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Investigation of Heat Exchanger Performance in Heat Pipe Solar Air Heater

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Abstarct: In this work, a heat pipe solar air heater has been developed with the intention of enhancing the performance of solar air heaters. Heat pipes have become more common in the design of solar collectors as a means of achieving more effective heat transmission. In recent years, heat pipes have undergone several iterations of improvement, and a micro heat pipe array with enhanced heat transmission properties has been produced. Even after sunset, the air temperature is maintained at a consistent level in the heat storage-based absorber for a brief period of time. Therefore, the incorporation of thermal storage into the solar collector not only stores heat for use during hours when the sun isn't shining, but it also increases the absorber's ability to retain energy and maintains a constant temperature. According to the findings, the solar air heater has an average thermal efficiency of up to 80% when it is functioning normally, and the time constant is around 12 minutes. According to the findings of the experiments, the heat pipe solar air heater has a higher thermal efficiency. The thermal and exergy efficiency of modified solar air heater setups are compared with those of a typical collector that consists of a simple absorber and does not include any energy storage.

Keywords: solar, air, heater, energy, storage, temperature, heat, pipe, thermal, efficiency

1. INTRODUCTION

Glass was traditionally the first material that was used for the cover of greenhouses. In the late eighteenth century, the Dutch experimented with using oiled paper as a cover material instead of glass. The use of oiled paper as a cover material continued to be widespread far into the twentieth century. After the end of the Second World War, there was an increase in the accessibility of plastic materials. The potential of transparent plastic materials, ever since they were first manufactured on a large scale for commercial use, to take the place of glass in agricultural facilities has been recognised from the beginning. These days, PVC and polyethylene films are bonded internally to the structure of the greenhouse, which results in the creation of an insulating air gap between the greenhouses outside cover and the artificial environment that it protects. Polyethylene is widely used in agricultural applications because it is both inexpensive and readily available in wider sections than the majority of other films.
Despite the fact that it has a relatively short lifespan of about one year when subjected to the typical weather conditions, polyethylene remains very popular among farmers. In addition, since polyethylene is the most prevalent kind of plastic film utilised, there is an abundance of information easily accessible about the light transmission through this material. Air that has

been heated by either solar or supplemental energy is used in the heating system for industrial processes. It is 37 degrees Celsius when it gets into the duct that supplies the air to the operation. The heat from the sun comes from a storage tank, and it is transmitted to the air using a water-to-air heat exchanger that has an efficiency of 0.95.

Auxiliary energy raises the temperature of the air to sixty degrees Celsius. The collection area is 70 m2, and the FRUL value is 6.15 W/m2 °C. The FR() value is 0.82. The completely mixed storage tank has a volume of 4.5 m3, has a UA value of 195 W/°C, and is housed in a chamber where the temperature is maintained at 18 °C. The collector side of the heat exchanger has a capacitance of 1150 W/°C, but the storage side only has 910 W/°C of capacitance. The burden must be carried for eight hours every day, from eight in the morning until four in the afternoon, and the air must flow at a steady rate of 0.25 kilogrammes per second. Both the flow rate of water via the load heat exchanger and the heat capacity of air are 1012 J/kg °C, and the flow rate of water is 0.07 kg/s. The table that follows contains the applicable radiation levels and ambient temperatures for the time period that was under inquiry. Calculate the quantity of energy that was given to the load as well as the amount of auxiliary energy that was needed by the system in order to cover the load if the starting temperature of the storage tank on the day of the investigation was 42 degrees Celsius. The receiver was the cause of even more complications. The panels buckled, which most likely occurred as a result of temperature gradients brought about by an uneven distribution of the incoming radiation. In addition, there were leaks that occurred in the tubes, which need repairs. Warpage did not have an effect on the functionality of the receiver on its own, with the exception of exposing the support structure to radiation that could enter through openings that developed between the panels; however, it most likely contributed to leaks and would shorten the receiver's useful life. The black paint on the receiver had an initial high absorptance of 0.96 to 0.97, but over the course of three years, this value dropped by around 0.02 percentage points annually.

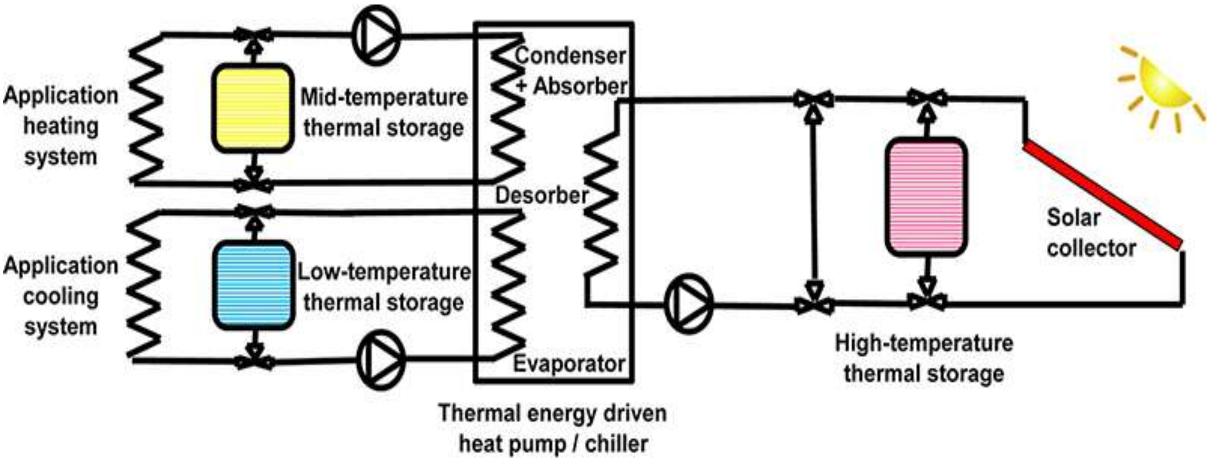

Figure 1 Solar Air Heater

During the period that the plant was actively producing electricity, the availability of the facility was, on average, 82% of the time that beam radiation was available to run it. Because of this, the turbogenerator was either connected to the grid or the store was being charged for 0.82 percent of the period during which beam radiation was accessible. (The remainder of the period, known as the downtime, was caused by maintenance that was either preplanner or impromptu, such as the stowing of the heliostats due of high wind speeds, etc.) The climate of Barstow resulted in an annual average availability that averaged 55%, calculated based on the total daylight hours. The plant's greatest power production was a net 11.7 MWe, exceeding the design objective of 10 MWe by a significant margin. This figure was calculated by subtracting the auxiliary energy required for plant operation. During the three years that power production was carried out, the yearly system efficiencies, which may be defined as the ratio of the net electrical energy generated (based on the 24-h plant energy needs) to the annual incident beam radiation, were 4.1, 5.8, and 5.7% respectively. The highest level of monthly efficiency was 8.7%. (The greatest instantaneous efficiencies would be far greater, most likely coming very near to the design limit of 15%.) The capacity factors, which represent the ratio of the actual net electrical output to the rated net output over a period of 24 hours, ranged from an all-time low of 8% to an all-time high of 11% over the course of the three years that the power plant was in operation, with a maximum monthly factor of 24% being reached during the warmest month of the year. Solar One was a large-scale experiment that offered operational data and experience on a variety of component and system difficulties while at the same time delivering peaking power to a utility. The data and experience were gleaned through Solar One's operation. One of the most significant takeaways from the operation of Solar One was the realisation that the storage system was insufficient to enable the turbine to function at its maximum efficiency. Solar One discontinued business operations and was subsequently refurbished and relaunched as Solar. The most significant change was the installation of a two-tank molten salt storage system in lieu of the oil-rock thermocline storage unit that had previously been in use.

A new receiver, a new steam generator, a new control system, and the installation of 108 heliostats, each with an area of were among the other upgrades (the original heliostats were). The effectiveness of the newly designed storage system was shown by its ability to function nonstop for 154 hours straight during a single test. This section offers an overview of the solar cooling and heating systems that have been documented in the literature and that feature latent heat storage. These systems may be found in both residential and commercial settings. Conducted a review of various uses of thermal storage in solar cooling systems. Unfortunately, every single one of the applications that have been documented uses water as a sensible heat storage medium, both warm and cold.

In addition, provide various instances of functioning or demonstration units of absorption chiller solar cooling systems; however, the storage medium used in all of these examples is water. The experimental results were collected using four pilot systems with nominal cooling capacities ranging from 7 to 90 kW and outfitted with salt hydrate latent heat storages with energy contents ranging from 80 to 240 kWh. The authors make use of the latent heat storage in order to support the heat dissipation system of the chiller and the applied calcium chloride hexahydrate, which has a phase change temperature of approximately 29 degrees Celsius and a melting enthalpy of approximately 150 kJ/kg or 240 kJ/dm3 between 22 degrees Celsius and 36 degrees Celsius. These values can be found in the authors' research. Both sensible and latent heat are included within this capacity for storage.

2. LITERATURE REVIEW

Wang (2019): In this portion of the examination, an experimental study is conducted to investigate the thermal performance of an integrated collector–storage solar air heater

(ICSSAH) based on a lap joint-type flat micro-heat pipe array during simultaneous charging and discharging mode. Within a built-out structure of ICSSAH, the phase change substance paraffin and the heat transfer fluid air both play their roles as air and air, respectively. An outdoor experiment is used to investigate the effects of seasonality, volume flow rate, and daily accumulative solar radiation, and the results of this experiment are used to evaluate the thermal performance of the ICSSAH. An in-depth examination of thermal energy is performed, and the results are explained and estimated in accordance with the experimental observations. According to the findings, the daily mean thermal efficiency throughout the summer is noticeably greater than it is during the transition season. The thermal efficiency will be reduced in direct proportion to the decrease in the volume flow rate. During the course of the tests, however, the influence of solar radiation on thermal efficiency was shown to be negligible. When the solar irradiance varies from 0 W/m2 to 874 W/m2 and the ambient temperature varies from 27.8 °C to 35.4 °C, the present study found that the volume flow rate of 141 m3/h resulted in the highest daily thermal efficiency of approximately 78.1%. This was the case in the scenario where the study was conducted.

Jayaraman Muthukumaran (2022): Because of the minimal amount of heat that is transferred from the air to the absorber, a basic energy conversion device known as a flat plate solar air collector has relatively poor performance. The localised air turbulence and the absorber-side contact area are both increased via the use of passive heat transfer augmentation techniques. This research paper presents a copper tube that serves a dual role as both an extended absorber surface and as a heat storage device. The absorber designs consist of spiral coiled and straight tubes with consistent spacing. These tubes are filled with glycerol and paraffin of commercial quality. The thermal and exergy efficiency of modified solar air heater setups are compared with those of a typical collector that consists of a simple absorber and does not include any energy storage. According to the findings of the experiments, the double-pass solar collector with a spiral tube that contains paraffin wax performs better in terms of thermal performance than collectors that use a straight tube and traditional designs. At an airflow velocity of 0.0076 kg/s and a maximum air temperature of 59 degrees Celsius, the spiral coil's thermal and exergy efficiencies using paraffin wax are, respectively, 29.86% and 1.11% when the air temperature is at its highest.

3. **METHODOLOGY**

Developed two distinct sizes of latent heat storage modules with internal heat exchanger matrices: one containing 1 m3 of PCM and providing 14 kW nominal thermal power and 83 kWh of storage capacity, and the other having 1.5 m3 of storage volume and 21 kW nominal thermal power at 124 kWh of storage capacity. Both of these modules are capable of storing a total of 124 kWh of energy. The heat exchanger is made up of capillary tubes, and it provides minimal pressure loss in the external hydraulic circuit. It offers 36.7 m2 of heat exchanger surface per cubic metre PCM. The energy and economy of a solar plant for heating and cooling an office building, with the primary goal of defining the size and the type (sensible vs. PCM) of thermal energy storage to be installed in the hot and in the cold side of the plant. The solar plant will be used to heat and cool the building.

A tank of 3000 L capacity filled with PCM S44 (phase change at 44°C; storage at intermediate temperature) and a tank of 2000 L capacity filled with water (sensible heat at 7–15°C; cold storage) proved to be the most effective option from an energy conservation standpoint. Because the mean operating temperature of the storage is near the melting point of this PCM for a longer time of the year, this combination offers the largest primary energy saving and solar ratio out of all the potential scenarios that were taken into consideration. According to the findings of the economic analysis, the higher investment cost of PCM technology is only justifiable in a solar cooling plant in the event that natural gas tariffs are high or the cost of PCM is low. The receiver is a single-pass superheat boiler with a typically cylindrical form, measuring 13.7 metres in height, 7 metres in diameter, and having its top 90 metres above ground level.

It is comprised of a total of 24 panels, each of which measures 0.9 metres in width and 13.7 metres in length. Six of the panels on the south side, which gets the least amount of radiation, are used as feedwater preheaters, while the other panels are put to use as boilers. Each panel is constructed using parallel alloy tubes with a diameter of 0.069 m that are welded together over their entire length. The panels have a coating of nonselective, flat-black paint that has been heat-cured in situ with solar radiation. Following the application of a second coating, the solar radiation absorption rate was around 0.96 on average. The receiver was developed to generate 50,900 kg/h of steam at a maximum temperature of the absorbing surface while running at the maximum temperature of the thermal storage system. The thermal storage system is in a fluid loop that is isolated from the steam cycle loop by heat exchangers. If more steam is produced than is necessary for the creation of electricity, it may be sent to the charging heat exchanger. This device heats oil in preparation for its transfer to a bed consisting of oil, sand, and gravel. The majority of the steam that is produced is utilised in the turbine, which is typical for peaking power plants like this one. The cooling system and the turbine generator are both part of the system that generates electricity. The cooling system is responsible for removing heat from the turbine generator. The computers that monitor and manage the plant are part of the control systems, as is the beam characterisation system, which is responsible for correcting the alignment of the heliostats and evaluating the performance of the heliostats. The plant support system is comprised of all of the ancillary components that are required for the plant to function properly, including but not limited to water conditioners, compressed gas supply, liquid waste disposal systems, and electrical systems.

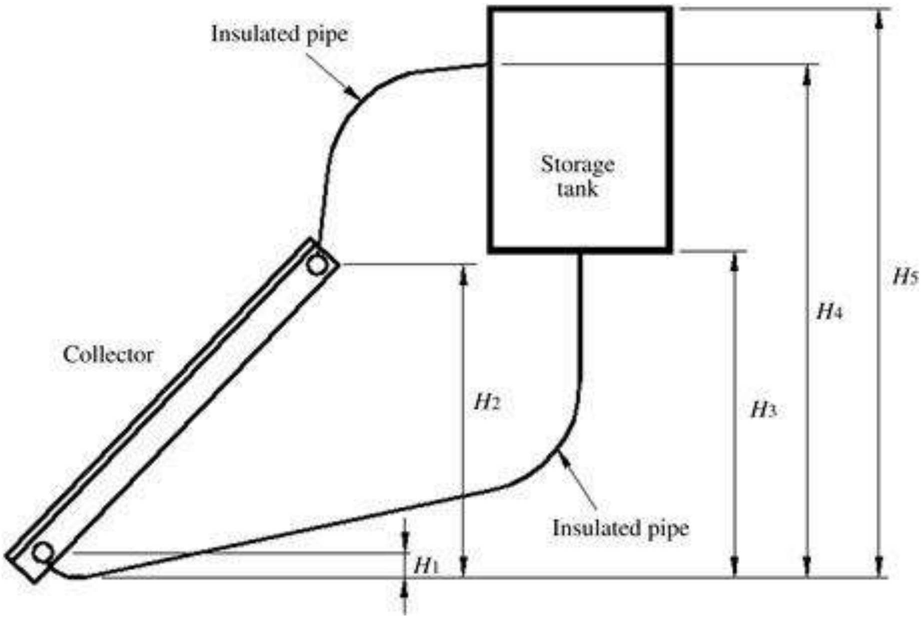

Figure 2 Heat Exchanger

Throughout the course of its three years of power generation operation, several measurements on the performance of the systems' components were taken and analysed. The most important takeaways from the operation and noteworthy aspects of their summary help to show both the promise and the challenges associated with the operation of large central receiver systems. Mirrors having a reflectivity of 90.3% on average are used in the heliostat field. This reflectance was diminished due to the accumulation of dirt on the mirrors, with the degree to which this diminution occurred depending on how often they were cleaned. It would seem, based on the experience that Solar One has had, that the reflectance of the mirrors may be maintained at around 93% of its nominal value if the heliostats are effectively cleansed at intervals of every two weeks. There was some corrosion of the silver backing, but it can be kept to a few percent each year by properly designing the modules to reduce the amount of time the silvering is in contact with moisture. The third factor to take into account in the expansive heliostat market is dependability. In the third year of the operation, an average of 98.8% of the 1818 heliostats were active. This was the highest percentage ever achieved. If the internal heat transfer coefficient is image = 1000 W/m2 K, which is easy to achieve, then the term related to the tube wall is negligible, and the term related to the PCM is a factor 10 to 30 times larger than the first term. This is because paraffin-based PCMs have a thermal conductivity that is close to that of water. It is feasible, to some degree, to compensate for the mismatch between the thermal resistances by making use of procedures that extend the surface area of the object's exterior. Without any external surface improvement, the Ui value will be in the range of 0.025–0.100 kW/m2 K.

However, using enhancement methods, this value may be enhanced all the way up to 0.500 kW/m2 K. An internal heat exchanging area between 0.3 and 8.0 m2 will be required per kilowatt of power that is transferred from PCM storage to HTF. This need is dependent on the design choices that are made. The phase transitions of a PCM from liquid to solid and solid to liquid are examples of shifting boundary issues. The intrinsic nonlinear character of phase change systems at the moving interface contributes to the difficulty in accurately forecasting the behaviour of phase change systems. In addition, the two phases have distinct thermophysical characteristics that differentiate them from one another. In the following lines, a numerical model will be presented with the purpose of simulating the transient behaviour of a system consisting of two concentric tubes.

We may use the approach of enthalpy formulation to explain the melting and solidification processes, and you can use a finite difference scheme to numerically solve differential equations. After the equations have been implemented, the results may be compared with experimental data, and then more sophisticated heat exchanger designs can be studied numerically. The topic is applicable to a shell-and-tube heat exchanger-based LHTS system, which is derived from the design of the heat exchanger. On the other hand, a PCM is found on the shell side of an HTF, and an HTF moves through the tubes. The variation in the circumstances at the HTF's input causes the dynamics of the system to be induced. To make the simulation of the LHTS system more straightforward, it is recommended to use a model with two concentric tubes.

4. EXPERIMENT RESULTS

The evaporation of water from the product requires a certain amount of energy, which may be provided by the product if it absorbs heat. Evaporation draws the moisture away from the product's surface, where it may then be removed. When a product has sufficiently increased in temperature due to the absorption of energy, and when the vapour pressure of the crop moisture is greater than the vapour pressure of the air around it, moisture will begin to evaporate off the surface of the product. It is dependent on the type of the product as well as its moisture content to determine how moisture is replaced on the surface. This is accomplished by diffusion from the inside. If the rate of diffusion is low, it will become the limiting factor in the drying process. On the other hand, if the diffusion rate is high enough, the rate of evaporation from the surface will become the controlling factor.

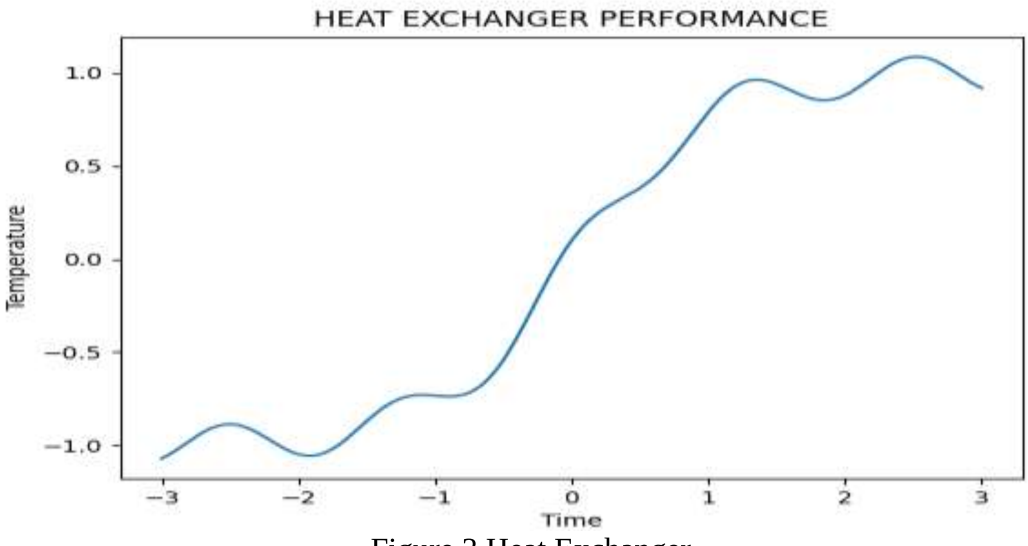

Figure 3 Heat Exchanger

Evaporation from the surface takes place at the beginning of the drying process. In the process of drying by direct radiation, a portion of the sun's rays are able to pass through the material, where it is then absorbed by the product. This causes the product to generate heat not only on its surface but also inside its interior. Because of this, the level of sun absorption

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that a product has is an essential consideration during direct solar drying. The majority of agricultural products have a reasonably high absorptance because of the colour and texture of such components. The rates of heat transfer and evaporation need to be tightly managed in order to ensure both the optimal drying rates and the quality of the product. This is done with product quality in mind. The maximum drying rate that must be achieved before drying may be considered economically feasible Dryers that are powered by solar energy are often thought of as being rather simple machines. They may be as simple as those seen in tiny desert or outlying towns, or they can be as complex as those found in more advanced industrial complexes; however, the latter are still quite uncommon and are in the process of being developed. Dryers that are powered by solar energy may be categorised based on the kind of heating method that is used, the manner in which solar heat is utilised, and the structural arrangement of the device. Dryers may be broken down into two primary groups, active and passive, based on the kind of heating method that is used. In active systems, air is circulated through the air collector to the product with the assistance of a fan. On the other hand, in passive systems, also known as natural circulation solar energy dryers, solar-heated air is circulated through the crop with the assistance of buoyancy forces brought on by wind pressure.

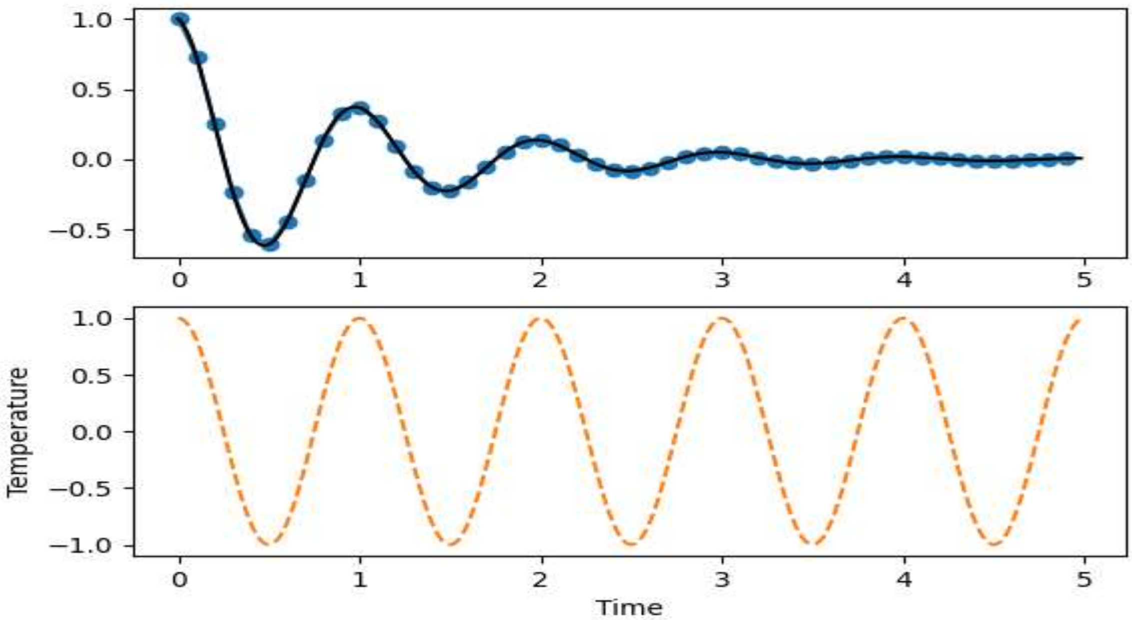

Figure 4 Heat Exchanger Performance Enhancement

In order to power fans for forced air circulation or for supplementary heating, active systems need the use of alternative non-renewable energy sources, most often electricity. This is because active systems cannot rely only on solar energy. Numerous studies on solar power have led researchers to the conclusion that the solar collector accounts for the greatest proportion of the total system cost. Under these conditions, the deployment of an efficient engine is warranted in order to achieve the greatest possible usable conversion of the energy that has been gathered. There have been a few different potential thermodynamic cycles taken into consideration. First, Brayton or Stirling gas cycle engines that operate at inlet temperatures of 800 degrees Fahrenheit are able to provide high engine efficiencies; however, these engines have limitations due to low gas heat transfer coefficients, the requirement for recuperators, and the practical constraints on collector design (i.e., the requirement for cavity receivers) that are imposed by the requirements of temperatures. Second, instead of using the Brayton cycle, you might use turbines that are powered by steam that is created in the receiver. These turbines would have various benefits over the Brayton cycle. Because the heat transfer coefficients in the steam generator are so high, it is possible to employ smaller receivers that have energy absorption on the outside surface. This opens up the possibility of higher energy densities. There is no need for cavity receivers, and the use of cylindrical receivers enables bigger heliostat fields to be used. Utilization of reheat cycles results in increased steam turbine performance but creates challenges for mechanical design. It is also feasible to employ steam turbines, with the steam being produced by an intermediary heat transfer fluid that is then cycled between the boiler and the collector. With these kinds of devices, the fluids in question may be molten salts or liquid metals, and the cylindrical receivers could be operated at approximately. Only these indirect systems are amenable to being used as storage because of how well it fits into their structure.

5. CONCLUSION

The feasibility of a revolutionary solar air heater that has a number of practical qualities has been investigated. According to the findings, the time constant of the solar-powered air warmer is around twelve minutes. For the aim of heating water, a three-dimensional transient numerical model of an evacuated solar collector based on a heat pipe array has been constructed, and its accuracy has been confirmed using previously published research. Solar energy-based devices are often dependent on environmental fluctuation; thus, in order to get an accurate image of the performance, it is necessary to take these factors into account. The temperatures of the air outlet and the absorber, as well as the thermal and exergy efficiency and the heat loss coefficient, are examined for each of the five possible absorber designs. In addition, the findings are contrasted with those obtained using a standard absorber in order to get an understanding of the consequences of the innovative arrangements. Heat transfer of solar air heater may be improved by the use of heat pipe arrays, which clearly takes place as a result of the good performance of heat pipe. This happens for the apparent reason that heat pipe is an outstanding performer. Solar radiation, the temperature of the surrounding environment, and the speed at which air is moving may be identified as the primary parameters that impact the effectiveness of the new solar air heater. The thermal efficiency of the collector improves together with the amount of solar radiation and the temperature of the surrounding environment.

6. REFERENCE

[1] Wang, Zeyu & Diao, Yanhua & Zhao, Yaohua & Chen, Chuanqi & Liang, Lin & Wang, Tengyue. (2019). Thermal performance investigation of an integrated collector–storage solar air heater on the basis of lap joint-type flat micro-heat pipe arrays: Simultaneous charging and discharging mode. Energy. 181. 10.1016/j.energy.2019.05.197.

[2] Jayaraman Muthukumaran, Ramalingam Senthil, Experimental performance of a solar air heater using straight and spiral absorber tubes with thermal energy storage, Journal of Energy Storage, Volume 45, 2022

[3] Thomas D.G. Transport characteristics of suspension: VIII. A note on the viscosity of Newtonian suspensions of uniform spherical particles. Journal of Colloid Science. 1965;20:267–277.
[4] Trelles J.P, Duffy J.J. Numerical simulation of porous latent heat thermal energy storage for thermoelectric cooling. Applied Thermal Engineering. 2003;23:1647–1664.
[5] Tsoutsou S, Infante Ferreira C, Krieg J, Ezzahiri M. Building integration of concentrating solar systems for heating applications. Applied Thermal Engineering. 2014;70:647–654.
[6] Udachin K.A, Ratcliffe C.I, Ripmeester J.A. Structure, composition, and thermal expansion of CO2 hydrate from single crystal X-ray diffraction measurements. Journal of Physical Chemistry B. 2001;105:4200–4204.
[7] van Leeuwen J. Feasibility Study Solar Refrigeration System for the Cooling Requirements of a Beach Bar. Internal report P&E 2430. Department Process & Energy. Delft University of Technology. 2010.
[8] Velraj R, Seeniraj R.V, Hafner B, Faber C, Swharzer K. Experimental analysis and numerical modelling of inward solidification on a finned vertical tube for a latent heat storage unit. Solar Energy. 1997;60:281–290.
[9] Vlahakis J, Chen H.S, Suwandi M, Barduhn A. The Growth Rate of Ice Crystals: Properties of Carbon Dioxide Hydrate, a Review of Properties of 51 Gas Hydrates Technical report, Research and Development. Report 830 Prepared for US Department of Interior; 1972.
[10] Wang J, Chen G, Zheng F. Study on phase change temperature distributions of composite PCMs in thermal energy storage. International Journal of Energy Research. 1999;23:277–285.
[11] Wendland M, Hasse H, Maurer G. Experimental pressure – temperature data on three- and four-phase equilibria of fluid, hydrate, and ice phases in the system carbon dioxide – water. Journal of Chemical and Engineering Data. 1999;44:901–906.
[12] Yang S.O, Yang I.M, Kim Y.S, Lee C.S. Measurement and prediction of phase equilibria for water + CO2 in hydrate forming conditions. Fluid Phase Equilibria. 2000;175:75–89.
[13] Yokozeki A. Solid-liquid-vapor phases of water and water-carbon dioxide mixtures using a simple analytical equation of state. Fluid Phase Equilibria. 2004;222-223:55–66.
[14] Yoon J.H, Yamamoto Y, Komai T, Haneda H. Rigorous approach to the prediction of the heat of dissociation of gas hydrates. Industrial and Engineering Chemistry Research. 2003;42:1111–1114.
[15] Youssef Z, Hanu L, Kappels T, Delahaye A, Fournaison L, Zambrana C, Pollerberg C. Experimental study of single CO2 and mixed CO2 + TBAB hydrate formation and dissociation in oil-in-water emulsion. International Journal of Refrigeration. 2014;46:207–218.