey of recent studies published between 2019 and 2026 on the performance evaluation of conventional and low-global-warming-potential (low-GWP) refrigerants and their associated condensation heat transfer correlations. The reviewed literature examines the thermodynamic and heat transfer performance of refrigerants such as R-134a, R-32, R-410A, R-454B, R-513A, R-744, R-600a, R-290, R-1234yf, and other emerging alternatives using experimental, theoretical, and numerical approaches. Particular emphasis is given to widely used condensation heat transfer correlations, including those proposed by Shah, Cavallini and Zecchin, Dobson and Chato, Traviss, Bohdal, Huang, and Park. The review compares refrigerant performance based on parameters such as condensation heat transfer coefficient, coefficient of performance (COP), compressor power, pressure drop, mass flux, and vapor quality. The analysis reveals that refrigerant thermophysical properties and operating conditions significantly influence condensation heat transfer performance, while the prediction accuracy of existing correlations varies for different refrigerants and heat exchanger configurations. Furthermore, the survey identifies key research gaps, including limited comparative studies under identical operating conditions, insufficient validation of existing correlations for emerging low-GWP refrigerants, and the lack of integrated assessments combining thermodynamic performance and condensation heat transfer characteristics. This review provides valuable insights for refrigerant selection, condenser design, and the development of more reliable condensation heat transfer correlations for future refrigeration applications.

***Keywords*— Condensation Heat Transfer, Refrigerants, Heat Transfer Correlations, Low-GWP Refrigerants, Natural Refrigerants and Heat Exchanger Performance etc**

I. INTRODUCTION

In Refrigeration and air-conditioning systems have become indispensable in residential, commercial, industrial, and transportation sectors, where they provide thermal comfort, food preservation, pharmaceutical storage, and process cooling. The performance and energy efficiency of these systems are strongly influenced by the heat transfer processes occurring in evaporators and condensers. Among these processes, condensation heat transfer is of particular importance because it governs the rate at which heat is rejected from the refrigerant to the surrounding environment, directly affecting system capacity, compressor power consumption, and overall coefficient of performance (COP). Consequently, accurate prediction of condensation heat transfer has become a critical aspect in the design and optimization of high-efficiency refrigeration and heat pump systems.

The continuous evolution of refrigeration technologies has been accompanied by significant changes in refrigerant selection. Conventional refrigerants such as chlorofluorocarbons (CFCs) and hydro chloro fluoro carbons (HCFCs) have been phased out because of their ozone depletion potential (ODP), while many hydro fluorocarbons (HFCs) are being replaced due to their high global warming potential (GWP). As a result, environmentally friendly alternatives, including hydro fluor oolefins (HFOs), natural refrigerants such as carbon dioxide (R744), ammonia (R717), propane (R290), and isobutane (R600a), as well as various refrigerant blends, have gained increasing attention. These refrigerants exhibit diverse thermo physical properties, making the prediction of condensation heat transfer more challenging and necessitating the development of reliable heat transfer correlations.

Over the past several decades, numerous theoretical, empirical, and semi-empirical condensation heat transfer correlations have been proposed to estimate the condensation heat transfer coefficient under different operating conditions. Classical models, beginning with Nusselt's film condensation theory, laid the foundation for modern condensation analysis. Subsequently, researchers such as Akers, Shah, Traviss, Dobson and Chato, Cavallini, Thome, and others developed correlations that account for factors including mass flux, vapor quality, flow patterns, pressure, tube diameter, surface enhancement, and refrigerant properties. These correlations have been extensively applied to smooth tubes, enhanced tubes, micro-fin tubes, and compact micro channel heat exchangers. However, their prediction accuracy often varies depending on the refrigerant type, operating conditions, and heat exchanger geometry.

With increasing demand for energy-efficient and sustainable cooling technologies, researchers have also explored advanced numerical and data-driven techniques, including computational fluid dynamics (CFD), artificial intelligence (AI), and machine learning (ML), to improve the prediction of condensation heat transfer characteristics. These approaches offer the potential to overcome some of the limitations associated with conventional empirical correlations, particularly for next-generation low-GWP refrigerants and complex heat exchanger designs.

This paper presents a comprehensive literature review of condensation heat transfer correlations developed for different refrigerants. It critically examines the theoretical background, classification, applicability, governing parameters, advantages, and limitations of the most widely used correlations. Furthermore, the review compares their predictive capabilities for conventional, natural, and low-GWP refrigerants under various operating conditions and heat exchanger configurations. Finally, the paper identifies current research gaps and discusses future research directions aimed at developing more accurate, generalized, and environmentally sustainable condensation heat transfer models for advanced refrigeration and thermal management applications.

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II. Literature Review

Abhishek Kumar et al. (2026) conducted a thermodynamic assessment of several low-global-warming-potential (GWP) refrigerants (R-152a, R-515B, R-1234ze(E), R-1234yf, R-290, R-600a, R-600, and R-1270) as alternatives to R-134a in vapor compression refrigeration (VCR) systems. A steady-state simulation was performed under varying evaporator and condenser temperatures to evaluate the coefficient of performance (COP), compressor power, refrigerant mass flow rate, and volumetric cooling capacity. The results showed that R-600a, R-600, and R-152a achieved higher COP with lower compressor power than R-134a, while R-515B and R-1234ze(E) exhibited performance very close to the baseline refrigerant. Conversely, R-1234yf demonstrated lower energy efficiency and required greater compressor power. The study concluded that several low-GWP refrigerants can effectively replace R-134a when thermodynamic performance, compressor compatibility, and environmental impact are simultaneously considered [1].

Ariyadi et al. (2026) investigated the energy performance of R-32 and R-134a refrigerants for fisheries cold storage applications. The study compared refrigeration capacity, compressor power consumption, coefficient of performance (COP), and energy efficiency under practical operating conditions. Experimental analysis indicated that R-32 provided higher refrigeration capacity and improved energy efficiency due to its superior thermo physical properties, whereas R-134a demonstrated more stable operating characteristics. The authors concluded that R-32 represents a promising alternative for fisheries refrigeration systems because of its enhanced cooling performance and reduced energy consumption [2].

Chaturvedi et al. (2025) performed an energy analysis of a vapor compression refrigeration system employing R-134a, R-600a, and R-125. The study evaluated compressor work, energy destruction, COP, and second-law efficiency under different operating conditions. The results demonstrated that R-600a achieved the highest energy efficiency and lowest irreversibility, while R-134a maintained balanced thermodynamic performance. The authors emphasized that energy analysis provides an effective framework for selecting environmentally sustainable refrigerants with improved system efficiency [3].

Rayhan et al. (2025) compared the thermodynamic performance of refrigeration systems using R-134a, R-744 (CO_2), and R-32 for Indonesian fishing boats. Parameters including cooling capacity, compressor work, energy efficiency, and environmental impact were evaluated. The results showed that R-744 exhibited excellent environmental characteristics, whereas R-32 delivered superior energy efficiency under tropical operating conditions. The study recommended selecting refrigerants based on both climatic conditions and operational requirements for marine refrigeration applications [4].

Ajayi et al. (2024) developed a generalized condensation heat transfer coefficient and pressure drop model applicable over a wide range of reduced pressures. Experimental data covering various refrigerants and operating conditions were used to formulate and validate the proposed correlation. The model accurately predicted condensation heat transfer coefficients and pressure drops across different flow regimes while reducing prediction errors compared with conventional empirical correlations. The proposed model provides an improved tool for condenser design and refrigeration system optimization **[5]**.

Fang et al. (2024) proposed a new condensation heat transfer correlation based on flow pattern transitions for hydrocarbon refrigerants. Experimental investigations examined the influence of vapor quality, mass flux, and flow regimes on condensation performance. The developed correlation significantly improved prediction accuracy by incorporating flow pattern characteristics rather than relying solely on conventional dimensionless parameters. The study demonstrated that flow-regime-based models enhance the reliability of condenser performance prediction **[6]**.

Zhang et al. (2023) proposed a modified empirical correlation for condensation heat transfer in horizontal enhanced tubes using **R-32** and **R-410A** refrigerants.

Experimental measurements were conducted under different operating conditions, including variations in mass flux, vapor quality, and condensation temperature. The modified correlation demonstrated improved prediction accuracy compared with existing models, particularly for enhanced tube geometries. The study concluded that incorporating surface enhancement effects substantially improves condensation heat transfer prediction **[7]**.

Höges et al. (2023) investigated the interactions between refrigerants, system configurations, and compressor characteristics in residential heat pumps. Numerical simulations evaluated refrigerant selection, compressor performance, and overall system efficiency under various operating conditions. The findings highlighted that refrigerant thermophysical properties significantly influence compressor efficiency and heating performance. The study emphasized integrated system optimization for achieving higher energy efficiency and reduced environmental impact **[8]**.

Sulaiman et al. (2022) performed a theoretical thermodynamic analysis of a high-temperature heat pump employing several low-GWP refrigerants under subcritical operating conditions. The investigation focused on system COP, compressor power consumption, discharge temperature, and exergy efficiency. The results indicated that appropriate refrigerant selection substantially improves heat pump efficiency while reducing greenhouse gas emissions. The study recommended low-GWP refrigerants as sustainable alternatives for future heating applications **[9]**.

Jajja et al. (2022) experimentally investigated in-tube condensation heat transfer and pressure drop characteristics of R-454B and R-32 as potential replacements for R-410A. The results demonstrated that condensation heat transfer increased with mass flux, while pressure drop also increased correspondingly. The authors concluded that R-454B offers comparable thermal performance with significantly lower environmental impact, making it a viable substitute for conventional refrigerants **[10]**.

Koruga et al. (2021) analyzed the influence of condensation temperature and compressor efficiency on heat pump performance. Numerical simulations indicated that increasing condensation temperature reduced system COP because of higher compressor power requirements. Improved compressor efficiency significantly enhanced overall system performance, emphasizing the importance of optimizing both operating conditions and component efficiencies in refrigeration and heat pump systems **[11]**.

Karageorgis et al. (2021) conducted a comparative study on the condensation heat transfer performance of **R-513A** as an alternative to **R-134a**. Experimental results showed that R-513A exhibited condensation heat transfer coefficients comparable to those of R-134a while maintaining lower environmental impact. The study concluded that R-513A is a practical replacement for R-134a in refrigeration applications without requiring significant system modifications **[12]**.

Kruzel et al. (2020) experimentally investigated refrigerant condensation heat transfer and pressure drop characteristics in compact heat exchangers. The study analyzed the effects of mass velocity, vapor quality, and refrigerant properties on condenser performance. Results indicated that compact heat exchangers provide enhanced heat transfer with acceptable pressure losses, making them suitable for modern refrigeration systems requiring high thermal efficiency **[13]**.

Shen and Ally (2020) evaluated low-GWP refrigerants as replacements for R-410A in two-speed heat pumps using energy and exergy analyses. The study compared system COP, exergy efficiency, compressor performance, and greenhouse gas emissions. Several low-GWP refrigerants demonstrated improved environmental performance while maintaining competitive energy efficiency, supporting their adoption in future heat pump technologies **[14]**.

Zhang et al. (2019) experimentally investigated condensation heat transfer and pressure drop characteristics of R-134a, R-1234ze(E), R-245fa, and R-1233zd(E) in a plate heat exchanger. The study evaluated the influence of mass flux, vapor quality, and saturation temperature on thermal performance. The results showed that refrigerant properties strongly affect condensation heat transfer coefficients and pressure losses. The developed experimental database provides valuable information for selecting suitable refrigerants in compact heat exchanger applications **[15]**.

Table I. Comparison of different refrigerants for condensation

Ref. / Year / Author(s)	Refrigerant(s) Investigated	Methodology	Performance Parameters	Major Findings	Research Gap / Limitation
[1] (2026) Kumar et al.	R-152a, R-515B, R-1234ze(E), R-1234yf, R-290, R-600a, R-600, R-1270, R-134a	Steady-state thermodynamic simulation	COP, Compressor Power, Mass Flow Rate, Volumetric Cooling Capacity	R-600a, R-600, and R-152a achieved higher COP with lower compressor power; R-515B and R-1234ze(E) showed performance close to R-134a	Condensation heat transfer coefficients and pressure drop characteristics were not investigated.
[2] (2026) Ariyadi et al.	R-32, R-134a	Experimental investigation	Cooling Capacity, Compressor Power, COP, Energy Efficiency	R-32 exhibited higher cooling capacity and better energy efficiency than R-134a	Limited to fisheries refrigeration; condensation performance was not analyzed.
[3] (2025) Chaturvedi et al.	R-134a, R-600a, R-125	Thermodynamic and exergy analysis	COP, Compressor Work, Exergy Destruction, Second-law Efficiency	R-600a showed the highest exergy efficiency and lowest irreversibility	No experimental validation of condensation heat transfer.
[4] (2025)	R-134a, R-744, R-32	Thermodynamic	Cooling Capacity,	R-744 offered superior	Restricted to marine

Rayhan et al.		analysis	Compressor Work, COP, Environmental Impact	environmental performance, whereas R-32 achieved higher energy efficiency	refrigeration applications.
[5] (2024) Ajayi et al.	Multiple Refrigerants	Experimental correlation development	Heat Transfer Coefficient, Pressure Drop	Proposed correlation improved prediction accuracy over a wide range of reduced pressures	System-level refrigeration performance was not evaluated.
[6] (2024) Fang et al.	Hydrocarbon Refrigerants	Experimental investigation	HTC, Vapor Quality, Mass Flux	Flow-pattern-based model significantly improved condensation prediction accuracy	Applicable mainly to hydrocarbon refrigerants.
[7] (2023) Zhang et al.	R-32, R-410A	Experimental study	HTC, Mass Flux, Vapor Quality	Modified empirical correlation improved prediction accuracy for enhanced tubes	Limited refrigerant selection and tube geometry.
[8] (2023) Höges et al.	Various Heat Pump Refrigerants	Numerical simulation	Compressor Efficiency, Heating Capacity, COP	Refrigerant properties significantly affected compressor efficiency and system performance	Condensation heat transfer analysis was not included.
[9] (2022) Sulaiman et al.	Low-GWP Refrigerants	Theoretical simulation	COP, Compressor Power, Exergy Efficiency, Discharge Temperature	Low-GWP refrigerants improved heat pump efficiency and reduced emissions	Experimental validation was not performed.
[10] (2022) Jajja et al.	R-454B, R-32, R-410A	Experimental investigation	HTC, Pressure Drop	R-454B provided thermal performance comparable to R-410A with lower GWP	Limited operating conditions and refrigerants.
[11] (2021) Koruga et al.	Heat Pump Refrigerants	Numerical simulation	COP, Compressor Efficiency	Higher condensation temperature reduced COP, while improved compressor efficiency enhanced performance	No comparative experimental refrigerant study.

III. Research Gap

Although Based on the reviewed literature (2019–2026), the following research gaps have been identified:

- Limited integration of thermodynamic and condensation analyses: Most studies focus either on the thermodynamic performance (COP, compressor power, energy efficiency) of low-GWP refrigerants or on condensation heat transfer characteristics. Very few studies combine both aspects in a comprehensive evaluation.
- Lack of comparative condensation heat transfer studies for multiple refrigerants: Existing condensation investigations are generally limited to one or two refrigerants (e.g., R-134a, R-32, R-410A, R-513A, or R-454B). A systematic comparison of several low-GWP refrigerants using common condensation heat transfer correlations is still lacking.
- Limited validation of existing condensation correlations: Numerous empirical correlations have been proposed; however, their applicability to newly developed low-GWP refrigerants has not been thoroughly evaluated across a wide range of operating conditions.
- Insufficient evaluation under identical operating conditions: Many studies employ different evaporating temperatures, condensing tempera-tures, tube geometries, and mass fluxes, making direct performance comparison between refrigerants difficult.
- Limited consideration of refrigerant thermo physical properties in correlation assessment: The influence of latent heat, viscosity, thermal conductivity, surface tension, and reduced pressure on condensation heat transfer prediction has not been comprehensively analyzed for alternative refrigerants.
- Scarcity of studies addressing refrigerant selection using both energy and heat transfer performance: Most refrigerant selection studies prioritize energy efficiency or environmental impact, while condenser heat transfer performance and pressure-drop characteristics receive comparatively less attention.
- Need for environmentally sustainable refrigerant assessment: Although many low-GWP refrige-rants have been proposed as replacements for R-134a, a detailed comparison considering thermodynamic performance, condensation heat transfer, pressure drop, and environmental characteristics together remains limited.
- Limited guidance for condenser design using alternative refrigerants: Existing research provides insufficient information for selecting suitable low-GWP refrigerants based on condensation heat transfer correlations, which are essential for condenser sizing and optimization.

IV. Conclusion

This survey comprehensively reviewed recent studies (2019–2026) on the performance evaluation of conventional and low-GWP refrigerants with particular emphasis on condensation heat transfer correlations and refrigeration system performance. The reviewed literature indicates that refrigerant thermo-physical properties, including latent heat of vaporization, thermal conductivity, viscosity, and Prandtl number, have a significant influence on condensation heat transfer coefficients and overall refrigeration system efficiency. Various studies have demonstrated that low-GWP refrigerants such as R-32, R-454B, R-513A, R-600a, R-290, and R-1234ze(E) exhibit promising thermodynamic performance and can serve as potential alternatives to conventional refrigerants. Furthermore, widely used condensation heat transfer correlations, including those proposed by Shah, Cavallini, Dobson and Chato, Traviss, Bohdal, Huang, and Park, provide useful prediction tools; however, their accuracy varies with refrigerant type, operating conditions, and heat exchanger geometry. The literature also reveals that most investigations focus either on thermodynamic performance or condensation heat transfer characteristics independently, with limited studies integrating both aspects. Overall, this review highlights the importance of selecting suitable refrigerants and appropriate condensation heat transfer correlations to improve condenser design, enhance energy efficiency, and support environmentally sustainable refrigeration systems.

V. FUTURE SCOPE

Future research should focus on conducting comprehensive comparative studies of multiple low-GWP refrigerants under identical operating conditions to enable fair performance evaluation. Existing condensation heat transfer correlations should be experimentally validated for emerging refrigerants over wider ranges of mass flux, vapor quality, condensing temperature, and tube geometries. Greater attention should also be given to simultaneously evaluating thermo-dynamic performance, condensation heat transfer, and pressure drop to provide a more complete basis for refrigerant selection and condenser design. In addition, further investigations involving compact and enhanced heat exchangers are required to improve the applicability of existing correlations and support the development of more reliable and generalized prediction methods for next-generation refrigeration systems.

References

[1]. Camilleri Tamrat, Bimrew, Dessie Tarekegn, and Velmurugan Paramasivam. "Numerical and experimental analysis of the effectiveness of solar air heaters combined with a continuous V-shaped ribbed roughness parameter." *International Journal of Thermo fluids* (**2026**): 101652.

[2]. Singh, Jitendra, Jaigopal Ambade, and Atul Lanjewar. "Thermal–hydraulic evaluation of solar air heaters with symmetrical gap arc rib roughness." *Journal of Thermal Analysis and Calorimetry* 150, no. 18 (**2025**): 14183-14201.

[3]. Singh, Rohit, and Ramadas Narayanan. "Comprehensive Review of Thermal and Thermo hydraulic Performance in Solar Air Heaters with Advanced Artificial Roughness Geometries." *Energies* 18, no. 23 (**2025**): 6157.

[4]. Alam, Tabish, and Deepak Gupta. "Thermo hydraulic performance of hybrid ribs pattern combining V and arc shape ribs in solar air heater." *Experimental Heat Transfer* 37, no. 7 (**2024**): 1084-1099.

[5]. Singh, Jitendra, and Atul Lanjewar. "Thermal performance of solar air heater having discrete symmetrical arc rib with staggered rib roughness." *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science* 238, no. 2 (**2024**): 598-617.

[6]. Rajendran, Vijayakumar, Muthuraman Ponrajan Vikram, Sung Chul Kim, Paride Gullo, Abdullah Alodhayb, Saravanan Pandiaraj, and Rajendran Prabakaran. "Enhancing the performance of a solar air heater by employing the broken V-shaped ribs. " *Environmental Science and Pollution Research* 30, no. 31 (**2023**): 77807-77818.

[7]. Dubey, Manoj Kumar, and Om Prakash. "Enhanced Heat Transfer Performance in a Solar Air Heater using discrete V-Rib Geometry with Gap." Research Square (**2023**).

[8]. Kumar, Rahul, Sujit Kumar Verma, Naveen Kumar Gupta, Andrés Z. Mendiburu, Abhishek Sharma, Tabish Alam, and Sayed M. Eldin. "Experimental assessment and modelling of solar air heater with V shape roughness on absorber plate." *Case Studies in Thermal Engineering* 43 (**2023**): 102784.

[9]. Rajendran, Vijayakumar, Harichandran Ramasubbu, Jaya Venkatesh Rajarathinam, and Ramanan Pichandi. "Experimental study on the thermal performance of a solar air heater integrated with multi-geometry arrangements over the absorber plate." *Environmental Science and Pollution Research* 29, no. 25 (**2022**): 38331-38345.

[10]. Rajendran, Vijayakumar, Harichandran Ramasubbu, Jaya Venkatesh Rajarathinam, and Ramanan Pichandi. "Experimental study on the thermal performance of a solar air heater integrated with multi-geometry arrangements over the absorber plate." *Environmental Science and Pollution Research* 29, no. 25 (**2022**): 38331-38345.

[11]. Rajendran, Vijayakumar, Harichandran Ramasubbu, Jaya Venkatesh Rajarathinam, and Ramanan Pichandi. "Experimental study on the thermal performance of a solar air heater integrated with multi-geometry arrangements over the absorber plate." *Environmental Science and Pollution Research* 29, no. 25 (**2022**): 38331-38345.

[12]. Alam, Tabish, Chandan Swaroop Meena, Nagesh Babu Balam, Ashok Kumar, and Raffaello Cozzolino. "Thermo-hydraulic performance characteristics and optimization of protrusion rib roughness in solar air heater." *Energies* 14, no. 11 (**2021**): 3159.

[13]. Kazemi Moghadam, Hamid, Seyed Soheil Mousavi Ajarostaghi, and Sébastien Poncet. "Numerical modelling of an innovative arc shape rib based solar air heater." *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science* 235, no. 24 (**2021**): 7992-8012.

[14]. Wang, Dengjia, et al. "Evaluation of the performance of an improved solar air heater with "S" shaped ribs with gap."Solar Energy 195 **(2020**): 89-101.

[15]. Saravanakumar, P. T., D. Somasundaram, and M. M. Matheswaran. "Thermal and thermo-hydraulic analysis of arc shaped rib roughened solar air heater integrated with fins and baffles."Solar Energy 180 **(2019**): 360-371.

[16]. Kumar, Rajesh, and Prabha Chand. "Performance prediction of extended surface absorber solar air collector with twisted tape inserts." Solar Energy 169 (**2018):** 40-48.

[17]. Aboghrara, Alsanossi M., et al. "Performance analysis of solar air heater with jet impingement on corrugated absorber plate."Case studies in thermal engineering 10 **(2017):** 111-120

[18]. Rajesh Maithani, J.S. Saini, "Heat transfer and friction factor correlations for a solar air heater duct roughened

artificially with V-ribs with symmetrical gaps" Experimental Thermal and Fluid Science, Volume70, Pages 220-227, **2016**.

[19]. Ehsan Ebrahimnia-Bajestan, Mohammad Charjouei Moghadam, Hamid Niazmand, Weerapun Daungthongsuk, Somchai Wongwises, "Experimental and numerical investigation of nano-fluids heat transfer characteristics for application in solar heat exchangers", International Journal of Heat and Mass Transfer, Volume 92, Pages 1041–1052, **2016.**

[20]. Hamdi E. Ahmed, M.I. Ahmed, M.Z. Yusoff, M.N.A. Hawlader, Habeeb Al-Ani "Experimental study of heat transfer augmentation in non-circular duct using combined nano-fluids and vortex generator" International Journal of Heat and Mass Transfer, Volume 90, Pages 1197–1206, **2015**

[21]. Alireza Zamani Aghaie, Asghar B. Rahimi, Alireza Akbarzadeh "A general optimized geometry of angled ribs for enhancing the thermo-hydraulic behavior of a solar air heater channel - A Taguchi approach" Elsevier Renewable Energy, Volume 83, Pages 47-54, **2015.**

[22]. Adem Acır, Ismail Ata "A study of heat transfer enhancement in a new solar air heater having circular type tabulators" *Elsevier Journal of the Energy Institute*, Pages 1-11, **2015.**

[23]. Anil Kumar, Man-Hoe Kim "Effect of roughness width ratios in discrete multi V-rib with staggered rib roughness on overall thermal performance of solar air channel" *Elsevier Solar Energy*, Volume 119, Pages 399–414, **2015**.

[24]. Dongxu Jin, Manman Zhang, Ping Wang, Shasha Xu, "Numerical investigation of heat transfer and fluid flow in a solar airheater duct with multi V-shaped ribs on the absorber plate" *Elsevier Energy*, Volume 89, Page 178-190, **2015.**

[25]. Chao Ma, Xiaoling Chen, Jianfei Wang, Shusheng Zang, Yongbin Ji, "An experimental investigation of heat transfer characteristics for steam cooling and air cooling in a rectangular channel roughened with parallel ribs" *Experimental Thermal and Fluid Science*, Volume 64, Page 142–151, **2015.**

