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Experimental Investigation Of Solar Air-Water Heater With Heat Exchanger For Industrial Process Heating

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Abstract: In order to promote the usage of environmentally friendly energy, it is of utmost importance to conduct a thorough analysis of the efficiency of solar air-water heaters. The incorporation of both the drain back system and the open loop system can play a vital role in enhancing the efficiency of air-water heaters that are powered by solar energy. The utilization of non-pressurized systems has brought about significant changes in the operation of air-water heaters used in industrial heating processes. Moreover, the introduction of a large piping system has been found to result in a considerable increase in the efficiency of air-water heaters used for industrial heating purposes.

Efficiency of the ventilation applications can be increased to a great extent by increasing efficiency of the air-water heaters operated by solar energy and this can be highly effective for betterment of the industrial heating procedure. In order to absorb radiation, the collectors used in the air-water heaters can show a high level of effectiveness. Along with this, temperature of water can have a huge impact on the procedure of industrial heating by air-water heaters operated by solar energy. Usage of the Series-parallel type of combination has led to significant improvement in the functioning of air-water heaters used in the purpose of industrial heating. At the same time, usage of metal plates as connectors can lead to positive outcomes in the development procedure of air-water heaters.

***Index Terms* - Air-water heaters, Heat transfer, Industrial heating, Temperature, Transferring heat, storage tanks, High performance.**

I. Introduction

Investigation on the solar thermal system is highly crucial in order to increase the usage of environment friendly energy. Solar air and water heaters can be of several types and the most used types are drain back system, active open loop system and the passive system of solar water heating. In production of distilled water, the role of solar water heater is highly important [51] [55]. It has been found that the usage of non-pressurised systems in solar water heaters can show a high level of efficiency in the process of industrial heating. Moreover, a large system of piping is another requirement which needs to be fulfilled by the designers of the solar water heaters. On the other hand, solar air heaters have been found as crucial in increasing efficiency of the ventilation applications. This study has evaluated the efficiency of the solar air-water heaters in exchange of heat within the process of industrial heating [1] [3]. [56-70] Patel Anand et al. for different geometries of the solar collector in various Solar Heater devices along with [71, 72, 73] analyses different condition in a heat exchanger. All these combined studies add to this review paper to provide additional improvements in the current topic.

II. OBJECTIVES

- To analyse the role of air-water heaters in increasing the efficiency of heat transfer within the procedure of industrial heating.
- To Identify the problems associated with air-water heaters when it comes to the heat transfer process in industrial heating systems.
- To analyse the effectiveness of the several types of air-water heaters in the industrial heating procedure.
- To identify the most effective methods of resolving the issues in industrial heating by solar air-water heaters.

III. METHODOLOGY

For the purpose of collecting information on the most efficient type of air-water heaters that are operated by solar energy, this research has collected information from the journals and articles of authors whose writings have been recognized for their repute. This study has collected quantitative information from secondary sources in order to provide qualitative information [12]. In addition to these, a thematic analysis method has also been used in the data analysis process by the researcher for the purpose of analysing the data. Authenticity and reliability of information are the most important factors which have been taken into consideration during the collection of data as part of this study. By collecting secondary data, one can reduce the cost and time involved in the process of conducting research as a result of a reduction in costs and time [8] [10].

The data gathered is analysed in order to evaluate the efficacy of the solar air-water heater system with a heat exchanger. Based on the acquired data, parameters such as thermal efficiency, heat transfer rates, and overall system performance are computed [18]. To obtain relevant insights and patterns from data, statistical analysis and mathematical modelling may be used.

IV. WORKING PRINCIPLE OF AIR-WATER HEATER FOR THE PROCESS OF INDUSTRIAL HEATING

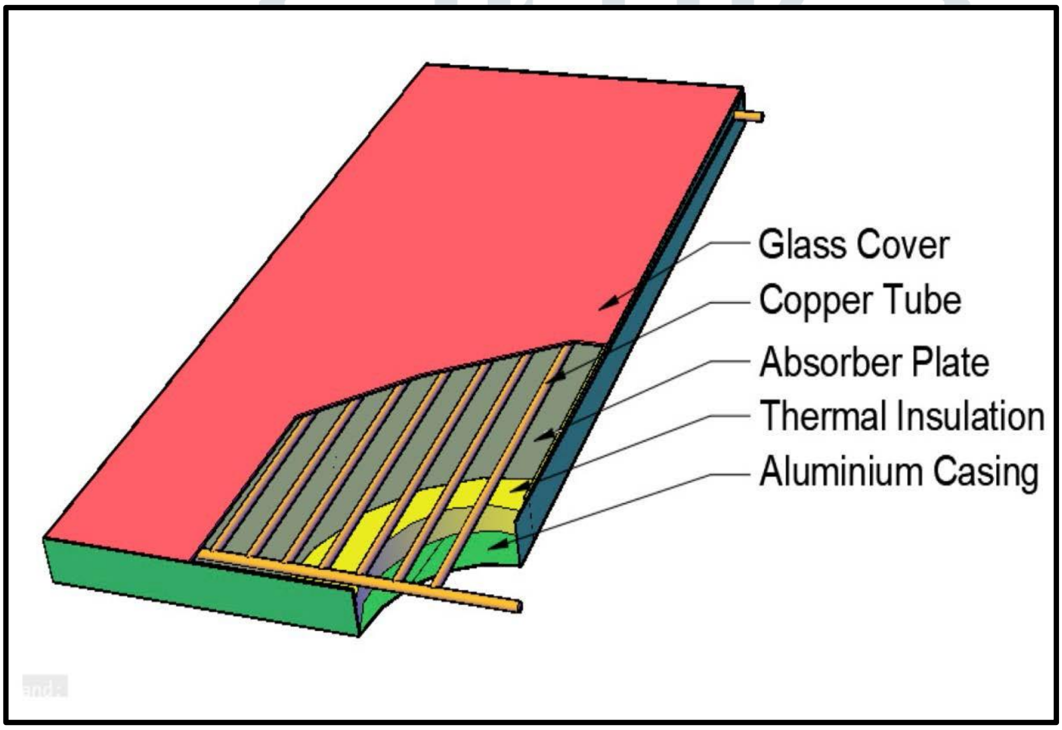

Figure 1: Structure of air-water heaters[3]

Collectors are used in air-water heaters which can absorb radiation in an effective manner. The absorbed radiation is converted into heat energy by this device [2] [26] [12]. At the same time, circulating pumps are used to pass the heat energy to water tanks of the system. It has been observed that Thermal regulators can play an important role in increasing efficiency of the procedure of industrial heating [22]. Temperature and density of water has been found as the other important factors which are taken into account in the designing procedure of air-water heaters operated by solar energy. Series-parallel combination has been found in the designing of collectors and this factor plays a crucial role in transferring heat for industrial purposes [3] [9].

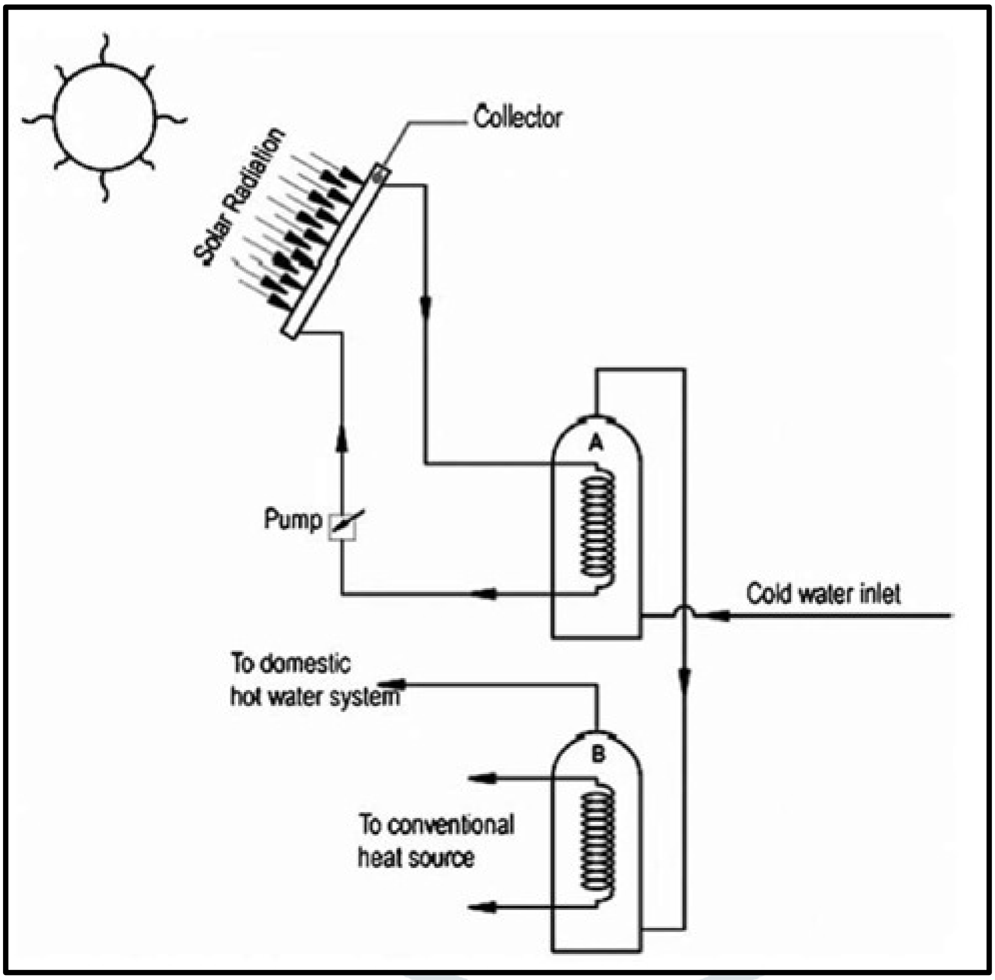

Figure 2: Procedure of solar water heating[4]

The temperature of the backup system can also be distinguished as another critical factor that has a huge impact on the industrial heat transfer process and can have a significant impact on the success of the process as well [49] [18]. Moreover, it has also been identified that the construction of solar collectors is one of the most crucial functions that needs to be carried out with the utmost precision in order to avoid the possibility of having an adverse effect on the procedure of industrial heat transfer. As a result, in order to construct air-water heaters in this case, metal plates can be used as connectors in the process of constructing the heaters [4].

V. EFFECTIVENESS OF THE SEVERAL TYPES OF AIR-WATER HEATERS IN THE INDUSTRIAL HEATING PROCEDURE

The drain back system can be marked as one of the most effective types of air-water heating used in the process of industrial heating. Usage of pump has been found as an important factor in this case which can affect the procedure of industrial heating [22] [19]. Air vents along with pressure gauge are the main determinants of functioning of this system of air-water heating for industrial purposes.

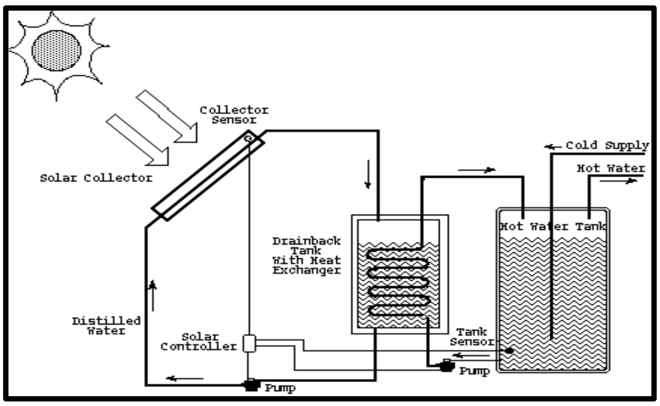

Figure 3: Structure of solar collector[7]

Active open loop has been identified as the other system which uses temperature controller in execution. Activation of the circulating pumps is done in this system which in turn can make the process of industrial heating highly efficient [32]. In addition, this system draws water from the storage tanks in execution. High performance can be obtained by the industries by using this system as heat loss is relatively lower in this case. Passive method of air-water heating has been found as the other method which can be useful for industrial heating. A storage tank is to be installed in this case on rooftops. Usage of an insulated tank can be marked as one of the most vital parts of this system [7] [13].

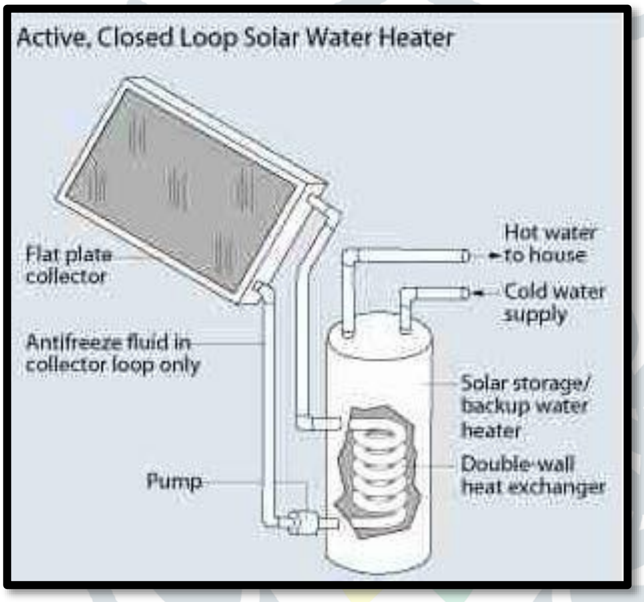

Figure 4: Structure of closed loop solar heater[7]

VI. THEORETICAL UNDERPINNING

Theory of technological determinism

The theory of technological determinism can be followed by the designers engaged in developing the air-water heaters operated by solar energy [16] [15]. This theory has taken into account the technological drivers for betterment of societies. Role of technology in social construction has been given a high priority by this theory. At the same time, the contingent social events are given a high level of importance by this theory [5].

The model of technology innovation

Developing air-water heaters that operate on solar energy can be an extremely complex and demanding undertaking for designers who are committed to pushing the boundaries of technological innovation. However, by embracing this model, developers can unlock numerous advantages and propel the innovation process forward in a remarkably efficient manner [13] [19]. This approach offers a multitude of benefits, chief among them being the ability to expedite the experimentation phase and test novel concepts with an unparalleled level of precision and accuracy [29] [36]. Consequently, the model outlined here serves as a powerful tool for developers seeking to explore and validate ground- breaking ideas in the realm of air-water heating technology[6] [26].

VII. PROBLEM STATEMENT

There is a lack of effective remedies available to overcome the issues due to fluid leakage that have been found to be a major problem in this particular case [48] [33]. Further, it was found that issues in the collector glass as well as the pipeline are equally important to increasing the efficiency of the air-water heaters due to their structural design [45] [34].

High-temperature heating is a common requirement in industrial operations, typically achieved using heating systems that rely on fossil fuels. These conventional systems contribute to environmental pollution, carbon emissions, and reliance on limited resources [50] [52]. The need for sustainable and energy-efficient alternatives that can fulfil the high-temperature heating demands of industrial processes is evident.

The challenge lies in the development of a solar-powered heating system that can effectively capture solar energy and provide adequaThe te heat transfer for industrial applications [45] [40]. This system should have the capability to utilize solar radiation to heat both air and water, with a heat exchanger facilitating efficient heat transfer between the two circuits. The task at hand is to create a system that can achieve optimal thermal efficiency, maintain the required temperature for industrial processes, and ensure cost-effectiveness [25] [33] [32].

To tackle this issue, an experimental investigation aims to evaluate the performance, efficiency, and feasibility of a solar air-water heater with a heat exchanger for industrial process heating [16] [45] [37]. By conducting experiments, measuring crucial parameters, and analysing the findings, the study seeks to determine the system's ability to meet the high-temperature heating demands of industrial processes while maximizing energy utilization and minimizing environmental impact [35] [40] [44].

The objective of this investigation is to address the challenge of attaining sustainable and efficient high-temperature heating in industrial processes, opening up opportunities for the development and adoption of solar-powered heating systems as a viable alternative to fossil fuel-based systems. [43] [41] [25].

VIII. RESULTS

Based on the methodological choices, the researchers have analyzed the acquired data on thermal efficiency, heat transfer rates, and overall system performance of the solar water heaters. Based on these investigation results, the efficiency of heaters has been discussed for large-scale industry uses [17]. In the case of these three factors, three different theoretical equation models have been used.
Heat transfer rates have been calculated through: $\varepsilon = F2CPwt(T8 - T7)/ F3Cpar(T8 - T9)$ [55]
Thermal efficiency rates have been calculated through: $\eta = Qu / Qs,SG + Qs,DG + Qs,ar + Qax$ [29]

The overall system performance has been calculated through: $\eta 0 = Qu/ Qs,SG + Qs,DG + Qs,ar + Qax + Qele$ [45]

Heat Transfer

The experimentation of heat transfer has been analysed through the reports of various studies focusing on this current situation [31]. The researchers found that the storage tank lost a heating coefficient of 3.21 W/m2K based on the experimentation data from mid-April to July [36]. Apart from that, the effectiveness of the heat exchange has also been seen as s 0.39 ± 0.16 [52].

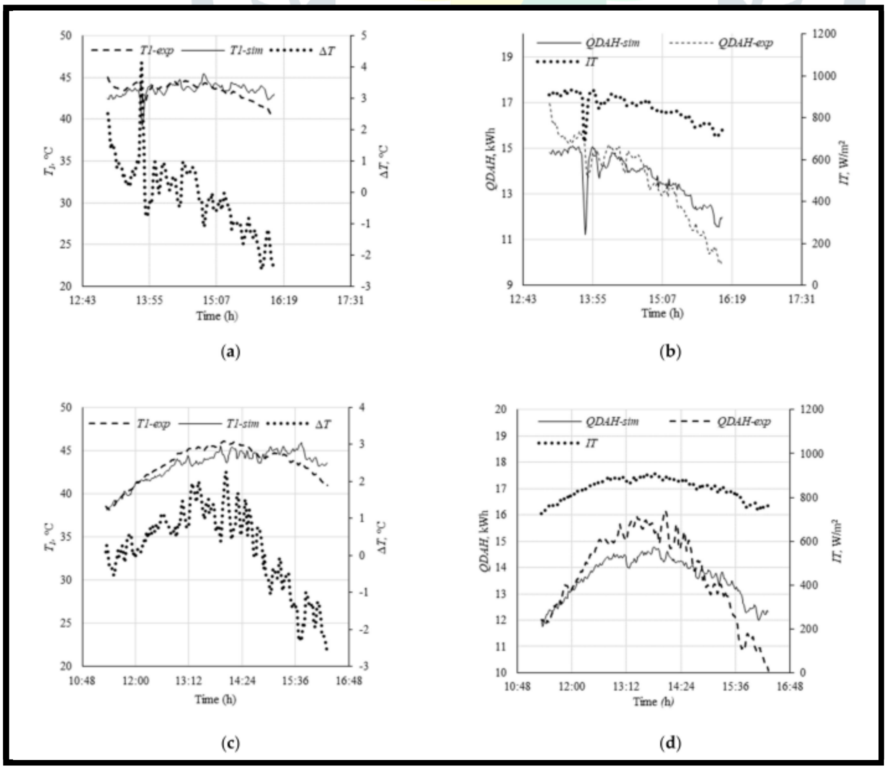

Figure 5: Heat Transfer Diagram of the experimental and simulated Temperature Outlets[11]

Based on the above figure, it can be said that the RMSE values of the experimental heater and simulator are found as 1.1, and 1.6 ◦C. This shows the heat transfer of the experimental heater was greater than the simulator [29]. Apart from that, the % MAE value was 0.62 for the simulator and 1.23 for the experimental [51]. The temperature differences found between these two T1_sim and T1_exp are −3.9 to 4.1 ◦C [55]. This concluded that the experimental thermal water air heater is efficient in heat transfer and storage in any simulated facility.

Thermal Performance

The thermal performance variations have shown the annual fluctuations of the annual data taken from both the simulated and experimental heaters [21].

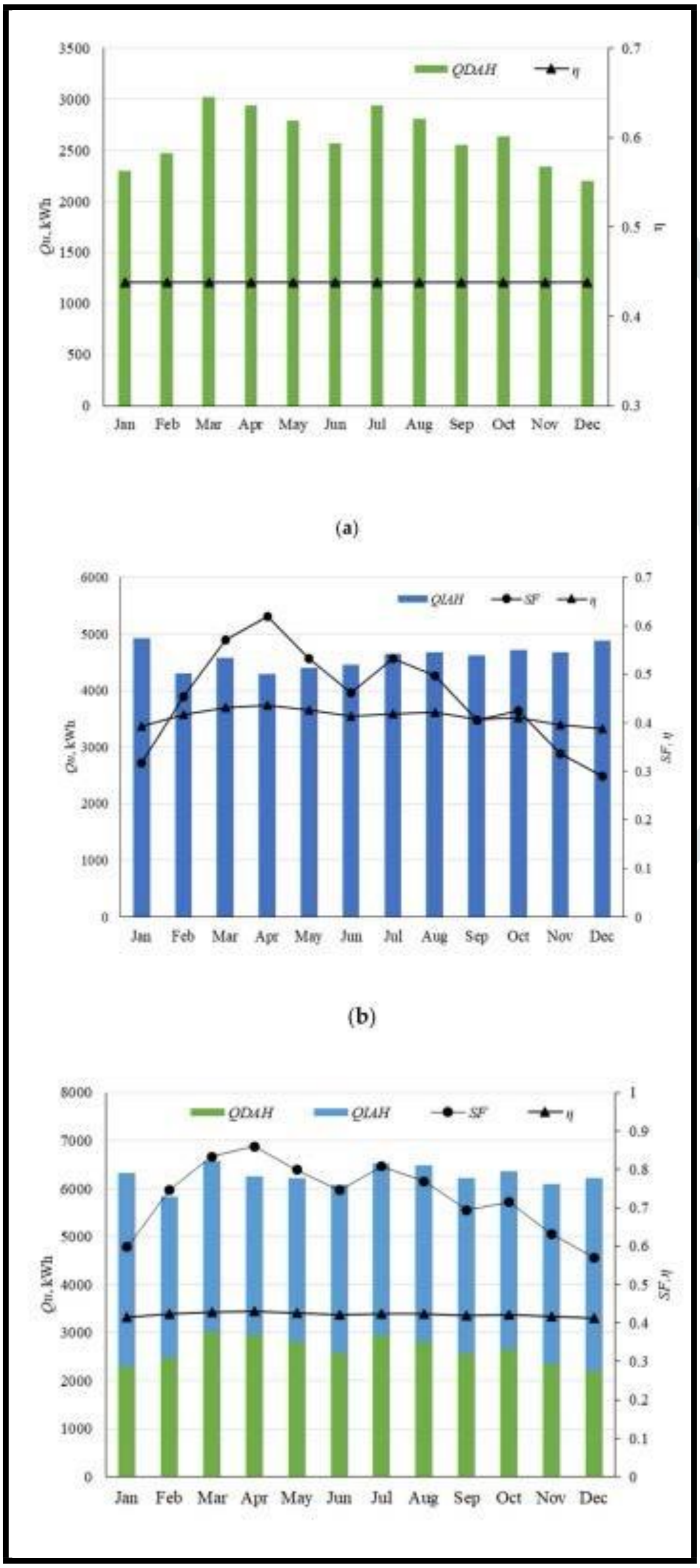

Figure 6: Thermal Performance diagram of the experimental and simulated Temperature Outlets[25]

Based on the above image it can be seen that the thermal performances of the experimental heater were found as 75.18 MWh, whereas the simulator performed way below 31.60 MWh [38]. The efficiency coefficients are found as 0.40 for the experimental heater and 0.37 for the simulator [49]. However, the third graph showed the hybridization of the experimental as well as the simulator heaters. Based on the graph, it can be seen that the hybrid heater has increased the amount of useful energy by 58% [55]. Apart from that, the hybrid model has also been found with an increasing solar fraction (0.73) than the separate experiment model (0.45) [39].

Overall system performance

The overall performance of the heaters has been done by a Pearson correlation coefficient matrix, which highlights the different relationships between the different variables, important for the optimum performance of the heater [32].

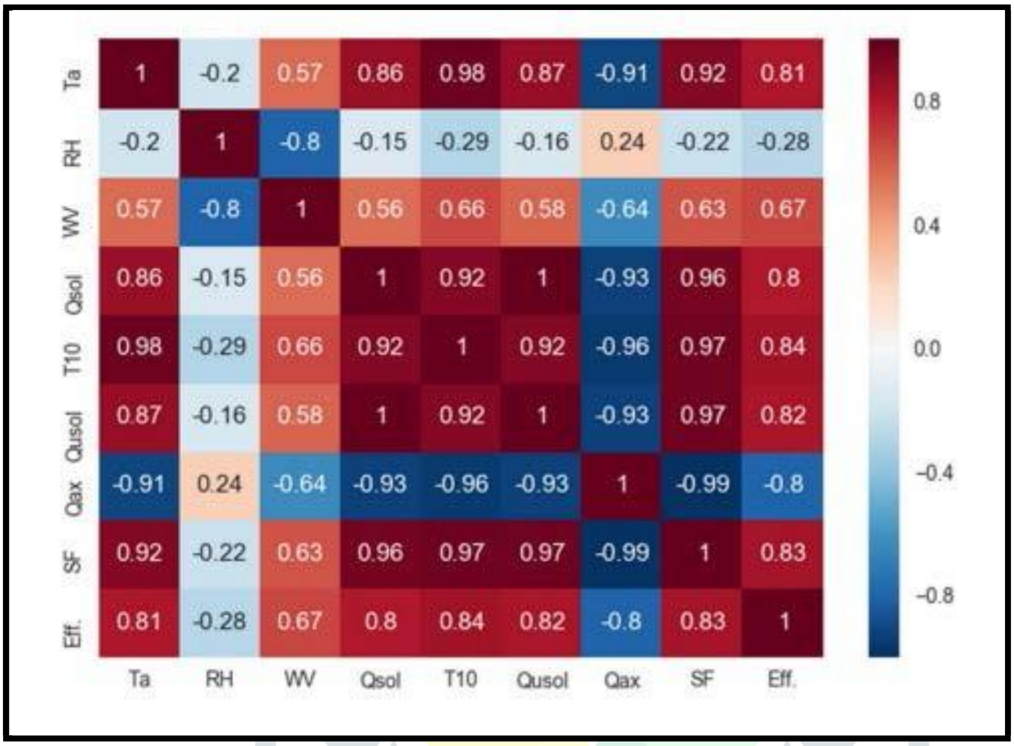

Figure 7: Sensitive analysis diagram of the experimental and simulated Temperature Outlets[32]

The sensitive analysis shows that the accumulation of useful energy for the heater is positively correlated with the ambient temperature and solar radiation [55]. It is also found that energy efficiency, as well as overall performance efficiency, are also highly correlated with the solar fraction, ambient temperature and solar radiation [27].

IX. DISCUSSION

The concerned discussion is focused on the different results collected through previous research articles, focused on the experimental performance analysis of the Solar Air-Water Heater with Heat Exchanger [29]. The data collected from the articles are identified from the experimental research, where prototyped models, as well as simulated models, were used to identify different variables related to the performance of the heater. It has been found that factors such as solar radiation, ambient temperature and solar fraction [14]. In addition, it has been found that the prototype experimental model of the heater has superior quality as well as performance than the simulator model. However, the hybrid model has been found as the most effective in terms of overall heater performance.

X. CONCLUSION

To sum up, based on the discussions and findings presented in this study, it is clear that the effectiveness of the piping system plays a crucial role in the heat transfer process of air-water heaters utilized for industrial heating. Inadequate piping systems can hinder the overall performance and efficiency of the heating system, resulting in suboptimal outcomes.

The planning and arrangement of the piping system should be carefully evaluated to minimize heat losses, pressure reductions, and flow limitations. Adequate insulation of the pipes can diminish heat losses and guarantee that the transferred heat is efficiently utilized for industrial processes. Furthermore, selecting suitable pipe materials with high thermal conductivity and minimal friction losses can enhance the overall system efficiency.

Moreover, the efficiency of the pumps utilized in the air-water heater system is another vital factor that impacts its performance. Pumps are responsible for circulating the air and water within the system, facilitating heat transfer. Inefficient pumps can lead to insufficient flow rates, reduced heat transfer rates, and decreased overall system efficiency. To optimize the efficiency of air-water heaters used in industrial heating, it is crucial to choose pumps with suitable specifications, such as adequate flow capacity and energy-efficient operation. Regular maintenance and monitoring of pump performance are also essential to ensure optimal functionality and prevent any decline in efficiency over time.

In conclusion, the efficiency of the piping system and pumps significantly determine the effectiveness and efficiency of air-water heaters used in industrial heating. By optimizing these components and considering factors like proper insulation, appropriate pipe materials, and efficient pump selection, the overall system efficiency can be substantially enhanced.

REFERENCES

[1]. Bazregari, M.J., Norouzi, N., Gholinejad, M. and Fani, M., (2022). A 2E analysis and optimization of a hybrid solar humidification-dehumidification water desalination system and solar water heater. Iranian Journal of Chemistry and

Chemical Engineering, 41(6), pp.2135-2152. Retrieved from:https://www.ijcce.ac.ir/article_247243_e47859e49ef7b6de08be3c803977c5b0.pdf

[2]. Bruno, R., Nicoletti, F., Cuconati, G., Perrella, S. and Cirone, D., (2020). Performance indexes of an air-water heat pump versus the capacity ratio: Analysis by means of experimental data. *Energies*, *13*(13), p.3391. Retrieved from:https://www.mdpi.com/1996-1073/13/13/3391/pdf

[3]. Leonzio, G., Fennell, P.S. and Shah, N., (2022). Air-source heat pumps for water heating at a high temperature: State of the art. Sustainable Energy Technologies and Assessments, 54, p.102866. Retrieved from:https://www.sciencedirect.com/science/article/pii/S2213138822009146

[4]. Nwaji, G.N., Okoronkwo, C.A., Ogueke, N.V. and Anyanwu, E.E., (2019). Hybrid solar water heating/nocturnal radiation cooling system I: A review of the progress, prospects and challenges. Energy and Buildings, 198, pp.412-430. Retrieved from: https://www.sciencedirect.com/science/article/pii/S0378778818338179

[5]. Shemelin, V. and Matuska, T., (2019). Performance Modelling of Dual Air/Water Collector in Solar Water and Space Heating Application. International Journal of Photoenergy, 2019. Retrieved from:

[6]. Somwanshi, A. and Sarkar, N., (2020). Thermal performance of a dual-purpose collector-cum-storage type air-water heater. Applied Thermal Engineering, 171, p.115094. Retrieved from:https://www.sciencedirect.com/science/article/pii/S1359431119343248

[7]. Soomro, S.H., Santosh, R., Bak, C.U., Kim, W.S. and Kim, Y.D., (2021). Humidification-dehumidification desalination system powered by simultaneous air-water solar heater. *Sustainability*, *13*(23), p.13491. Retrieved from:https://www.mdpi.com/2071-1050/13/23/13491

[8]. Braun, V., Clarke, V., Boulton, E., Davey, L. and McEvoy, C., (2021). The online survey as a qualitative research tool. International journal of social research methodology, 24(6), pp.641-654. Retrieved from:https://uwerepository.worktribe.com/index.php/preview/6634609/The%20Online%20Survey%20as%20a%20Qualitative%20Research%20Tool%20UWE%20Repository%20Version%20%281%29.pdf

[9]. Vengadesan, E., Bharathwaj, D., Kumar, B. S., &Senthil, R. (2022). Experimental study on heat storage integrated flat plate solar collector for combined water and air heating in buildings. *Applied Thermal Engineering*, *216*, 119105.Retrieved from:https://www.sciencedirect.com/science/article/pii/S1359431122010365

[10]. Wang, Z., Diao, Y., Zhao, Y., Wang, T., Liang, L., & Chi, Y. (2018). Experimental investigation of an integrated collector–storage solar air heater based on the lap joint-type flat micro-heat pipe arrays. *Energy*, *160*, 924-939.Retrieved from:https://www.sciencedirect.com/science/article/pii/S0360544218313495

[11]. Xu, J., Pan, Q., Zhang, W., Liu, Z., Wang, R., & Ge, T. (2022). Design and experimental study on a hybrid adsorption refrigeration system using desiccant coated heat exchangers for efficient energy utilization. *Renewable and Sustainable Energy Reviews*, *169*, 112890.Retrieved from:https://www.sciencedirect.com/science/article/pii/S1364032122007729

[12]. Sun, X. Y., Chen, J. L., Zhao, Y., Li, X., Ge, T. S., Wang, C. H., & Dai, Y. J. (2021). Experimental investigation on a dehumidification unit with heat recovery using desiccant coated heat exchanger in waste to energy system. *Applied Thermal Engineering*, *185*, 116342.Retrieved from:https://www.sciencedirect.com/science/article/pii/S1359431120338205

[13]. Almeshaal, M., Arunprasad, V., Palaniappan, M., &Kolsi, L. (2020). Experimental study of a solar water heater fitted with spacer at the leading edge of Left-Right screw tapes. *Case Studies in Thermal Engineering*, *22*, 100777.Retrieved from:https://www.sciencedirect.com/science/article/pii/S2214157X20305190

[14]. Shao, N., Ma, L., & Zhang, J. (2020). Experimental investigation on the performance of direct-expansion roof-PV/T heat pump system. *Energy*, *195*, 116959.Retrieved from:https://www.sciencedirect.com/science/article/pii/S0360544220300669

[15]. Farzan, H., &Zaim, E. H. (2023). Study on thermal performance of a new combined perforated metallic/asphalt solar air heater for heating Applications: An experimental study. *Solar Energy*, *249*, 485-494.Retrieved from:https://www.sciencedirect.com/science/article/pii/S0038092X22008799

[16]. Kumar, P. G., Balaji, K., Sakthivadivel, D., Vigneswaran, V. S., Velraj, R., & Kim, S. C. (2021). Enhancement of heat transfer in a combined solar air heating and water heater system. *Energy*, *221*, 119805.Retrieved from:https://www.sciencedirect.com/science/article/pii/S0360544221000542

[17]. Ali, M., Habib, M. F., Sheikh, N. A., & Akhter, J. (2022). Experimental investigation of an integrated absorption-solid desiccant air conditioning system. *Applied Thermal Engineering*, *203*, 117912.Retrieved from:https://www.sciencedirect.com/science/article/pii/S1359431121013351

[18]. Chai, S., Sun, X., Zhao, Y., & Dai, Y. (2019). Experimental investigation on a fresh air dehumidification system using heat pump with desiccant coated heat exchanger. *Energy*, *171*, 306-314.Retrieved from:https://www.sciencedirect.com/science/article/pii/S0360544219300258

[19]. Hamada, M. A., Khalil, H., Abou Al-Sood, M. M., &Sharshir, S. W. (2023). An experimental investigation of nanofluid, nanocoating, and energy storage materials on the performance of parabolic trough collector. *Applied Thermal Engineering*, *219*, 119450.Retrieved from:https://www.sciencedirect.com/science/article/pii/S1359431122013801

[20]. Croci, L., Cristiani, N., Benini, M., &Besagni, G. (2021). Experimental Study of a Novel Integrated System for Air Conditioning and Domestic Hot Water Production. *Chemical Engineering Transactions*, *86*, 631-636.Retrieved from:https://www.cetjournal.it/index.php/cet/article/view/CET2186106

[21]. Marouf, Z. M., Fouad, M. A., & Hassan, M. A. (2022). Experimental investigation of the effect of air bubbles injection on the performance of a plate heat exchanger. *Applied Thermal Engineering*, *217*, 119264.Retrieved from:https://www.sciencedirect.com/science/article/pii/S1359431122011942

[22]. Shao, N., Ma, L., Zhou, C., & Zhang, D. (2022). Experimental study on the heat transfer performance of the PVT ventilated roof as heat exchanger for heat pump system. *Renewable Energy*, *187*, 995-1008.Retrieved from:https://www.sciencedirect.com/science/article/pii/S0960148122000945

[23]. Shafiee, M., Farbeh, A., &Firoozzadeh, M. (2022). Experimental study on using oil-based nanofluids in a vacuumed tube solar water heater: an exergy analysis. *International Journal of Ambient Energy*, *43*(1), 7387-7399.Retrieved from:https://www.tandfonline.com/doi/abs/10.1080/01430750.2022.2073267

[24]. Raju, G., & Kumar, M. M. J. (2021). Experimental study on solar air heater with encapsulated phase change material on its absorber plate. *Energy Storage*, *3*(5), e256.Retrieved from:https://onlinelibrary.wiley.com/doi/abs/10.1002/est2.256

[25]. Lee, Y., Jeong, H., Park, J. T., Delgado, A., & Kim, S. (2020). Experimental investigation on evaluation of thermal performance of solar heating system using Al2O3 nanofluid. *Applied Sciences*, *10*(16), 5521.Retrieved from:https://www.mdpi.com/2076-3417/10/16/5521

[26]. Lee, Y., Jeong, H., Park, J. T., Delgado, A., & Kim, S. (2020). Experimental investigation on evaluation of thermal performance of solar heating system using Al2O3 nanofluid. *Applied Sciences*, *10*(16), 5521.Retrieved from:https://www.mdpi.com/2076-3417/10/16/5521

[27]. Abdelaziz, G. B., Abdelbaky, M. A., Halim, M. A., Omara, M. E., Elkhaldy, I. A., Abdullah, A. S., ... &Kabeel, A. E. (2021). Energy saving via Heat Pipe Heat Exchanger in air conditioning applications "experimental study and economic analysis". *Journal of Building Engineering*, *35*, 102053.Retrieved from:https://www.sciencedirect.com/science/article/pii/S2352710220336858

[28]. Chien, L. H., Chen, D. C., Liu, Y. J., Yan, W. M., &Ghalambaz, M. (2021). Heat and mass transfer of evaporative cooler with elliptic tube heat exchangers-an experimental study. *International Communications in Heat and Mass Transfer*, *127*, 105502.Retrieved from:https://www.sciencedirect.com/science/article/pii/S073519332100395X

[29]. Khangembam, C., & Singh, D. (2019). Experimental investigation of air–water mist jet impingement cooling over a heated cylinder. *Journal of Heat Transfer*, *141*(8), 082201.Retrieved from:https://asmedigitalcollection.asme.org/heattransfer/article-abstract/141/8/082201/727011

[30]. Tian, Z., Liu, X., Wang, C., Zhang, D., Tian, W., Qiu, S., & Su, G. H. (2021). Experimental investigation on the heat transfer performance of high-temperature potassium heat pipe for nuclear reactor. *Nuclear Engineering and Design*, *378*, 111182.Retrieved from:https://www.sciencedirect.com/science/article/pii/S0029549321001345

[31]. Hossen, S., Mahmud-Or-Rashid, M. T., Shakil, F. A., &Morshed, A. M. Experimental Investigation of an Air to Air Heat Pipe Heat Exchanger for Moderate Temperature Waste Heat Recovery.Retrievedfrom:https://www.academia.edu/download/83563156/ICMIEE18-227.pdf

[32]. Yan, J., Pan, Z. H., & Zhao, C. Y. (2020). Experimental study of MgO/Mg (OH) 2 thermochemical heat storage with direct heat transfer mode. *Applied Energy*, *275*, 115356.Retrieved from:https://www.sciencedirect.com/science/article/pii/S0306261920308680

[33]. Zhou, J., Zhu, Z., Zhao, X., Yuan, Y., Fan, Y., & Myers, S. (2020). Theoretical and experimental study of a novel solar indirect-expansion heat pump system employing mini channel PV/T and thermal panels. *Renewable Energy*, *151*, 674-686.Retrieved from:https://www.sciencedirect.com/science/article/pii/S0960148119317410

[34]. Kazem, H. A., Chaichan, M. T., Al-Waeli, A. H., &Sopian, K. (2021). Comparison and evaluation of solar photovoltaic thermal system with hybrid collector: An experimental study. *Thermal Science and Engineering Progress*, *22*, 100845.Retrieved from:https://www.sciencedirect.com/science/article/pii/S245190492100007X

[35]. Abdel-Hady, F., El-Halwagi, M. M., Alghamdi, M., Mazher, A. K., &Alzahrani, A. (2018). Experimental Study of Humidification AndDehumidification Desalination Process.Retrieved from:https://www.researchgate.net/profile/Abdel-Hamid-Mazher/publication/324944950_Experimental_Study_of_Humidification_AndDehumidification_Desalination_Process/links/5c7ffc9f458515831f8b03cb/Experimental-Study-of-Humidification-AndDehumidification-Desalination-Process.pdf

[36]. Nada, S. A., Fouda, A., Mahmoud, M. A., &Elattar, H. F. (2021). Experimental investigation of air-conditioning and HDH desalination hybrid system using new packing pad humidifier and strips-finned helical coil. *Applied Thermal Engineering*, *185*, 116433.Retrieved from:https://www.sciencedirect.com/science/article/pii/S1359431120339119

[37]. El-Hadary, M. I., Senthilraja, S., &Zayed, M. E. (2023). A hybrid system coupling spiral type solar photovoltaic thermal collector and electrocatalytic hydrogen production cell: Experimental investigation and numerical modeling. *Process Safety and Environmental Protection*, *170*, 1101-1120.Retrieved from:https://www.sciencedirect.com/science/article/pii/S0957582022011569

[38]. Khanlari, A., Sözen, A., Sahin, B., Di Nicola, G., &Afshari, F. (2020). Experimental investigation on using building shower drain water as a heat source for heat pump systems. *Energy Sources, Part A: Recovery, Utilization, and Environmental Effects*, 1-13.Retrieved from:https://www.tandfonline.com/doi/abs/10.1080/15567036.2020.1796845

[39]. RaamDheep, G. (2018). *Experimental studies on solar thermal collectors integrated with latent heat based thermal energy storage system* (Doctoral dissertation, Centre for Green Energy Technology, Pondicherry University).Retrieved from:http://dspace.pondiuni.edu.in/jspui/bitstream/123456789/3165/1/T6914.pdf

[40]. Hossen, S., Morshed, A. M., Tikadar, A., Salman, A. S., & Paul, T. C. (2019). Experimental Investigation of Heat Pipe Heat Exchanger (HPHE) For Waste Heat Recovery Application. In *ASTFE Digital Library*. Begel House Inc..Retrieved from:https://www.researchgate.net/profile/Azzam-Salman/publication/333985419_EXPERIMENTAL_INVESTIGATION_OF_HEAT_PIPE_HEAT_EXCHANGER_HPHE_FOR_WASTE_HEAT_RECOVERY_APPLICATION/links/5d13f6ae92851cf4404f0a87/EXPERIMENTAL-INVESTIGATION-OF-HEAT-PIPE-HEAT-EXCHANGER-HPHE-FOR-WASTE-HEAT-RECOVERY-APPLICATION.pdf

[41]. Chen, H., Zhang, H., Li, M., Liu, H., & Huang, J. (2018). Experimental investigation of a novel LCPV/T system with micro-channel heat pipe array. *Renewable energy*, *115*, 773-782.Retrieved from:https://www.sciencedirect.com/science/article/pii/S0960148117308273

[42]. SuranjanSalins, S., Anusha Siddiqui, S., Reddy, S. K., & Kumar, S. (2021). Experimental investigation on the performance parameters of a helical coil dehumidifier test rig. *Energy Sources, Part A: Recovery, Utilization, and*

Environmental Effects, *43*(1), 35-53.Retrieved from:https://www.tandfonline.com/doi/abs/10.1080/15567036.2020.1814455

[43]. Mohamed, A. S. A., Ahmed, M. S., &Shahdy, A. G. (2020). Theoretical and experimental study of a seawater desalination system based on humidification-dehumidification technique. *Renewable Energy*, *152*, 823-834.Retrieved from:https://www.tandfonline.com/doi/abs/10.1080/15435075.2019.1671401

[44]. Chabane, F., Grira, F., Moummi, N., &Brima, A. (2019). Experimental study of a solar air heater by adding an arrangement of transverse rectangular baffles perpendicular to the air stream. *International Journal of Green Energy*, *16*(14), 1264-1277.Retrieved from:https://www.tandfonline.com/doi/abs/10.1080/15435075.2019.1671401

[45]. Fudholi, A., Zohri, M., Rukman, N. S. B., Nazri, N. S., Mustapha, M., Yen, C. H., ...&Sopian, K. (2019). Exergy and sustainability index of photovoltaic thermal (PVT) air collector: A theoretical and experimental study. *Renewable and Sustainable Energy Reviews*, *100*, 44-51.Retrieved from:https://www.sciencedirect.com/science/article/pii/S1364032118307238

[46]. Rahmani, A., & Zaidi, Y. (2022). Effect of condenser design on the performance of the natural circulation loop solar still: An experimental study. *Heat Transfer*, *51*(5), 4783-4798.Retrieved from:https://onlinelibrary.wiley.com/doi/abs/10.1002/htj.22523

[47]. Sarafraz, M. M., Safaei, M. R., Leon, A. S., Tlili, I., Alkanhal, T. A., Tian, Z., ...&Arjomandi, M. (2019). Experimental investigation on thermal performance of a PV/T-PCM (photovoltaic/thermal) system cooling with a PCM and nanofluid. *Energies*, *12*(13), 2572.Retrieved from:https://www.mdpi.com/1996-1073/12/13/2572

[48]. Guo, J., Liu, Z., Du, Z., Yu, J., Yang, X., & Yan, J. (2021). Effect of fin-metal foam structure on thermal energy storage: An experimental study. *Renewable energy*, *172*, 57-70.Retrieved from:https://www.sciencedirect.com/science/article/pii/S0960148121003724

[49]. Farzan, H., &Yousefelahi, M. J. (2023). Study on collection and retention efficiencies of a new integrated collector storage solar water heating system using a planar thermal diode: an experimental study. *Environmental Science and Pollution Research*, 1-15.Retrieved from:https://link.springer.com/article/10.1007/s11356-023-27700-z

[50]. Tao, X., Dahlgren, E., Leichsenring, M., & Ferreira, C. A. I. (2020). NH3 condensation in a plate heat exchanger: Experimental investigation on flow patterns, heat transfer and frictional pressure drop. *International Journal of Heat and Mass Transfer*, *151*, 119374.Retrieved from:https://www.sciencedirect.com/science/article/pii/S0017931019359629

[51]. Rezazadeh, R., Jafarmadar, S., Khorasani, S., &Niaki, S. R. A. (2022). Experimental investigation on thermal behavior of non-boiling slug and bubbly two phase-flow in helical tube with spiral. *Proceedings of the Institution of Mechanical Engineers, Part C: Journal of Mechanical Engineering Science*, *236*(7), 3434-3446.Retrieved from:https://journals.sagepub.com/doi/abs/10.1177/09544062211042045

[52]. Fan, X., Lu, X., Nie, H., Zhu, H., Wang, Q., Kang, Y., ...& Li, J. (2021). An experimental study of a novel dew point evaporative cooling tower based on M-cycle. *Applied Thermal Engineering*, *190*, 116839.Retrieved from:https://www.sciencedirect.com/science/article/pii/S135943112100288X

[53]. Rahman, M. S., Chauvin-Bossé, T., Akbarzadeh, A., Guerini, A., Chapelat, J., &Lefsrud, M. (2022). Experimental investigation of heat and moisture transfer with ventilation through porous concrete with embedded coils for air conditioning. *Building and Environment*, *222*, 109370.Retrieved from:https://www.sciencedirect.com/science/article/pii/S0360132322006035

[54]. Thyagarajan, A., Dhir, V., & Banerjee, D. (2022, October). Experimental Investigation of Solar-Thermal Desalination Platform Leveraging Dynamic Flash Evaporation and Swirl Flow Separator. In *ASME International Mechanical Engineering Congress and Exposition* (Vol. 86700, p. V008T11A056). American Society of Mechanical Engineers. Retrieved from:https://asmedigitalcollection.asme.org/IMECE/proceedings-abstract/IMECE2022/V008T11A056/1157425

[55]. M Almari, R., AAbdelrahman, M., & A Moawad, M. (2022). An experimental investigation of the Evacuated Tube solar collector in conjunction with a latent heat storage tank. *Engineering Research Journal-Faculty of Engineering (Shoubra)*, *51*(1), 20-28.Retrieved from:https://erjsh.journals.ekb.eg/article_224245.html

[56]. Álvarez-Sánchez, F., Flores-Prieto, J., & García-Valladares, O. (2021). Annual Thermal Performance of an Industrial Hybrid Direct–Indirect Solar Air Heating System for Drying Applications in Morelos-México. *Energies*, *14*(17), 5417. Retrieved from: https://www.mdpi.com/1996-1073/14/17/5417/pdf.

[57]. Anand Patel and Sadanand Namjoshi, "Phase change material based solar water heater," International Journal of Engineering Science Invention., vol. 5, no. 8, August 2016.

[58]. Anand Patel, Divyesh Patel, Sadanand Namjoshi (2018); Thermal Performance Evaluation of Spiral Solar Air Heater; Int J Sci Res Publ 5(9) (ISSN: 2250-3153). http://www.ijsrp.org/research-paper-0915.php?rp=P454598

[59]. Patel A, Parmar H, Namjoshi S 2016 Comparative thermal performance studies of serpentine tube solar water heater with straight tube solar water heater. IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE) 13 79–83.

[60]. Patel, Anand et al."Thermal Performance Analysis of Fin Covered Solar Air Heater", "International Journal of Engineering Science and Futuristic Technology" (2017).

[61]. HD Chaudhary, SA Namjoshi, A Patel, Effect of Strip Insertion on Thermal Performance Evaluation in Evacuated Tube Solar Water Heater with Different Inner Tube Diameter REVISTA GEINTEC-GESTAO INOVACAO E TECNOLOGIAS, Volume 11, Issue 3, Page- 1842-1847

[62]. Anand Patel. "Effect of Inclination on the Performance of Solar Water Heater." International Journal for Scientific Research and Development 11.3 (2023): 413-416.

[63]. Patel, Anand. "The Performance Investigation of Square Tube Solar Water Heater", International Journal of Science & Engineering Development Research (www.ijsdr.org), ISSN:2455-2631, Vol.8, Issue 6, page no.872 - 878, June-2023, Available :http://www.ijsdr.org/papers/IJSDR2306123.pdf

[64]. Anand Patel. ""Comparative Thermal Performance Investigation of Box Typed Solar Air heater with V Trough Solar Air Heater"". International Journal of Engineering Science Invention (IJESI), Vol. 12(6), 2023, PP 45-51. Journal DOI-10.35629/6734".

[65]. Patel, Anand, et al. "Comparative Thermal Performance Evaluation of U Tube and Straight Tube Solar Water Heater." International Journal of Research in Engineering and Science (IJRES), vol. 11, no. 6, June 2023, pp. 346–52. www.ijres.org/index.html.

[66]. Patel, A., Namjoshi, Dr. S., & Singh, S. K. (2023). Comparative Experimental Investigation of Simple and V-Shaped Rib Solar Air Heater. International Journal of All Research Education and Scientific Methods (IJARESM), 11(6), 2455–6211. http://www.ijaresm.com/uploaded_files/document_file/Anand_PatelYHv7.pdf

[67]. Patel, Anand. "Experimental Investigation of Oval Tube Solar Water Heater With Fin Cover Absorber Plate." International Journal of Enhanced Research in Science, Technology & Engineering, vol. 12, issue no. 7, July 2023, pp. 19–26, doi:10.55948/IJERSTE.2023.0704.

[68]. Patel, Anand. "Comparative Thermal Performance Evaluation of V-shaped Rib and WShape Rib Solar Air Heater." International Journal of Research Publication and Reviews, vol. 14, issue no. 7, July 2023, pp. 1033–39.

[69]. Patel, Anand. "Experimental Evaluation of Twisted Tube Solar Water Heater." International Journal of Engineering Research & Technology (IJERT), vol. 12, issue no. 7, IJERTV12IS070041, July 2023, pp. 30–34, https://www.ijert.org/research/experimental-evaluation-of-twisted-tube-solar-water-heater-IJERTV12IS070041.pdf.

[70]. Patel, Anand."Comparative Thermal Performance Investigation of the Straight Tube and Square Tube Solar Water Heater." World Journal of Advanced Research and Reviews, vol. 19, issue no. 01, July 2023, pp. 727–735. https://doi.org/10.30574/wjarr.2023.19.1.1388.

[71]. Patel, AK, & Zhao, W. "Heat Transfer Analysis of Graphite Foam Embedded Vapor Chamber for Cooling of Power Electronics in Electric Vehicles." Proceedings of the ASME 2017 Heat Transfer Summer Conference. Volume 1: Aerospace Heat Transfer; Computational Heat Transfer; Education; Environmental Heat Transfer; Fire and Combustion Systems; Gas Turbine Heat Transfer; Heat Transfer in Electronic Equipment; Heat Transfer in Energy Systems. Bellevue, Washington, USA. July 9–12, 2017. V001T09A003. ASME. https://doi.org/10.1115/HT2017-4731.

[72]. Anand Patel, "Thermal Performance Investigation of Twisted Tube Heat Exchanger", International Journal of Science and Research (IJSR), Volume 12 Issue 6, June 2023, pp. 350-353, https://www.ijsr.net/getabstract.php?paperid=SR23524161312, DOI: 10.21275/SR23524161312.

[73]. Patel, Anand "Performance Analysis of Helical Tube Heat Exchanger", TIJER - International Research Journal (www.tijer.org), ISSN:2349-9249, Vol.10, Issue 7, page no.946-950, July-2023, Available :http://www.tijer.org/papers/TIJER2307213.pdf.