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RECENT ADVANCEMENTS IN HEAT EXCHANGERS: DESIGN, ANALYSIS AND OPTIMIZATION

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Abstract
In the current article, the discussion has been developed by focusing on the advancement happening in the heat exchangers field. The design and optimization level has been determined for the observing models or techniques built up in this context. Before being involved in advancement observing discussion short but accurate information is shared regarding the existing constraints. Financial and operating constraints that continuously bother the excellence of heat exchanger performance have been analyzed in this study. Knowing the barrier determining the development is processed through that advancement is become easy to detect.

Through the current study main discussion has been made for phase change material cooling technology, twisted heat exchanger, and microplate heat exchanger. Comparing these identified advancements with existing traditional heat exchanger technology reflects the advantages gained in specific aspects. Changes in efficiency in heat transferring and lowering of the power need are noticed for this developing heat exchanger design, throughout the observation of the design configuration specific eco-friendly and economically supportive changes happening for the field of heat exchanger context are determined.

Keywords: *Heat exchanger, phase change material, design twisted heat exchanger.*

Introduction

In the current article, the discussion has been developed for the advancement happening around heat exchangers. Dimension of these happening changes defines the possibility of evaluating design, analysis, and measuring optimization. The current article development specification has been added for how this change happens. The basic concept of a heat exchanger is performing the heat transfer activity in between the source and the working fluid. Application of this model of heat exchangers chances of including in cooling and heating process is possible. This process of heat exchangers included working fluid that can be separated through the use of a solid wall that processes the scope of direct contact prevention. Knowing the fundamental process of heat exchanger flow here the article focused on system design that is using even the process optimization. Suitable data has been gathered to reflect the flow of the heat exchanger process to understand the actual advancement.

1. Problem Statement

In the process of heat exchangers flow it needs to be understood that the whole process outcome efficiency depends on the efficiency that holds by heat transferring. It has been observed that compared with plate-type coolers this heat exchanger has lower efficiency. Another issue that is faced by the heat exchanger model is cleaning and maintenance difficulty. It needs to be considered to have control over the process managing to have the stability of performance efficiency. As per Diwania et al. (2020) continuously facing the constraints of handling this heat exchangers system makes the concern of financial constraints. As well as the efficiency management it becomes difficult to control stability.

The limitation of tube cooler capacity is considered the concern which continuously makes the performance efficiency poor. Needed more space to work over the performance standard. It makes the operative problem in handling the heat exchanger process that leads to the efficiency affecting concern. Having financial and even non-financial efficiency considering the concern makes the need of solving the issue that can uplift the standard of heat exchanger performance (Kumar et al. 2019). Without improving the cleaning barrier chances of having accession to the performance efficiency is considered as complexity.

2. Aim and Objectives

Aim: Current research aims to develop the analysis for the happening heat exchanger advancement regarding the aspect of design, analysis even optimization.

Objectives:

- To analyze the developing heat exchanger advancement happening around the world.
- To analyze the heat exchanger advancement impact on design and state of optimization.
- To analyze the associated potential challenges that grow with this happening advancement.
- To analyze the solution that can expand the future application of this advancement of the heat exchanger.

3. Literature Review

Currently Happening Advancement for Heat Exchangers

Several recent advancements have been in the design, analysis, and optimization of heat exchangers. Many of these developments aim to improve the flexibility and scalability of heat exchangers as well as their efficiency and efficacy. This involves the creation of better materials, the use of cutting-edge mathematical models to support current designs, and the investigation of new applications for contemporary computer-aided design systems (Diwania et al. 2020). Engineers may study the geometry of the heat exchanger and its performance under different circumstances by using mathematical models. Designers are now more often using waste heat produced during industrial operations as well as renewable energy sources like solar energy to boost the efficiency of heat exchangers (Kumar et al. 2019). As an example, 3M uses its proprietary Heat Mirror technology to control indoor temperature as well as to improve the effectiveness of commercial and industrial environments. These energy-saving techniques may result in considerable short- and long-term energy savings as people become more conscious of the global warming threat.

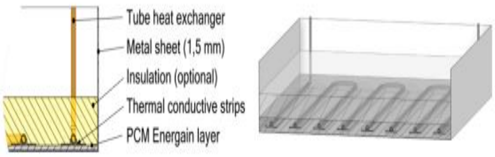

Figure 1: Applied Advancement of Exchangers

(Source: Liu et al. 2019)

Modern design, analysis, and optimization technologies have been developed recently to improve the efficiency of heat exchangers. In order to correctly forecast the performance of various designs without the need for costly prototypes, simulations are increasingly being utilized to make use of new materials, such as nanofluids, that provide thermal qualities beyond what conventional heat exchangers can give. In order to determine the ideal design parameters for a given operating condition while accounting for complex phenomena, computer-aided optimization techniques like genetic algorithms are being developed (Zhuang et al. 2021). The incorporation of artificial intelligence techniques can be used to improve predictive maintenance and optimize the scheduling of maintenance operations. This method enables the creation of sophisticated and customized designs for a fraction of the price of conventional manufacturing. Advanced fin structures and configurations, compact heat exchange designs, combined heat transfer, double-pipe systems, tubular systems, transient heat transfer, and the use of novel materials are some examples of advanced heat exchanger designs that are currently the focus of research and development (Malinowski et al. 2020).

Observation of the Design and Optimization Changes from Advancement

Recent developments in heat exchangers have increased their reliability, robustness, and user-friendliness. Increased use of finned tubes and micro fin tubes to increase surface area and improve heat transfer performance, porous metal heat exchangers that do not require routine cleaning, more efficient, compact exchangers, increased airflow on low-temperature finned tubes, and modifications to header design, such as the use of top-level headers and variable headers, are just a few examples of design changes (Zhang et al. 2021). The use of more realistic transient simulations, such as conjugate heat transfer, to account for multiple fluid streams; the use of models that can capture the influence of fouling; and the use of optimization techniques, such as genetic algorithms, that can identify the optimal design of heat exchangers are some of the analysis changes.

On the front of optimization, advancements have been made in the creation of improved manufacturing procedures, the use of more effective active management of methods, and the creation of the ideal system architecture to lessen pressure drop. Design, analysis, and optimization of heat exchangers have seen significant modifications recently (Baroutaji et al. 2021). Having more computer capabilities at one's disposal has made it possible to build more complicated and sophisticated heat exchangers, as well as to use advanced modeling tools to analyze temperature distributions and predict pressure decreases.

The design, analysis, and optimization of heat exchangers have made tremendous strides in recent years. This development has made it possible to boost energy efficiency, decrease operational and capital expenses, improve thermal performance, and have a smaller environmental effect. As per Zhang et al. (2021) improvements in heat exchanger design, such as the use of high-efficiency exchanger geometries, cutting-edge materials, specialized performance optimization techniques, and more effective performance prediction and design optimization techniques, are just a few of the significant advancements that have taken place. These developments have increased heat exchangers' overall effectiveness, resulting in more effective and cost-effective systems.

4. Methods

The current article has been developed to analyze the advancement of heat exchangers for which descriptive design is used. It helps to make the research investigation observation based. Through critical observation chances of objective achieving are getting easier than current research used to analyze the design and associated scope of optimization. Considering these objectives secondary data collection has been used that reflect about the types of this advancement regarding optimization is happening. A detailed discussion of the advancement reflects the design changes happening and makes the easier way to present the future leading scope of optimization.

5. Data Analysis

Phase change material is one of the advancements that happened in the heat exchanger which is processed for storing thermal energy by phase change cooling technology. The ability of this technology in processing the functionality of absorbing large amounts of latent energy (Yuan et al. 2020). The matter of selecting materials for phase changes depends on the user parameters included for the purpose of the experiment. Identified Basic ranges that can be applied for this application are between 10 ◦C to 60 ◦C. In between these ranges, chances of observing the performance efficiency is become increased.

Ranges of temperature	Applied area of PCMs
10 ◦C to 22 ◦C	For cooling purpose
22 to 28◦C	Building structure
29 to 60 ◦C	Heating accumulation

Table 1: Ranges and Its application

(Source: Tao et al. 2019)

From the above table, it has been observed that different ranges of phase-change materials applications are varied. The concern of using it for cooling technology in heat exchangers having the required temperature is crucial. In the process of including in design through the cooling technology demand for the use of the hydraulic circuit. The importance of the suitable distribution of surface temperature is essential to have the efficient for using PCMs (Sajid and Ali 2019). As a result of these developments, brand-new approaches to heat exchanger optimization have emerged, including the use of genetic algorithms to determine the ideal configuration or the analysis of various design factors. In addition, more precise analyses and simulations of heat exchangers have been made possible by the development of effective numerical tools and a better knowledge of the physics of flow, leading to improved designs. These developments have the potential to lead to more compact designs and increased thermal efficiency.

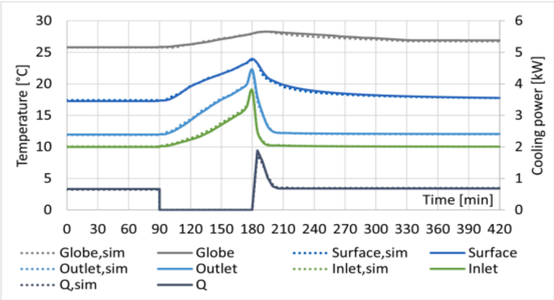

Figure: Validation for the Simultaneous Exchanges

(Source : Mousa et al. 2022)

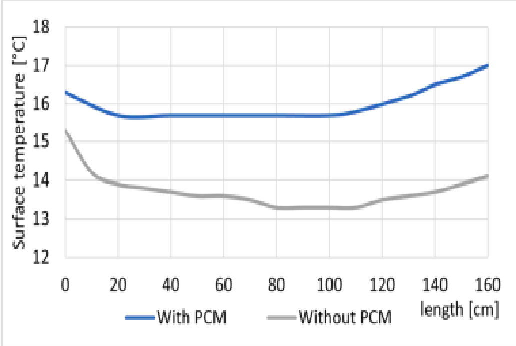

Figure: Surface Temperature Distribution

(Source : Maghrabie et al. 2021)

Since its creation, heat exchangers have advanced significantly, becoming more efficient and useful in a wide range of sectors. These heat exchangers are used more often than ever to maximize the transfer of thermal energy and contribute to energy and resource savings thanks to developments in design, analysis, and optimization. Their potential for energy optimization can only grow as metallurgy, materials engineering, and computational engineering continue to progress. To increase heat transfer efficiency, new heat transfer surfaces such as finned surfaces and multi-positioned heat exchangers have been created. In order to improve heat transfer efficiency, advanced heat transfer methods such as metal foam technology and nanofluids have been created (Menni et al. 2020). The design and analysis of complicated heat exchanger designs have been made easier with the use of mathematical approaches like computational fluid dynamic analysis. Moreover, process design has been improved for improved heat exchanger performance using optimization techniques including artificial intelligence and non-linear optimization.

From the above figure, it has been observed that with the generating advancement for the field of heat exchangers selecting technology dependency is there for outer distribution. The above figure denotes the dependency on phase-changing material-induced cooling technology on temperature distribution.

To maximize the potential advantages of these advancements, it is advised that their effects be further researched. Heat transfer and pressure drop performance improvements have been shown to be possible using systems including horizontal cross-flow, coaxial roll-bond, and variable curvature fin-and-tube. For different geometries and configurations of heat exchangers, a variety of numerical techniques, including CFD, structural analysis, and optimization, as well as nonlinear finite element-based methods, have made it possible to accurately assess the thermal-hydraulic performance and gain a deeper understanding of the underlying physical phenomena (Gao et al. 2022). The microplate heat exchanger is another advancement that is happening in the heat exchanger field. Advancement of this design makes the better flow of performance and the degrading impact on the environment is getting reduced.

At the time developing analysis on advancement happening for heat exchangers knowing the fundamental aspect is very crucial. The identified factor that defines the strength of a heat exchanger is energy-storing capacity. The use of latent heat makes the application of phase change material technology way more functional and accurate. The existing thermal energy equation makes the better managing scope of PCM surroundings (Nafis et al. 2021). The reason for specifying the considering factors is to make the controlled accession in the growth of the heat exchanger process. There is the availability of different complexity of surroundings and the favorability of the initial condition makes the scope of solving numerical equations. Ghalambaz et al. (2021) stated that knowing the functionality of storage phenomena for the transforming heat form of solar energy values of having the controlled cooling temperature of 18°C is crucial. To develop the investigation efficiency, the need of working on fusion configuration is essential as it holds the fundamental process of tubular exchanger including having five horizontal fins.

Looking at the advancement that is processed in heat exchanger configuration is about twisted heat exchanger. The composition of this technique's performance is combining the form of tube assembling together without including any baffle. The overlapping position of the heat tube is noticed which makes the position flexible. A clear difference is noticed between traditional tube shell heat exchangers and twisted tube heat exchangers. The twisted number per unit can expand and depends on design. In this design development need of considering wall thickness and control over the exceeded material yielding. The form of this twisting patch is basically done in "s" and the maintained degree of twist is 360 degrees (Berce et al. 2023). There are mainly 6 points of contact for this twisting tube configuration. Swirl intensity generally depends on the shape of cross sections and the obligated diameter ratio for twisted pitch.

6. Discussion

Looking at the design of phase change material cooling technology importance of distribution temperature stability is noticed. The capacity of the cooling system needs to be understood while working with heat exchanger advancement. To make the measurement for the technological advancements need for steady state conditions is observed. Under this consideration measuring the temperature of cooling water, air temperature even room temperature is essential. Abouelregal and Alesemi (2022) mentioned that identified parameters that are working for the development of PCM energain is for a density of approximately 4.5 kg-m-2.

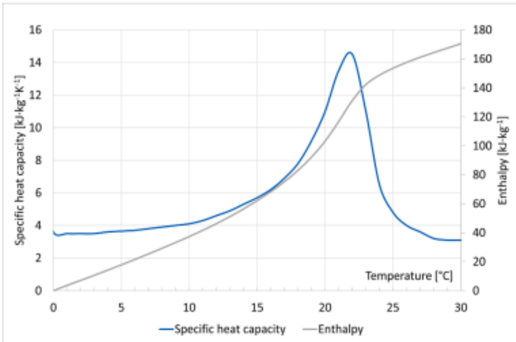

Figure 2: Distribution Curve for Phase Change Material Cooling Technology

(Source : Aboulregal and Alesemi 2022)

The need of checking feasibility is essential to understand the suitability of the developing design through heat exchanger advancement. Heat exchanger designs are altering in form, becoming more straightforward and effective as a result of efforts to lower manufacturing costs. In order to help in the creation of new designs and quickly optimize the ones that already exist, analytical technologies like computational fluid dynamics (CFD), finite element analysis (FEA), artificial neural networks (ANN), and particle tracking are also being used (Hong et al. 2023). Before creating the real component, these tools enable designers to swiftly assess the system's performance, and they also assist in optimising the system's performance appropriately. In order to suit customer demands without generating excessive refrigeration or heat transfer, new optimization approaches are being developed to determine the ideal size, shape, and material of heat exchangers. Heat exchangers may become more dependable, efficient, and cost-effective with these cutting-edge developments (Auld et al. 2020).

It has been observed that the inclusion of a twisted heat exchanger tube makes the scope for possible benefits gaining. The efficiency of thermal activity always makes an impact on developing advantages in heat-storing and exchanging functionality. Values for heat transferring co-efficiency are developed through this advancement of the heat exchanger. Even the pressure drop reduction is noticed for the application of this heat exchanger advancement. A clear reduction of fouling and zero vibration rate becomes accessible through this specified advancement of heat exchanger design. Through this detailed discussion advancement-specific gaining optimized scope can be determined easily. As per Shakeriaski et al. (2021) developing the actual comparison for the developing benefits of this happening advancement in multiple aspects. The rate of heat transfer is growing heavier with this happening of advancement and the advantages of the economical aspect are also determined for the development. In the traditional heat exchanger rate of this functional heat, transferring is comparatively lower even if it is economically less fitted.

Eco-friendly configuration always remains in demand for the field of heat exchangers in that aspect newer development provide that facility. Space requirement is comparatively higher for traditional heat exchanger tubes but that gets changed with the advancement of configuration (Kumar et al. 2019). Now the space requirements are getting reduced and looking for the needed maintenance it has been getting reduced for advancement. Looking over these aspects makes the realization for the changes and optimization is processing for the happening advancement of heat exchanger technology. Even the power requirement is also get reduced which makes the values for the efficiency processed for the advancement of heat exchanger facilities.

7. Findings

Design, analysis, and optimization have recently advanced as a result of recent developments in heat exchangers. Baroutaji et al. (2021) stated that the use of CFD tools in heat exchanger design, the creation of novel models that permit the fusion of numerous heat transfer and convection processes, sophisticated numerical solution methodologies, and the inclusion of sophisticated control systems are a few examples of such improvements. Last but not least, a number of approaches have been created for improving the design of already-existing heat exchangers, including predictive optimization techniques for improving the parameters that control heat transfer efficiency. Researchers and engineers may now boost performance while using less energy and resources because of recent developments in heat exchanger design, analysis, and optimization.

The introduction of high-performance technologies, such as plate-fin heat exchangers, rotary heat exchangers, and small counter-flow exchangers that react fast to changing circumstances, has advanced recent innovations beyond conventional finned tube designs and procedures. Additionally, several materials are employed to enhance the thermal efficiency and insulation of heat exchangers (Santosh et al. 2019). In order to simulate and optimize the design of heat exchangers, raise their performance, boost efficiency, and decrease energy waste, computational methodologies, techniques, and tools have been created. In a single system, heat exchangers may now be constructed to replicate various thermal loads and operate under various operating circumstances.

Designing heat exchangers with particular materials and fin shapes suited to a particular environment has become possible because of advancements in multi-scale materials engineering. As per Ghachem et al. (2021) the use of intelligent materials and improved heat transfer surfaces, improved heat transfer mechanisms, streamlined analysis and design using mathematical methodologies, and process design optimization for better performance are just a few examples of recent developments in heat exchangers. Shape memory alloys and piezoelectric materials are examples of smart materials that have been created to provide for improved control of quality and performance in heat exchanger design.

8. Conclusion

Improved performance, higher energy efficiency, cost savings, and increased safety have all been made possible by recent developments in heat exchanger design, analysis, and optimization. A variety of designs that may meet the various demands of the business have been presented to the market. Advanced simulation procedures are used in the development of design optimization strategies. Additionally, sophisticated studies have been used to enhance the design and comprehension of heat exchanger behaviour, such as those performed using Computational Fluid Dynamics (CFD) and Finite Element Analysis (FEA). These developments will ultimately help create better heat exchangers in the future.

The designs, analysis, and optimization of heat exchangers have recently advanced, creating new opportunities for increased performance and energy efficiency. The difficulties of the global energy environment are being addressed by businesses and academics thanks to these developments. The total performance of heat exchangers may be significantly enhanced by using more complex designs, reliable analysis, and optimization approaches. As a result, emissions are decreased and energy efficiency is increased.

9. Recommendation

- Recent developments in heat exchanger design, analysis, and optimization have been very beneficial to businesses in various industries. Improved multiphase flow calculations, mathematical modelling and simulation tools, and improved optimization techniques, in particular, have allowed engineers to build more effective and economical heat exchangers.
- Engineers are able to reduce the size and weight of heat exchangers while increasing their thermal efficiency thanks to improved materials including high-performance alloys and sophisticated coatings. Utilizing these technologies and improvements may result in significant long-term cost reductions for enterprises aiming for the best performance from their heat exchangers.
- Heat exchanger design, analysis, and optimization have advanced greatly in recent years as a result of developments in technology and materials as well as the accessibility of new computational tools. These days, heat exchangers are made with more accuracy and control for improved performance and efficiency. For design, analysis, and optimization, cutting-edge numerical and simulation techniques are being applied.

- The development of smaller, more effective heat exchangers makes use of modern materials, including nanofluids, microchannel technology, and polymer-based materials. The performance of heat exchangers is now being optimized and improved via the use of cutting-edge artificial intelligence technologies and the integration of existing optimization methodologies.
- The performance of heat exchange technologies has also been enhanced by the creation of creative designs like microchannel heat exchangers and cutting-edge materials. Therefore, the key to achieving the highest potential energy efficiency and operational value is to use the most recent developments in heat exchangers via design, analysis, and optimization.

References

Abouelregal, A.E. and Alesemi, M., 2022. Vibrational analysis of viscous thin beams stressed by laser mechanical load using a heat transfer model with a fractional Atangana-Baleanu operator. *Case Studies in Thermal Engineering*, *34*, p.102028.

Auld, D.S., Coassin, P.A., Coussens, N.P., Hensley, P., Klumpp-Thomas, C., Michael, S., Sittampalam, G.S., Trask, O.J., Wagner, B.K., Weidner, J.R. and Wildey, M.J., 2020. Microplate selection and recommended practices in high-throughput screening and quantitative biology. *Assay Guidance Manual [Internet]*.

Baroutaji, A., Arjunan, A., Ramadan, M., Robinson, J., Alaswad, A., Abdelkareem, M.A. and Olabi, A.G., 2021. Advancements and prospects of thermal management and waste heat recovery of PEMFC. *International Journal of Thermofluids*, *9*, p.100064.

Baroutaji, A., Arjunan, A., Ramadan, M., Robinson, J., Alaswad, A., Abdelkareem, M.A. and Olabi, A.G., 2021. Advancements and prospects of thermal management and waste heat recovery of PEMFC. *International Journal of Thermofluids*, *9*, p.100064.

Berce, J., Zupančič, M., Može, M. and Golobič, I., 2023. Infrared thermography observations of crystallization fouling in a plate heat exchanger. *Applied Thermal Engineering*, *224*, p.120116.

Diwania, S., Agrawal, S., Siddiqui, A.S. and Singh, S., 2020. Photovoltaic–thermal (PV/T) technology: a comprehensive review on applications and its advancement. *International Journal of Energy and Environmental Engineering*, *11*, pp.33-54.

Gao, J., Hu, Z., Yang, Q., Liang, X. and Wu, H., 2022. Fluid flow and heat transfer in microchannel heat sinks: Modelling review and recent progress. *Thermal Science and Engineering Progress*, p.101203.

Ghachem, K., Aich, W. and Kolsi, L., 2021. Computational analysis of hybrid nanofluid enhanced heat transfer in cross flow micro heat exchanger with rectangular wavy channels. *Case Studies in Thermal Engineering*, *24*, p.100822.

Ghalambaz, M., Mahdi, J.M., Shafaghat, A., Eisapour, A.H., Younis, O., Talebizadeh Sardari, P. and Yaïci, W., 2021. Effect of twisted fin array in a triple-tube latent heat storage system during the charging mode. *Sustainability*, *13*(5), p.2685.

Hong, J., Su, M., Zhao, K., Zhou, Y., Wang, J., Zhou, S.F. and Lin, X., 2023. A Minireview for Recent Development of Nanomaterial-Based Detection of Antibiotics. *Biosensors*, *13*(3), p.327.

Kumar, L., Hasanuzzaman, M. and Rahim, N.A., 2019. Global advancement of solar thermal energy technologies for industrial process heat and its future prospects: A review. *Energy Conversion and Management*, *195*, pp.885-908.

Kumar, L., Hasanuzzaman, M. and Rahim, N.A., 2019. Global advancement of solar thermal energy technologies for industrial process heat and its future prospects: A review. *Energy Conversion and Management*, *195*, pp.885-908.

Liu, J., Zhou, Z., Zhang, J., Feng, W. and Zuo, J., 2019. Advances and challenges in commercializing radiative cooling. *Materials Today Physics*, *11*, p.100161.

Maghrabie, H.M., Elsaid, K., Sayed, E.T., Abdelkareem, M.A., Wilberforce, T., Ramadan, M. and Olabi, A.G., 2021. Intensification of heat exchanger performance utilizing nanofluids. *International Journal of Thermofluids*, *10*, p.100071.

Malinowski, R., Parkin, I.P. and Volpe, G., 2020. Advances towards programmable droplet transport on solid surfaces and its applications. *Chemical Society Reviews*, *49*(22), pp.7879-7892.

Menni, Y., Chamkha, A.J. and Ameur, H., 2020. Advances of nanofluids in heat exchangers—A review. *Heat Transfer*, *49*(8), pp.4321-4349.

Mousa, M.H., Yang, C.M., Nawaz, K. and Miljkovic, N., 2022. Review of heat transfer enhancement techniques in two-phase flows for highly efficient and sustainable cooling. *Renewable and Sustainable Energy Reviews*, *155*, p.111896.

Nafis, B.M., Whitt, R., Iradukunda, A.C. and Huitink, D., 2021. Additive manufacturing for enhancing thermal dissipation in heat sink implementation: a review. *Heat Transfer Engineering*, *42*(12), pp.967-984.

Sajid, M.U. and Ali, H.M., 2019. Recent advances in application of nanofluids in heat transfer devices: a critical review. *Renewable and Sustainable Energy Reviews*, *103*, pp.556-592.

Santosh, R., Arunkumar, T., Velraj, R. and Kumaresan, G., 2019. Technological advancements in solar energy driven humidification-dehumidification desalination systems-A review. *Journal of Cleaner Production*, *207*, pp.826-845.

Shakeriaski, F., Ghodrat, M., Escobedo-Diaz, J. and Behnia, M., 2021. Recent advances in generalized thermoelasticity theory and the modified models: a review. *Journal of Computational Design and Engineering*, *8*(1), pp.15-35.

Tao, P., Chang, C., Tong, Z., Bao, H., Song, C., Wu, J., Shang, W. and Deng, T., 2019. Magnetically-accelerated large-capacity solar-thermal energy storage within high-temperature phase-change materials. *Energy & Environmental Science*, *12*(5), pp.1613-1621.

Yuan, K., Shi, J., Aftab, W., Qin, M., Usman, A., Zhou, F., Lv, Y., Gao, S. and Zou, R., 2020. Engineering the thermal conductivity of functional phase-change materials for heat energy conversion, storage, and utilization. *Advanced Functional Materials*, *30*(8), p.1904228.

Zhang, S., Feng, D., Shi, L., Wang, L., Jin, Y., Tian, L., Li, Z., Wang, G., Zhao, L. and Yan, Y., 2021. A review of phase change heat transfer in shape-stabilized phase change materials (ss-PCMs) based on porous supports for thermal energy storage. *Renewable and Sustainable Energy Reviews*, *135*, p.110127.

Zhuang, S., Qi, H., Wang, X., Li, X., Liu, K., Liu, J. and Zhang, H., 2021. Advances in solar-driven hygroscopic water harvesting. *Global Challenges*, *5*(1), p.2000085.