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Technological Innovations in Solar Heater Materials and Manufacturing

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***Abstract*— With the use of SolidWorks software, thereby this research explores the innovative world of solar heaters by using cutting-edge materials and production methods. The study uses a descriptive methodology and a method based on inference, which are informed by an interpretive theory research philosophy. Additional resources lay the groundwork for examining the potential of cutting-edge materials like phase-change and nanotechnology. The study also looks into how SolidWorks may improve virtual prototyping, simulated accuracy, including design quality. The knowledge of thermal dynamics is further improved by the incorporation of computational fluid dynamics. Parametric is indispensable for understanding innovation, but physical validation is also necessary to ensure real-world application. According to the research, this complementary strategy provides a thorough way to advance solar heater technology while enhancing effectiveness, environmental sustainability, as well as design optimization.

***Keywords*— Energy-efficient, SolidWorks, light-trapping, phase change, household, decommissioning.

I. INTRODUCTION

1.1 Background

Due to increasing environmental worries and the demand for alternate energy sources, solar energy as an environmentally friendly and environmentally friendly option has received a lot of attention recently. Solar heaters are essential in the move to greener energy sources since they are made to capture the sun's warm rays and transform it into useful thermal energy [5]. The materials utilized in their construction as well as the manufacturing processes used have a big impact on how effective solar heaters are. Glass and copper, which are common materials for solar heaters, have drawbacks in terms of expense, effectiveness, and adaptability [6]. This study explores the most recent developments in solar heater components and production techniques. The objective is to pave the path for more effective, reasonably priced, and sustainable solar heaters by researching novel materials with enhanced thermal qualities and endurance and by utilizing the capability of CAD software like Siemens for complex designs. Such advancements have the potential to hasten the uptake of solar energy, making a substantial contribution to the global search for sustainable and environmentally friendly energy sources [7].

1.2 Problem statement

Efficiency and affordability are hampered by the current limits of standard solar heater supplies and production processes. It is essential for improving solar heater performance along with adoption to address these limits by creative material selections and cutting-edge manufacturing techniques, made possible by tools like SolidWorks [8].

1.3 Aim and Objectives

Aim

In order to improve efficiency, cost, and sustainability, this project will look into and create technological advances in solar radiator materials and production processes.

Objectives

- To look into and assess new materials for solar thermal applications that have better thermal characteristics and are more affordable.
- to investigate cutting-edge manufacturing methods using SolidWorks in order to streamline the design and manufacturing of solar heaters.
- To determine and evaluate the effects of cutting-edge components and production techniques on the effectiveness, capture of heat, retention, as well as overall performance of solar heaters.
- to determine whether the created solar heaters innovations are environmentally sustainable, taking into account elements like material sourcing, industrial energy usage, including end-of-life disposal.

1.4 Research questions

RQ1: What new materials are cost-effective and have better thermal characteristics for use in solar heaters?

RQ2: How can the design and manufacture of solar heaters be optimized using sophisticated production methods and SolidWorks?

RQ3: What is the quantifiable effect of incorporating cutting-edge materials and production techniques on the effectiveness, absorbed heat, retention, and general efficiency of solar heaters?

RQ4: What are the established solar heater technologies' overall environmental effects, taking into account things like material procurement, manufacturing energy usage, including terminal illness disposal?

1.5 Rationale

The vital need to enhance solar heater technologies in response to sustainability challenges with energy needs serves as the foundation for this research. Traditional solar heaters have limitations in terms of pricing and efficiency [9]. It may be able to get beyond these obstacles by investigating novel materials and cutting-edge production methods with the help of SolidWorks. The most important thing is to increase the absorption of heat, retention, as well as performance as a whole while keeping economic feasibility in mind [10]. In addition, gauging an innovation's environmental impact guarantees its long-term viability. The ultimate goal of this research is to hasten the widespread utilization of photovoltaic heaters, thereby promoting ecologically sound growth and the use of cleaner energy on a worldwide scale [11].

II. LITERATURE REVIEW

2.1 Introduction

Let's begin our investigation into improvements in solar heaters with the literature review chapter. Analyzing the advantages and disadvantages of current solar heating technology reveals these. Understanding new material advancements provides information on improved thermal performance [12]. This evaluates the contribution of SolidWorks to the optimization of design and production using modern manufacturing techniques. We also explore sustainability issues, carefully examining how solar heater advancements affect the environment. This chapter establishes a link between current understanding and our search for novel materials and production techniques, paving the way for well-informed research and game-changing contributions to the field of solar heating [13].

2.2: Current Solar Heater Technologies and Limitations

Despite their inherent drawbacks, current solar heaters technologies constitute a considerable step towards environmentally friendly power solutions. The flat-plate collectors and concentrate solar collectors that make up the majority of these technologies are each made to capture solar energy for household, industrial, and commercial heating purposes [14]. The most popular type of solar heating system is flat-plate collectors. They usually consist of an opaque cover, frequently glass, covering a dark absorbing plate. Sunlight passes through the cover and gets heated up as it hits the absorbing plate. However, due to their insufficient ability for heat absorption as well as retaining heat, these kinds of collectors frequently struggle to reach high thermal efficiency. Additionally, heat losses and decreased overall efficiency may be caused by the glass cover [15]. On the other side, concentrated solar collectors employ lenses or reflectors to focus sunlight over a smaller absorbing area, greatly boosting the heat produced. This group includes dish collectors including parabolic troughs. Although solar collectors can reach greater temperatures and efficiency, they are quite expensive and require complicated tracking technologies to follow the course of the sun. Cost-effectiveness along with scalability issues affect both technologies [16]. The widespread adoption is hampered by high initial costs related to materials, production, and installation. The short-term availability of sunlight necessitates effective energy storage techniques, which sometimes involve pricey heat storage apparatuses like salt molten reservoirs or phase-change compounds. Additionally, the effectiveness of modern solar heater techniques is limited in areas with variable sunlight due to their difficulty in adapting to changing environmental factors and geographical conditions [17]. The demands of maintenance can also have an effect on viability over time.

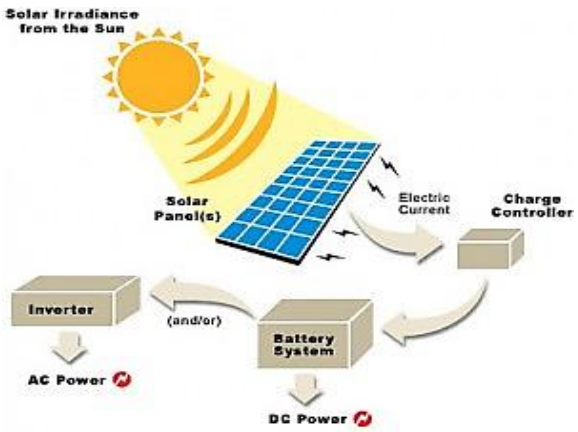

Figure 2.2.1: *Solar Power Energy*

The recent advancement in solar collector devices include thermal performance analysis by varying the geometry and material of the collector to enhance heat transfer and renewability in [56, 57, 58, 59, 60] [61, 62, 63, 64, 65] Anand Patel et al. for solar air & water heater

[66, 67] Patel Anand et al. for solar cooker [69] Thakre, Shekhar et al. [68] [70, 71, 72] Anand Patel et al. for heat exchanger.

2.3: Recent Advances in Solar Heater Materials

Recent developments in solar warmer materials have aimed to solve the shortcomings of existing choices and open the door for more effective and affordable energy conversion. These advancements cover a variety of materials, coatings, including composites, all of which are designed to improve particular thermal qualities necessary for solar-powered heating applications [18]. The field of nanomaterials has become increasingly interesting. Nanostructured absorbent coatings have outstanding light absorption properties, efficiently converting sunshine into heat. These coatings are frequently comprised of materials including graphene as well as carbon nanotubes. Additionally, these coatings limit heat losses, boosting overall effectiveness. Another innovation is selective coatings [19]. These coatings have the capacity to selectively soak up and release specific radiation frequencies, optimizing solar heat absorption while reducing heat loss. In particular in colder locations, this raises temperatures and improves performance. Phase-change semiconductors (PCMs) are increasing popularity because of their capacity to store thermal power. These materials can deliver and distribute heat more steadily over time because they conserve and release electricity during phase transitions [20]. Even when there is no sunlight, PCMs in solar heater systems increase efficiency and provide better heat control. Metamaterials provide unheard-of management of absorption of light as well as radiation emission since they are designed to possess remarkable electromagnetic capabilities [21]. They can be made to interact with particular solar wavelengths, providing customized thermal behavior for better performance.

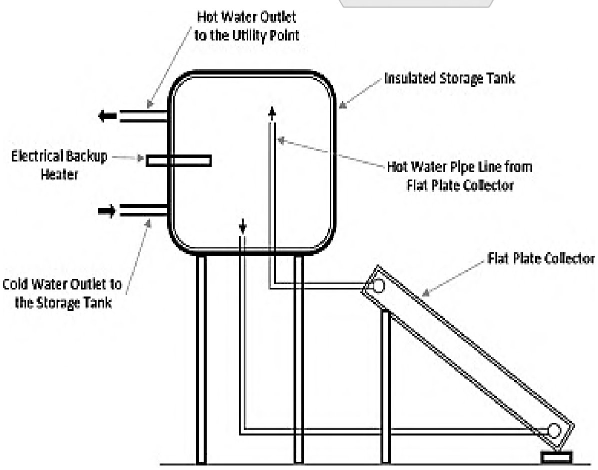

Figure 2.3.1: *Solar Power Heating System*

2.4: Advanced Manufacturing Techniques for solar heater

Modern manufacturing methods have become crucial tools for changing the development, manufacture, and use of solar warming systems. Utilizing cutting-edge manufacturing techniques and CAD software like SolidWorks has a number of advantages that improve productivity, cut costs, and maximize performance [22]. Computer-assisted simulations are essential during the design stage. Engineers can evaluate various designs, materials, and combinations and forecast how they will communicate with light and heat processes through realistic modeling and simulation [23]. This makes it possible to optimize iteratively while reducing trial-and-error in the manufacturing stage. Rapid prototyping also quickens the development process. Before agreeing to complete production, designers can visualize concepts and see possible faults with the help of 3D printing as well as quick manufacturing processes. This eliminates material waste and related expenses while also saving time [24]. Accurate duplication of complex designs is guaranteed by precision manufacturing procedures. Components with exact dimensions and complex shapes can be made using automated manufacturing techniques like laser cutting as well as CNC machining. Maintaining ideal absorption of heat, distribution, along with system efficiency all depend on this accuracy [25].

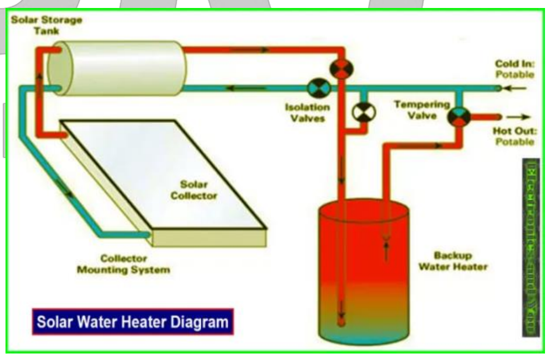

Figure 2.4.1: *Solar Water Heater*

2.5: Sustainability Considerations in Solar Heater Development

The creation of solar heaters incorporates sustainability factors to guarantee that their adoption is consistent with more general environmental objectives. The analysis of the environmental effects resulting from the mining of materials to end-of-life disposal using a life cycle assessments (LCA) technique is essential [26]. The whole ecological footprint is determined by taking into account elements like consumption of energy, carbon dioxide emissions, before depletion of resources during production, both of operation, as well as eventual

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decommissioning. The choice of materials is crucial to sustainability. It is essential to choose environmentally friendly supplies with less embodied energy and little negative environmental impact [27]. Additionally, effective manufacturing procedures, such as those governed by SolidWorks, can minimize the generation of waste and the use of energy. The sustainability of a solar heater is increased by using proper construction and upkeep techniques [28]. In order to make a significant contribution to environmentally friendly energy options, solar powered heaters must eventually show an energy balance that is favorable over the course of their lives. The industry may reduce its environmental impact and make sure that the production of clean energy coexists peacefully with the protection of the environment through incorporating ecological factors into the construction of solar heaters [29].

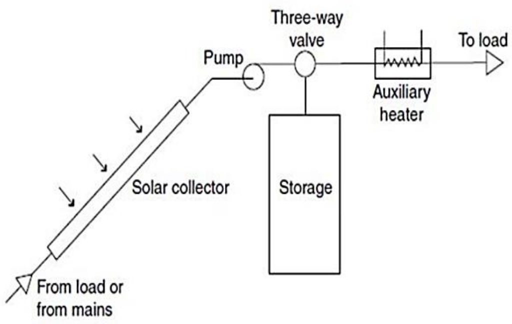

Figure 2.5.1: *Solar Energy System*

2.6 Literature gap

There is frequently a lack of thorough examination of the inclusion of both innovative materials and production procedures in the literature already available on solar heater technology. Few research bridge the gap to look at the combined influence on system performance, economic effectiveness, including environmental sustainability. Individual studies focus on either novel materials or methods of manufacture [30]. The difficulties in actual implementation that may result from incorporating these developments have also received little attention. This lacuna in the literature necessitates a thorough examination into the synergistic impacts of cutting-edge materials and production processes, giving a comprehensive view on improving both the feasibility and effectiveness of solar heaters [31].

2.7 Summary

Current solar warmer technologies, latest material advances, cutting-edge production techniques, as well as environmental issues are all thoroughly examined in the literature review chapter. Existing technologies have advantages but can have drawbacks. Improved thermal absorption and preservation is provided by material innovations including phase-change substances and nanoparticles. SolidWorks-like tools help advanced manufacturing by optimizing design and production. Energy-efficient methods and environmentally friendly materials are prioritized in sustainability concerns. The chapter establishes the groundwork for the investigation's contributions to improved solar heater effectiveness and environmental responsibility by bridging integration as well as operational execution gaps.

III. METHODOLOGY

3.1 Choice of methods

The investigation's chosen techniques are described in the Method chapter, which is informed by the Interpretivism Investigation Philosophy. This school of thought seeks to comprehend the deeper significance and experiences of inventions with solar heaters while acknowledging the subjective character of knowledge [32]. The research strategy follows a Descriptive strategy, and there with the goal of fully describing the state of solar thermal advancements at this time and their possible effects. The use of deductive methods will enable organized investigation. The research framework will be influenced by existing ideas and literature, which will direct data gathering and analysis [33]. The study relies on additional information like scholarly publications, reports, including case studies to get pertinent data because original data collecting is not included. SolidWorks software, which acts as the foundation for computation, visualization, as well as simulation, is the main resource for this project. The project will make use of its skills to model solar radiator designs, mimic material conduct, and determine the viability of fabrication [34]. The software's accuracy and adaptability fit the research's objectives perfectly.

3.2 Justification of chosen methods

To provide a robust and thorough investigation of solar heater advancements, the study methodology selections are carefully coordinated. The decision to use the theory of interpretivism was made in acknowledgment of the fact that human experiences and views play a role in the development of solar heater technology. A more thorough understanding into the underlying ideas and motives guiding technical progress is made possible by this philosophy [35]. A comprehensive depiction of the current status of solar warmer materials, production processes, and their limits is made possible by the descriptive design, which is therefore justified. This method enables a thorough examination of the elements influencing their effectiveness and maintenance. Deductive reasoning is used to make an intuitive link between accepted theories as well as empirical findings, strengthening the validity of research findings [36].

The study gains from the depth of scholarly perspectives by using secondary sources, ensuring a thorough and well-informed analysis. The ability of SolidWorks software to enable complex modeling, exercises, as well as visualizations, improving the preciseness of the evaluation and enabling realistic considerations during design, is the last justification for using it [37]. Together, these methodological decisions guarantee a methodical and insightful evaluation of solar heater advances.

3.3 Tools and Techniques

To enable a thorough investigation of solar heater advances, the research makes use of a combination of specialist tools and procedures. A key tool that provides innovative features for modeling in three dimensions, simulations, and visualizations is the SolidWorks software.

This makes it easier to describe solar heater designs accurately, evaluate their viability, and forecast how they will perform in various scenarios [38]. Additionally, machine learning simulations make it possible to test the behaviors of novel materials in a virtual setting, including information on thermal absorption, continuation, and dispersion. Utilizing secondary sources, which provide a broad base of information to support the research's background and findings, among them scholarly publications, reports, including case studies, complements this process [39].

These methods and technologies work together to offer a methodical way to research solar heater developments, assuring a thorough awareness of their possible effects on effectiveness, sustainability, and industrial viability.

3.4 Ethical consideration

In this study, ethics is of utmost importance. Academic integrity is maintained by making sure that sources are correctly cited and acknowledged. It is crucial to protect sensitive data and proprietary rights related to cutting-edge manufacturing methods and designs.

Additionally, following ethical standards when using software like Autodesk promotes ethical and lawful behavior [40]. Concerns about consent and privacy are unimportant in this study using secondary sources.

IV. RESULTS AND DISCUSSION

The absorbers in solar-powered water heaters were made of copper or aluminum. Selective coating and absorber foils are two examples of novel materials with improved heat-absorbing properties that have been developed recently.

These materials are made to absorb solar radiation as much as possible while losing as little heat as possible, increasing the overall efficiency of the solar heater system. Solar water heater efficiency has been improved because of nanotechnology.

The energy efficiency is improved by light-trapping effectiveness, and heat absorption, absorbers and glazing surfaces are being coated with nanomaterials and Nano coatings [1]. Additionally, these nanoparticles have the potential to create surfaces that clean themselves, requiring less maintains.

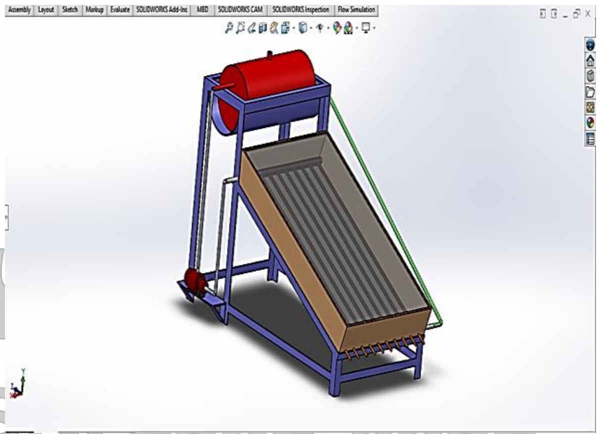

Figure 4.1: *Final view of the model*

The above image shows the final view of the model all components of the solar heater materials are present in this image. This model uses solar energy to convert the light into heat, this is used to increase the temperature of the water. The absorber plate is an essential part of the collection system for a solar water heater.

The absorber plate's significance lies in its capacity to effectively absorb solar energy and enable the passage of that energy to the heat transfer fluid.

The absorber plate's main purpose is to absorb solar energy. This is constructed of a substance with high thermal conductivity and is intended to effectively absorb a variety of sun wavelengths. The plate becomes warm as a result of this absorption [2].

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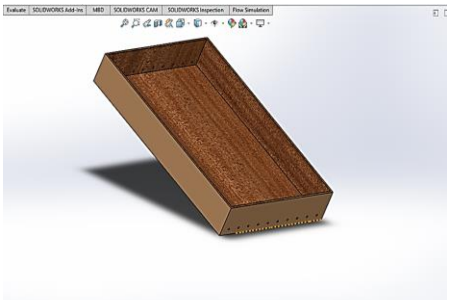

Figure 4.2: *Mounting of solar collectors*

The structure that holds the solar collector firmly in place and places it in the best possible position to capture sunlight is referred to as the mounting of a solar collector. The collector must be mounted properly for it to perform well, receive the most sunlight, and stay stable over time. The mounting of the collector is significant since it helps with efficient energy capture and system longevity. The solar collectors are mounted using a technique that maximizes the sunshine it receives throughout the day and seasons. The collector's capacity to absorb solar radiation and transform it into thermal energy is improved by this ideal location.

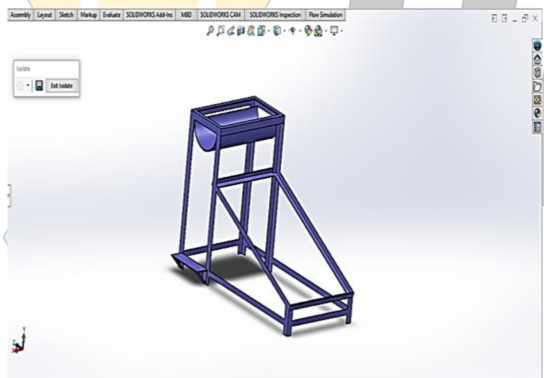

Figure 4.3: *Mounting system*

The design of structure that firmly holds solar panels or collectors in place is shown in the image. This enabling their installation on roofs, flat surfaces, or other suitable sites. The mounting system makes sure that the solar panels or collectors are oriented and angled in the best possible way to maximize sunlight absorption. The mounting system's significance comes from its part in guaranteeing effective energy harvesting, system lifetime, and stability.

A mounting system's main function is to place solar panels or collectors at the ideal angle for receiving direct sunlight. This ideal location increases the solar system's energy output and maximizes solar radiation absorption [3].

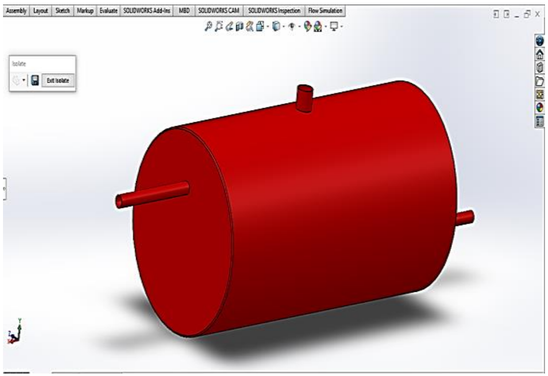

Figure 4.4: *Storage tank*

The warm water produced by the solar collector system is kept in storage tanks. This is essential for ensuring that the heated water is accessible when needed and supplies a steady stream of hot water for different home, commercial, or industrial uses. This is used to fulfill the demand for hot water even when solar energy is not available, this is utilized to store and regulate the thermal energy produced by the solar collector. A storage tank's main function is to hold warm water for later use. This makes sure that there is always hot water accessible, even when the sun isn't shining or when there is more demand for hot water than there is immediate solar output.

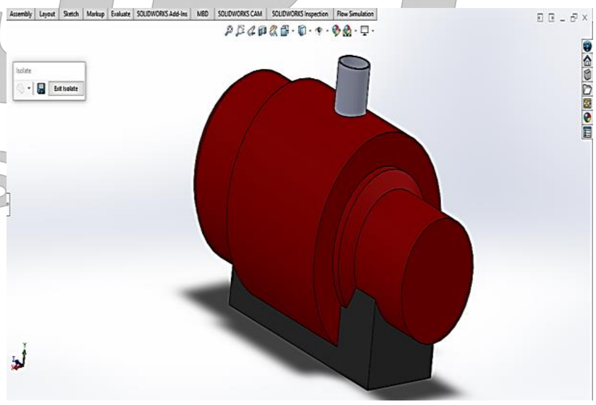

Figure 4.5: *Circulation pump*

This is an integral part of a solar water heater system is a circulation pump, commonly referred to as a circulating pump or circulation pump. This is in charge of transporting the heat transfer fluid, which absorbs heat from the solar collector and transfers it to the storage tank or other heat exchangers, from the collector to the latter. This continuous circulation maximizes heat transfer from the absorber plate of the collector to the fluid, increasing energy absorption and conversion. The circulation pump helps prevent the establishment of distinct temperature layers in the storage tank in systems where hot water stratification is an issue. The circulation pump keeps the fluid from pooling in the collector where it can heat up and cause system damage [4]. This well-working circulation pump ensures the efficient transfer of solar collector heat to the heat transfer fluid. This improves the solar water heating system's overall effectiveness, leading to improved energy utilization.

SolidWorks also incorporates powerful simulation tools that let engineers mimic real-world scenarios, enabling thorough analysis of the behavior of solar heaters. For instance, heat transfer models aid in comprehending how different materials absorb, hold, and distribute heat [41]. This information is essential for choosing the best materials that improve system performance as a whole. The interoperability of this modeling program with CFD (computational fluid dynamics) calculations considerably deepens the comprehension of the thermal thermodynamics of solar heaters [42]. Engineers can learn more about complex phenomena like convection as well as radiation through simulating fluid movement and heat transfer inside the system. This knowledge immediately influences design decisions, resulting in higher efficiency, enhanced heat distribution of wealth, and lower losses. The function that SolidWorks plays in assisting the development of new manufacturing procedures is another crucial aspect of the software [43]. The program facilitates the development of complex machining routes, allowing for the exact manufacture of components with intricate geometry. This level of accuracy is essential for getting the best performance possible from solar heaters since effective heat absorption as well as distribution depend on carefully built parts. System efficiency forecasting under various environmental conditions, assisting in design optimization as well as performance forecasting [44]. The discussion also emphasizes how SolidWorks' capabilities and sophisticated material exploration work together. The efficiency of solar heaters is strongly impacted by new materials, as was described in the literature research. With the help of SolidWorks, it is possible to test these materials virtually in order to better comprehend their thermodynamics and solar power system reliability. This anticipatory knowledge streamlines the subject selection procedure, hastening the transition from theoretical study to real-world application [45]. Furthermore, SolidWorks supports the exploration of innovative manufacturing techniques. By generating precise machining paths and production simulations, the software guides the fabrication of intricate components. This is particularly relevant in solar heater systems where specialized geometries are essential for efficient energy absorption and distribution [46]. Collaboration and iteration are also facilitated by SolidWorks. Engineers can collaborate in real-time, share models and simulations, and iterate designs quickly, reducing communication barriers and streamlining decision-making processes. However, it is important to recognize that while SolidWorks offers a powerful platform for understanding and implementing solar heater innovations, it is not a replacement for physical testing and validation [47]. Simulated changes, material characteristics, and complicated processes might not always correctly reflect the real world. In order to ensure that theoretical discoveries convert into real-world triumphs, the software is something that works in conjunction with empirical evaluation [48].

V. FUTURE WORK

There are various potential directions for future studies and developments in the effort to advance solar heating technologies. First of all, although this research depends on secondary sources, gathering primary data could offer a more thorough insight of the real-world difficulties encountered when integrating modern materials and production methods [49]. Industry professionals, engineers, and consumers could be surveyed or interviewed to gain insightful information on implementation challenges and possible remedies. Another intriguing path is to investigate the long-term dependability and environmental effects of the recently suggested solar heater technologies [50]. To fully understand the environmental impact of these technologies, life- cycle analyses (LCAs) should be conducted, taking into account things like energy usage, emissions, as well as disposal of waste. Further research into particular manufacturing processes outside the purview of SolidWorks may also provide new insights [51]. Investigating cutting-edge techniques for generating solar heater components, such as additive manufacturing (3D printing), may lead to the discovery of creative ways to optimize designs and reduce costs. The research's ability to forecast the system's efficiency under various weather situations could be improved by using dynamic simulators [52]. Simulations using CFD (computational fluid dynamics) may be able to shed light on the dynamics of heat transfer and suggest ways to boost efficiency. Additionally, working with industry stakeholders including practitioners could result in the creation of prototype based on the study's findings [53]. In order to provide empirical proof of the efficacy of the suggested changes, real-world testing and verification could close the gap between simulated and application in real life. An emerging option is investigating the combined use of smart as well as internet-based (Internet of Things) technology to remotely regulate and monitor solar heating installations [54]. Examining the potential for monitoring from afar and data-driven optimization could improve system performance and user experience. Understanding and promoting technological progress in solar heaters depends critically on the incorporation of SolidWorks software. Designing, analyzing, and optimizing solar heating systems is made simple and successful by its 3D modeling, simulations capability, and interoperability with modern manufacturing techniques. SolidWorks leads to a greater understanding of renewable energy heater innovation through the selection of superior materials and the prediction of system performance under diverse scenarios [55]. Although there are obstacles, there is no denying that it has the potential to speed up the development of effective, long-lasting, and affordable solar heaters.

VI. CONCLUSION

Ultimately, this investigation into the latest developments in solar heater production and material science has found a wealth of knowledge that has great promise for expanding the field of environmentally friendly energy. Review of the literature revealed the benefits and drawbacks of current solar heater technologies, highlighting the need for creative solutions to improve effectiveness, accessibility, and sustainable development. A systematic investigation of developments in solar heater technology was made possible by the integration with an Interpretivism Investigation Philosophy, a Descriptive Studies Design, and a Deductive Approach. A thorough investigation was conducted to shed light on the possible influence of new materials and production techniques using secondary sources as well as SolidWorks software. The significance of new material breakthroughs, such as nanomaterials, selective protective coatings, as well as phase-change resources, for improving heat absorption, pupil retention, and energy preservation capabilities was demonstrated by study..Furthermore, the significance of innovative manufacturing methods supported by SolidWorks as a vital tool for improving designs, cutting production costs, and streamlining manufacturing procedures was emphasized. In this scenario, environmental sustainability has become a crucial issue. The study stressed the need of selecting eco-friendly materials and employing energy-saving manufacturing techniques in order to support more general environmental objectives. It was decided that in order to maintain the ecological responsibility of solar heater improvements, a comprehensive analysis taking into account life cycle implications was necessary. In short, this research highlights the potential to close the gap between present technologies and more effective, economical, and sustainable alternatives, adding to the expanding body of information about solar heater advancements. The solar heater business can play a critical part in the global switch to alternative forms of energy by embracing modern components, manufacturing processes, and environmentally friendly considerations, assuring a greener and further environmentally friendly planet for the next generation.

REFERENCES

[1] Zayed, M.E., Zhao, J., Elsheikh, A.H., Hammad, F.A., Ma, L., Du, Y., Kabeel, A.E. and Shalaby, S.M., 2019. Applications of cascaded phase change materials in solar water collector storage tanks: A review. Solar Energy Materials and Solar Cells, 199, pp.24-49.

[2] Douvi, E., Pagkalos, C., Dogkas, G., Koukou, M.K., Stathopoulos, V.N., Caouris, Y. and Vrachopoulos, M.G., 2021. Phase change materials in solar domestic hot water systems: A review. International Journal of Thermofluids, 10, p.100075.

[3] Manoj Kumar, P., Mylsamy, K., Alagar, K. and Sudhakar, K., 2020. Investigations on an evacuated tube solar water heater using hybrid-nano based organic phase change material. International Journal of Green Energy, 17(13), pp.872-883.

[4] Lamrani, B., Kuznik, F. and Draoui, A., 2020. Thermal performance of a coupled solar parabolic trough collector latent heat storage unit for solar water heating in large buildings. Renewable Energy, 162, pp.411-426.

[5] Tagle-Salazar, P.D., Nigam, K.D. and Rivera-Solorio, C.I., 2020. Parabolic trough solar collectors: A general overview of technology, industrial applications, energy market, modeling, and standards. Green Processing and Synthesis, 9(1), pp.595-649.

[6] Ahmad, L., Khordehgah, N., Malinauskaite, J. and Jouhara, H., 2020. Recent advances and applications of solar photovoltaics and thermal technologies. Energy, 207, p.118254.

[7] Alnaimat, F., Ziauddin, M. and Mathew, B., 2021. A review of recent advances in humidification and dehumidification desalination technologies using solar energy. Desalination, 499, p.114860.

[8] Ebhota, W.S. and Jen, T.C., 2020. Fossil fuels environmental challenges and the role of solar photovoltaic technology advances in fast tracking hybrid renewable energy system. International Journal of Precision Engineering and Manufacturing-Green Technology, 7, pp.97-117.

[9] Huang, J., Luo, Y., Weng, M., Yu, J., Sun, L., Zeng, H., Liu, Y., Zeng, W., Min, Y. and Guo, Z., 2021. Advances and applications of phase change materials (PCMs) and PCMs-based technologies. ES Materials & Manufacturing, 13, pp.23-39.

[10] 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.

[11] Zou, C., Xue, H., Xiong, B., Zhang, G., Pan, S., Jia, C., Wang, Y., Ma, F., Sun, Q., Guan, C. and Lin, M., 2021. Connotation, innovation and vision of "carbon neutrality". Natural Gas Industry B, 8(5), pp.523-537.

[12] 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.

[13] Hayat, M.B., Ali, D., Monyake, K.C., Alagha, L. and Ahmed, N., 2019. Solar energy—A look into power generation, challenges, and a solar-powered future. International Journal of Energy Research, 43(3), pp.1049-1067.

[14] Menon, A., Stojceska, V. and Tassou, S.A., 2020. A systematic review on the recent advances of the energy efficiency improvements in non-conventional food drying technologies. Trends in Food Science & Technology, 100, pp.67-76.

[15] Evangelisti, L., Vollaro, R.D.L. and Asdrubali, F., 2019. Latest advances on solar thermal collectors: A comprehensive review. Renewable and Sustainable Energy Reviews, 114, p.109318.

[16] Cao, S., Jiang, Q., Wu, X., Ghim, D., Derami, H.G., Chou, P.I., Jun, Y.S. and Singamaneni, S., 2019. Advances in solar evaporator materials for freshwater generation. Journal of Materials Chemistry A, 7(42), pp.24092-24123.

[17] Chauhan, V.K., Shukla, S.K., Tirkey, J.V. and Rathore, P.K.S., 2021. A comprehensive review of direct solar desalination techniques and its advancements. Journal of Cleaner Production, 284, p.124719.

[18] Jarimi, H., Aydin, D., Yanan, Z., Ozankaya, G., Chen, X. and Riffat, S., 2019. Review on the recent progress of thermochemical materials and processes for solar thermal energy storage and industrial waste heat recovery. International Journal of Low-Carbon Technologies, 14(1), pp.44-69.

[19] Ma, Z., Ren, H. and Lin, W., 2019. A review of heating, ventilation and air conditioning technologies and innovations used in solar-powered net zero energy Solar Decathlon houses. Journal of Cleaner Production, 240, p.118158.

[20] Allouhi, A., 2019. Advances on solar thermal cogeneration processes based on thermoelectric devices: A review. Solar Energy Materials and Solar Cells, 200, p.109954.

[21] Shubbak, M.H., 2019. Advances in solar photovoltaics: Technology review and patent trends. Renewable and Sustainable Energy Reviews, 115, p.109383.

[22] Bretado-de los Rios, M.S., Rivera-Solorio, C.I. and Nigam, K.D.P., 2021. An overview of sustainability of heat exchangers and solar thermal applications with nanofluids: A review. Renewable and Sustainable Energy Reviews, 142, p.110855.

[23] Hoskins, A.L., Millican, S.L., Czernik, C.E., Alshankiti, I., Netter, J.C., Wendelin, T.J., Musgrave, C.B. and Weimer, A.W., 2019. Continuous on-sun solar thermochemical hydrogen production via an isothermal redox cycle. Applied Energy, 249, pp.368-376.

[24] Schoeneberger, C.A., McMillan, C.A., Kurup, P., Akar, S., Margolis, R. and Masanet, E., 2020. Solar for industrial process heat: A review of technologies, analysis approaches, and potential applications in the United States. Energy, 206, p.118083.

[25] Choudhary, P. and Srivastava, R.K., 2019. Sustainability perspectives-a review for solar photovoltaic trends and growth opportunities. Journal of Cleaner Production, 227, pp.589-612.

[26] Victoria, M., Haegel, N., Peters, I.M., Sinton, R., Jäger-Waldau, A., del Canizo, C., Breyer, C., Stocks, M., Blakers, A., Kaizuka, I. and Komoto, K., 2021. Solar photovoltaics is ready to power a sustainable future. Joule, 5(5), pp.1041-1056.

[27] Gorjian, S., Calise, F., Kant, K., Ahamed, M.S., Copertaro, B., Najafi, G., Zhang, X., Aghaei, M. and Shamshiri, R.R., 2021. A review on opportunities for implementation of solar energy

technologies in agricultural greenhouses. Journal of Cleaner Production, 285, p.124807.

[28] 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.

[29] Hossain, M.A., 2023. Simultaneous Thermoregulated and Sensorial effect of Smart Textiles with Artificial Composite Phase Change Materials (CPCM) incorporated with Carbon Nano Conductive Materials for special workers and extreme weather conditions. School of Fashions and Textiles, RMIT University, Victoria 3056, Australia (engr. anowar@ yahoo. com).

[30] Song, H., Luo, S., Huang, H., Deng, B. and Ye, J., 2022. Solar-driven hydrogen production: Recent advances, challenges, and future perspectives. ACS Energy Letters, 7(3), pp.1043-1065.

[31] Yaro, N.S.A., Sutanto, M.H., Baloo, L., Habib, N.Z., Usman, A., Yousafzai, A.K., Ahmad, A., Birniwa, A.H., Jagaba, A.H. and Noor, A., 2023. A comprehensive overview of the utilization of recycled waste materials and technologies in asphalt pavements: towards environmental and sustainable low-carbon roads. Processes, 11(7), p.2095.

[32] Li, Z., Lu, Y., Huang, R., Chang, J., Yu, X., Jiang, R., Yu, X. and Roskilly, A.P., 2021. Applications and technological challenges for heat recovery, storage and utilisation with latent thermal energy storage. Applied Energy, 283, p.116277.

[33] Obaideen, K., AlMallahi, M.N., Alami, A.H., Ramadan, M., Abdelkareem, M.A., Shehata, N. and Olabi, A.G., 2021. On the contribution of solar energy to sustainable developments goals: Case study on Mohammed bin Rashid Al Maktoum Solar Park. International Journal of Thermofluids, 12, p.100123.

[34] Cai, Q., You, H., Guo, H., Wang, J., Liu, B., Xie, Z., Chen, D., Lu, H., Zheng, Y. and Zhang, R., 2021. Progress on AlGaN-based solar-blind ultraviolet photodetectors and focal plane arrays. Light: Science & Applications, 10(1), p.94.

[35] Junaid, M.F., ur Rehman, Z., Čekon, M., Čurpek, J., Farooq, R., Cui, H. and Khan, I., 2021. Inorganic phase change materials in thermal energy storage: A review on perspectives and technological advances in building applications. Energy and Buildings, 252, p.111443.

[36] Dao, V.D., Vu, N.H. and Yun, S., 2020. Recent advances and challenges for solar-driven water evaporation system toward applications. Nano Energy, 68, p.104324.

[37] Chadha, U., Selvaraj, S.K., Raj, A., Mahanth, T., Vignesh, S.P., Lakshmi, P.J., Samhitha, K., Reddy, N.B. and Adefris, A., 2022. AI-driven techniques for controlling the metal melting production: a review, processes, enabling technologies, solutions, and research challenges. Materials Research Express, 9(7), p.072001.

[38] Kumar, K.R., Chaitanya, N.K. and Kumar, N.S., 2021. Solar thermal energy technologies and its applications for process heating and power generation–A review. Journal of Cleaner Production, 282, p.125296.

[39] Liu, G., Chen, T., Xu, J., Li, G. and Wang, K., 2020. Solar evaporation for simultaneous steam and power generation. Journal of Materials Chemistry A, 8(2), pp.513-531.

[40] Mohana, Y., Mohanapriya, R., Anukiruthika, T., Yoha, K.S., Moses, J.A. and Anandharamakrishnan, C., 2020. Solar dryers for food applications: Concepts, designs, and recent advances. Solar Energy, 208, pp.321-344.

[41] Uekert, T., Pichler, C.M., Schubert, T. and Reisner, E., 2021. Solar-driven reforming of solid waste for a sustainable future. Nature Sustainability, 4(5), pp.383-391.

[42] Achkari, O. and El Fadar, A., 2020. Latest developments on TES and CSP technologies–Energy and environmental issues, applications and research trends. Applied Thermal Engineering, 167, p.114806.

[43] Zhu, L., Ding, T., Gao, M., Peh, C.K.N. and Ho, G.W., 2019. Shape conformal and thermal insulative organic solar absorber sponge for photothermal water evaporation and thermoelectric power generation. Advanced Energy Materials, 9(22), p.1900250.

[44] Verma, S.K., Sharma, K., Gupta, N.K., Soni, P. and Upadhyay, N., 2020. Performance comparison of innovative spiral shaped solar collector design with conventional flat plate solar collector. Energy, 194, p.116853.

[45] Lippiatt, N., Ling, T.C. and Pan, S.Y., 2020. Towards carbon-neutral construction materials: Carbonation of cement-based materials and the future perspective. Journal of Building Engineering, 28, p.101062.

[46] Michas, S., Stavrakas, V., Spyridaki, N.A. and Flamos, A., 2019. Identifying Research Priorities for the further development and deployment of Solar Photovoltaics. International Journal of Sustainable Energy, 38(3), pp.276-296.
[47] Rehfeldt, M., Worrell, E., Eichhammer, W. and Fleiter, T., 2020. A review of the emission reduction potential of fuel switch towards biomass and electricity in European basic materials industry until 2030. Renewable and Sustainable Energy Reviews, 120, p.109672.
[48] Aramesh, M., Ghalebani, M., Kasaeian, A., Zamani, H., Lorenzini, G., Mahian, O. and Wongwises, S., 2019. A review of recent advances in solar cooking technology. Renewable Energy, 140, pp.419-435.
[49] Shahabuddin, M., Alim, M.A., Alam, T., Mofijur, M., Ahmed, S.F. and Perkins, G., 2021. A critical review on the development and challenges of concentrated solar power technologies. Sustainable Energy Technologies and Assessments, 47, p.101434.
[50] Sharshir, S.W., Algazzar, A.M., Elmaadawy, K.A., Kandeal, A.W., Elkadeem, M.R., Arunkumar, T., Zang, J. and Yang, N., 2020. New hydrogel materials for improving solar water evaporation, desalination and wastewater treatment: A review. Desalination, 491, p.114564.
[51] Palacios, A., Barreneche, C., Navarro, M.E. and Ding, Y., 2020. Thermal energy storage technologies for concentrated solar power–A review from a materials perspective. Renewable Energy, 156, pp.1244-1265.
[52] Xie, Z., Duo, Y., Lin, Z., Fan, T., Xing, C., Yu, L., Wang, R., Qiu, M., Zhang, Y., Zhao, Y. and Yan, X., 2020. The rise of 2D photothermal materials beyond graphene for clean water production. Advanced Science, 7(5), p.1902236.
[53] Gorjian, S., Singh, R., Shukla, A. and Mazhar, A.R., 2020. On-farm applications of solar PV systems. In Photovoltaic solar energy conversion (pp. 147-190). Academic Press.
[54] Lingayat, A., Balijepalli, R. and Chandramohan, V.P., 2021. Applications of solar energy based drying technologies in various industries–A review. Solar Energy, 229, pp.52-68.
[55] Kumar, A., Tiwari, A.K. and Said, Z., 2021. A comprehensive review analysis on advances of evacuated tube solar collector using nanofluids and PCM. Sustainable Energy Technologies and Assessments, 47, p.101417.
[56] Patel, A. (2023f). Thermal Performance of Combine Solar Air Water Heater with Parabolic Absorber Plate. International Journal of All Research Education and Scientific Methods (IJARESM), 11(7), 2385–2391. http://www.ijaresm.com/uploaded_files/document_file/Anand_Patel3pFZ.pdf
[57] Patel, Anand. "Effect of W Rib Absorber Plate on Thermal Performance Solar Air Heater." International Journal of Research in Engineering and Science (IJRES), vol. 11, no. 7, July 2023, pp. 407–412. Available: https://www.ijres.org/papers/Volume-11/Issue-7/1107407412.pdf
[58] Patel, Anand. "Performance Evaluation of Square Emboss Absorber Solar Water Heaters." International Journal For Multidisciplinary Research (IJFMR), Volume 5, Issue 4, July-August 2023. https://doi.org/10.36948/ijfmr.2023.v05i04.4917
[59] Anand Patel. (2023). Thermal Performance Analysis of Wire Mesh Solar Air Heater. Eduzone: International Peer Reviewed/Refereed Multidisciplinary Journal, 12(2), 91–96. Retrieved from https://www.eduzonejournal.com/index.php/eiprmj/article/view/389
[60] Patel, A (2023). "Thermal performance analysis conical solar water heater". World Journal of Advanced Engineering Technology and Sciences (WJAETS), 9(2), 276–283. https://doi.org/10.30574/wjaets.2023.9.2.02286
[61] Patel, A (2023). ""Comparative analysis of solar heaters and heat exchangers in residential water
[62] heating"". International Journal of Science and Research Archive (IJSRA),09(02), 830–843. https://doi.org/10.30574/ijsra.2023.9.2.0689."
[63] Patel, A. (2023k). Enhancing Heat Transfer Efficiency in Solar Thermal Systems Using Advanced Heat Exchangers. Multidisciplinary International Journal of Research and Development (MIJRD), 02(06), 31–51. https://www.mijrd.com/papers/v2/i6/MIJRDV2I60003.pdf.
[64] Patel, Anand "Optimizing the Efficiency of Solar Heater and Heat Exchanger Integration in Hybrid System", TIJER - International Research Journal (www.tijer.org), ISSN:2349-9249, Vol.10, Issue 8, page no.b270-b281, August-2023, Available :http://www.tijer.org/papers/TIJER2308157.pdf

[65] 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.

[66] 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.

[67] Anand Patel, "Comparative Thermal Performance Analysis of Circular and Triangular Embossed Trapezium Solar Cooker with and without Heat Storage Medium", International Journal of Science and Research (IJSR), Volume 12 Issue 7, July 2023, pp. 376-380, https://www.ijsr.net/getabstract.php?paperid=SR23612004356

[68] Patel, Anand.""Comparative Thermal Performance Analysis of Box Type and Hexagonal Solar Cooker"", International Journal of Science & Engineering Development Research (www.ijsdr.org), ISSN:2455-2631, Vol.8, Issue 7, page no.610 - 615, July-2023, Available :http://www.ijsdr.org/papers/IJSDR2307089.pdf".

[69] Anand Patel. TheEffect of Moisture Recovery System on Performance of Cooling Tower. International Journal for Modern Trends in Science and Technology 2023, 9(07), pp. 78-83. https://doi.org/10.46501/IJMTST0907013.

[70] Thakre, Shekhar, Pandhare, Amar, Malwe, Prateek D., Gupta, Naveen, Kothare, Chandrakant, Magade, Pramod B., Patel, Anand, Meena, Radhey Shyam, Veza, Ibham, Natrayan L., and Panchal, Hitesh. "Heat transfer and pressure drop analysis of a microchannel heat sink using nanofluids for energy applications" Kerntechnik, 2023. https://doi.org/10.1515/kern-2023-0034

[71] Patel, Anand. “Advancements in Heat Exchanger Design for Waste Heat Recovery in Industrial Processes.” World Journal of Advanced Research and Reviews (WJARR), vol. 19, no. 03, Sept. 2023, pp. 137–52, doi:10.30574/wjarr.2023.19.3.1763.

[72] 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.

[73] Patel, Anand. “EFFECT OF PITCH ON THERMAL PERFORMANCE SERPENTINE HEAT EXCHANGER.” INTERNATIONAL JOURNAL OF RESEARCH IN AERONAUTICAL AND MECHANICAL ENGINEERING (IJRAME), vol. 11, no. 8, Aug. 2023, pp. 01–11. https://doi.org/10.5281/zenodo.8225457.