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EXPERIMENTAL AND COMPUTATIONAL ANALYSIS OF SOLAR AIR HEAT EXCHANGER WITH HEAT PIPE

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ABSTRACT

The purpose of the comparison was to explore the enhancement in the heat transmission and friction factor of solar air heat with the various baffles. An examination and investigation of the thermal balance of the newly created installation is carried out. It is determined how much effect the most important heat engineering factors have on the total thermal power of the system. Solar air warmers are straightforward devices that may be used to harness the power of the sun. The design of the solar air heater's primary focus is on extracting the maximum amount of thermal energy possible from the sun. Experiments were run using the same operational and geometric parameters as the computations, which allowed the results of the computations to be confirmed. According to the findings, the location of the baffle and the shape it takes have a direct impact on the performance of the solar air heater. It is well knowledge that hot air has a wide range of applications.Among the several designs that are looked at, it can be concluded that the turbulator configuration is the one that offers the most amount of heat gain for the amount of flow work that it does. In this study, the performance of two distinct configurations, a turbulator placed at the bottom of the channel and a longitudinal rectangular fin placed on the absorber plate, is investigated using various performance parameters. The turbulator is placed at the bottom of the channel, and the fin is placed on the absorber plate.

Keywords: solar, air, heater, heat pipe, sun, system, thermal, power, longitudinal

INTRODUCTION

Thermal energy storage, often known as TES, is a technology that helps to bridge the gap between the supply of energy and the demand from end users in an affordable and ecologically responsible way. The notion of storing energy is highly significant in a great number of different commercial and industrial applications. However, due to the widespread promotion of renewable energy, especially in the area of solar energy, this technology has only gotten increased attention in recent years. This is because solar energy is one of the most prominent forms of renewable energy. Because there is a timing mismatch between the supply of energy and its usage, TES is an extremely important component of solar application technology. This suggests that a solar energy-based equipment or service must undergo dynamic matching at both the source point and the application point in order to function properly.

Once the characteristics of the end-user demand and the nature of the energy source options have been determined, the total demand and supply in the time domain need to be brought together. This can be accomplished by integrating an energy storage system that is both efficient and effective with the distribution network. The TES is an economically feasible technology that assists in shaping the demand from end users in an effective manner. In recent years, there has been significant progress made on TES systems, which has made it feasible for solar technology to be used in a variety of household and industrial settings. Solar water-heating, sun space-heating and cooling, solar drying, and other process industrial applications are among the most prominent applications that have gained prominence in the area of solar thermal technology.

The usage of renewable energy sources and the energy efficiency of traditional systems are both improved by TES. According to the laws of thermodynamics, it is well knowledge that the amount of exergy lost throughout the course of any process involving the conversion or transfer of energy will be greater if there is a greater temperature differential connected with the operation. Thermal storage devices prevent the quick or unexpected loss of the source's available energy to the surrounding environment (sink). As a result, the operating temperature difference will diminish, which will lead to a reduction in both the exergy destruction and the environmental damage that it causes. Therefore, in the process of building a sustainable energy programme that is kind to the environment, solar energy sources that are integrated with TES should be pushed, and actions such as these should form the foundation for the short-term and long-term policies of any nation. Heat may be stored in a TES system in both its sensible and latent forms, as well as via thermochemical processes. Increasing the temperature of the solid or liquid storage medium is done through the process known as sensible thermal storage (STS), which stores heat energy. STS, which is characterised by temperature variation, is a simpler technique, and the amount of stored energy depends on the specific heat of the medium, the temperature change, and the mass of storage material; on the other hand, latent heat storage is based on heat absorption or release when a phase change material (PCM) undergoes the phase transition from solid to liquid or vice versa. The amount of stored energy depends on the specific heat of the medium, the temperature change, and the mass of storage material. The heat is either stored or recovered in thermochemical heat storage devices by use of an endothermic or exothermic chemical process. This chapter devotes a lot of attention to the sensible TES technique, which is one of these storage methods; it is discussed specifically in relation to solar heating and cooling.

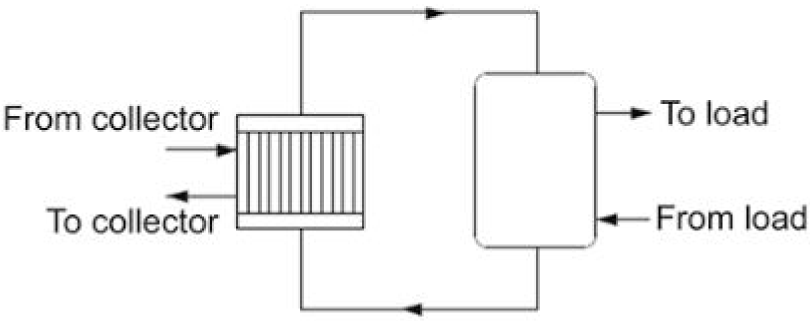

Figure 1 Solar Air Heater

Because of their poor mechanical properties at the high temperatures and pressures required for this solar application, metals with high thermal conductivity, such as copper or aluminium, cannot be used for this application. As a result, steel is the material that is most commonly utilised for this application. Carbon and low-alloyed stainless steels have superior thermal conductivity than high-alloyed austenitic stainless steel, and they are cheaper as well. On the other hand, carbon and low-alloyed stainless steels have lesser corrosion resistance than austenitic stainless steel. Carbon steel with the ASTM 335 grade P22 specification was utilised in the DISS plant in PSA. The DSG was used with water as the HTF, and corrosion issues were discovered as a result of the erosion and cavitation caused by biphasic flow. Now, in this technology, manufacturers are employing austenitic stainless steel AISI 316 to guarantee mechanical robustness against high operating pressures and radial temperature gradients caused by biphasic flow. This is done in order to ensure that the technology can withstand high working pressures. The thickness of the receiver grows in proportion to the maximum operating pressure, which is 100 bar. This results in a tube that is thicker than 4.5 millimetres, which in turn immediately reflects in an increase in the effective cost of the technology. Due to its decreased hydrogen permeability in contrast to other austenitic stainless steels, austenitic AISI 321L stainless steel is often the material of choice when synthetic oil and organics such as biphenyl/diphenyl oxide systems are employed as HTF. As a result of HTF thermal deterioration and the fact that large hydrogen partial pressures may be obtained in vacuum annulus, hydrogen diffusion is the most significant downside of this technology. The wall thickness that is most often used is 2 millimetres. In most cases, molten salt receiver tubes employ either a combination of $NaNO_3$ salts, often known as solar salt, or a mixture of $NaNO_3$.Nickel alloys with 15–20% chromium content performed the best in terms of their resistance to corrosion when exposed to molten salts, whereas iron alloys with low or almost zero nickel content showed poor resistance to corrosion when exposed to high temperatures.

These findings can be found in a number of reports that have been published in the academic literature on the topic of corrosion issues involving molten salts and metallic alloys. Consequently, AISI 321 stainless steel is the material of choice when it comes to making receiver tubes for molten salt. Other HTF materials, such as superheated steam or cooled gases, are currently being researched in order to improve the thermal efficiencies of solar power plants. These other HTF materials present the opportunity to reduce the requirements for, as well as the cost associated with, the metallic tube that is used in receiver tubes. The application that the energy is going to be put to, as well as the temperature at which it is going to be given, are the two key considerations that need to be examined when thinking about a probable industrial process application.

In the event that a procedure calls for hot air for direct drying, an air heating system is most likely the solar energy system that is going to be the finest fit for the need. In the event that steam is necessary for the operation of an autoclave or indirect dryer, the solar energy system must be built to create steam, and it is quite likely that concentrating collectors will be essential. If the preparation of food requires the use of hot water for cleaning, then the solar energy system will function as a liquid heater. The temperature of the fluid when it reaches the collector is an essential component in determining which system is the most suitable for a certain application. The generalisations that can be made about heating applications in buildings, such as the fact that return air to collectors in air systems is typically at or near room temperature, do not necessarily apply to industrial processes.

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LITERATURE REVIEW

W. Zhenkui et al (2021): Researchers are drawn to the solar tower technology because it is one of the most exciting technologies now accessible for generating power from concentrated sun radiation (CSP). In this study, a numerical simulation is used to analyse the thermal performance of the central receiver of the proposed solar power plant, which is based on the Brayton cycle with a volumetric air receiver. The performance of the solar tower plant was evaluated with the use of the software known as TRNSYS 16, which is a transient system simulation. The system was tested in a variety of climates throughout the MENA area. The data that were obtained indicate that, during the operation of the plant, the temperature of the working fluid may reach 1080 degrees Celsius for a volumetric receiver that has an aperture that is equivalent to 25 square metres, which is a high temperature. In addition, it has been determined that the high working temperature accounts for about 88% of the thermal receiver's overall efficiency. According to the findings of the research, there is a correlation between the amount of solar radiation and the total thermal efficiency.

S. E. Hassani (2020): Within the scope of this research is the proposal of a solar heat pump heating system that makes use of an aluminium tube collector. Along with the heat-absorption coefficient of the working material, mathematical models are developed for the solar energy absorption and air energy absorption of the aluminium tube collector. The electronic expansion valve is controlled by a fuzzy PID approach, which allows for the adjustment of the flow rate of the working material, as well as the control of the evaporator overheating and the setting of the temperature of the interior heating. When analysing the impacts of wind speed, solar radiation quantity, ambient temperature, and working substance flow rate on the heat transfer performance of an aluminium tubular collector, the TRNSYS programme is used. According to the findings, the performance of the aluminium tube collector as a heat transfer medium is greatly impacted not only by the amount of solar radiation but also by the velocity of the wind. When the wind speed is more than 2 metres per second, the absorbed power of the collector grows at a rate proportional to the increase in wind speed; nevertheless, the collector's absorption power tends to be saturated when the working-medium flow rate approaches 4 metres per second. After that, the construction of a pilot experimental heating system with a heating area of 170 m2 is begun. Experiments showed that the heating system has a maximum coefficient of performance (COP) of 4.46, and the average COP value is 3.95, which indicates that the heating effect is excellent.

METHODOLOGY

The system configurations and energy uses in industrial processes can be quite different from those in building heating applications. It is possible that the energy will be required at a certain temperature or throughout a range of temperatures. If low-pressure steam is condensed in an indirect drier, the condensate will most likely be recirculated, and the solar process system will be asked to give almost all of the energy at a temperature that is maintained throughout. It is possible that a once-through cleaning procedure will need the heating of freshwater from the temperature at which it is supplied to a useful minimum level. This is done so that energy can be added to the water at a range of temperatures. It is likely that an intermediate temperature range will be suitable for the operation of a system in which a working fluid is continuously recycled back into the tank. The features of traditional energy

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suppliers have not been able to restrict the temperature range within which energy may be employed in a significant number of industrial operations.

In retrofit applications, using solar energy to partially replace conventional sources of energy is often restricted to processes that take place within the same temperature ranges as the sources of energy that are being replaced. Since solar collectors function more effectively at lower temperatures, the industrial process itself need to be investigated in order to determine whether or not the temperature of energy supply may be adjusted. This is necessary for new applications. In most cases, storage would be used in industrial processes; nevertheless, there are certain instances in which the greatest rate at which a solar energy system is capable of delivering energy is not considerably more than the pace at which the process consumes energy.If the operation is carried out during times other than daylight, the yearly proportion of the required energy that can be supplied by solar energy will be low under these circumstances.

The sol–gel dip-coating approach is the technology that is utilised for creating the ARC on glass receiver tubes more often than any other method. In addition to being an inexpensive technique that is simple to scale up, it has the capability of coating both sides of the tubes simultaneously. From colloidal solutions (obtained by basic catalysis of metal alkoxides or commercial SiO2 colloidal dispersion), which is the route that Schott uses, or from polymeric solutions (obtained by acid catalysis of metal alkoxides), where the porous structure is achieved by adding a compound to the solution that is removed during a heat treatment, leaving pores in its place, porous silica coatings can be produced. Schott utilises the colloidal solution This is the path that Solar took to get here. The first one generates coatings that have high optical qualities but have poor mechanical capabilities. As a result, improved techniques have been devised to acquire better coating adherence on the glass and to enhance the mechanical properties. The second method results in coatings that have superior mechanical qualities, despite the fact that these coatings are still susceptible to the same processes of water absorption inside the pores and rapid soiling as a result of the porous structure. In the end, the most significant obstacle that must be overcome in the ARC is reconciling the seeming incompatibility of the porous structure's low refractive index and high stability. Current and upcoming trends and advances are geared toward achieving this objective. The ARC's durability may be improved by changing the sort of porosity that exists in the silica coating. For photovoltaic (PV) glass coverings, for instance, DSM has developed a porous silica ARC coating that has near surface porosity and strong binding with the glass, both of which boost the coating's endurance.

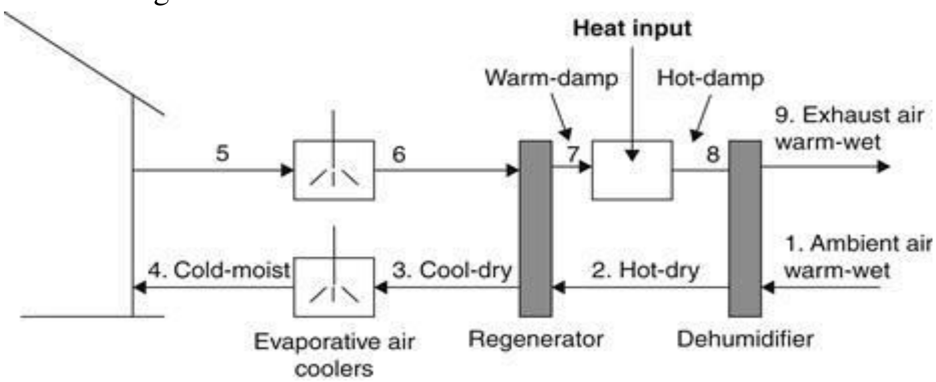

FIGURE 2 SOLAR AIR HEATER USING HEAT PIPE

The development of multifunctional coatings that operate not only as ARC but also as coatings that are simple to clean or that clean themselves is considered to as another key area of research effort. They will do this by increasing the efficiency of the receiver, and in addition to this, they will lower the expenses associated with clean receivers in solar power plants. The optical effectiveness of solar plants may be greatly hampered by the accumulation of dirt on the glass tube receivers. In addition, because to the porous nature of the ARC, it is more susceptible to being dirty than raw glass or mirrors because of its structure. The application of a treatment or coating that makes the surface hydrophobic and the application of a photocatalytic coating that generates a hydrophilic surface are the two procedures that may be used in order to achieve these surfaces that are simple to clean or that clean themselves. Although the procedures that take place in each strategy are distinct from one another, the end result of each one is a surface that prevents the coatings from being soiled for any reason. The durability of these multifunctional coatings and their general capacity to provide an anti-soiling behaviour while maintaining transmittance are the two most important aspects of the coatings. In further study, these constraints need to be the primary emphasis. When evaluating the thermal load of a building, appropriate findings may be achieved by first doing a steady-state heat transfer study, then computing the heat losses and gains associated with the structure. Since the heat gain into a conditioned space fluctuates substantially with time, mostly due to the high transient effects caused by the hourly fluctuation of solar radiation, transient analysis is required in order to get more accurate findings and conduct an energy analysis. Estimating the thermal load of buildings may be done using a variety of different ways. The heat balance, weighting factors, thermal network, and radiant time series are the ones most people are familiar with. Only a condensed explanation of the thermal balancing approach is provided in this paper.

In addition, a discussion of the degree-day technique, which is an approach to calculating seasonal energy use that is less complicated than others, is included. However, before moving on, a brief explanation of the three fundamental words that play an essential role in the calculation of thermal load will be given. The radiant energy coming from the interior surfaces and the direct solar radiation that is allowed to enter a room via openings are both absorbed almost entirely by the space, which is the primary reason why the cooling load is not the same as the heat gain. This energy does not become a component of the cooling load until the air in the room absorbs it via the process of convection. This takes place when the temperatures of the different surfaces in the room rise above that of the air in the room. Because of this, there is a time lag that varies depending on the properties of the structure and the things contained inside it. This time lag becomes more important when the heat capacity (the product of mass and specific heat) is higher.

As a result, the peak cooling load may be much less than the greatest heat gain, and it may also occur significantly later than the time during which the highest heat gain occurs. The heating load operates in a way that is analogous to the functioning of the cooling load. The rate at which energy is extracted from a room via the use of cooling and dehumidifying equipment is referred to as the heat extraction rate. This rate is equivalent to the cooling load whenever the circumstances of the space are same and the equipment is functioning. The functioning of the control systems generates some variation in the temperature of the room, which in turn causes some variation in the rate at which heat is extracted, which in turn causes some variation in the amount of cooling load.

EXPERIMENT RESULT

The heat balance approach is capable of delivering real-time simulations of the load placed on the structure. It serves as the basis for all of the many ways of computation that may be used to get an estimate of the heating and cooling loads. Given that each zone's total energy fluxes must be brought into equilibrium, it is necessary to concurrently solve a set of equations that describe energy balance for the zone's air as well as the inner and external surfaces of each wall, roof, and floor. The energy balancing approach incorporates a number of different equations, including equations for transient conduction heat transfer via walls and roofs, algorithms or data for determining the weather conditions, and equations for determining the amount of heat produced inside.

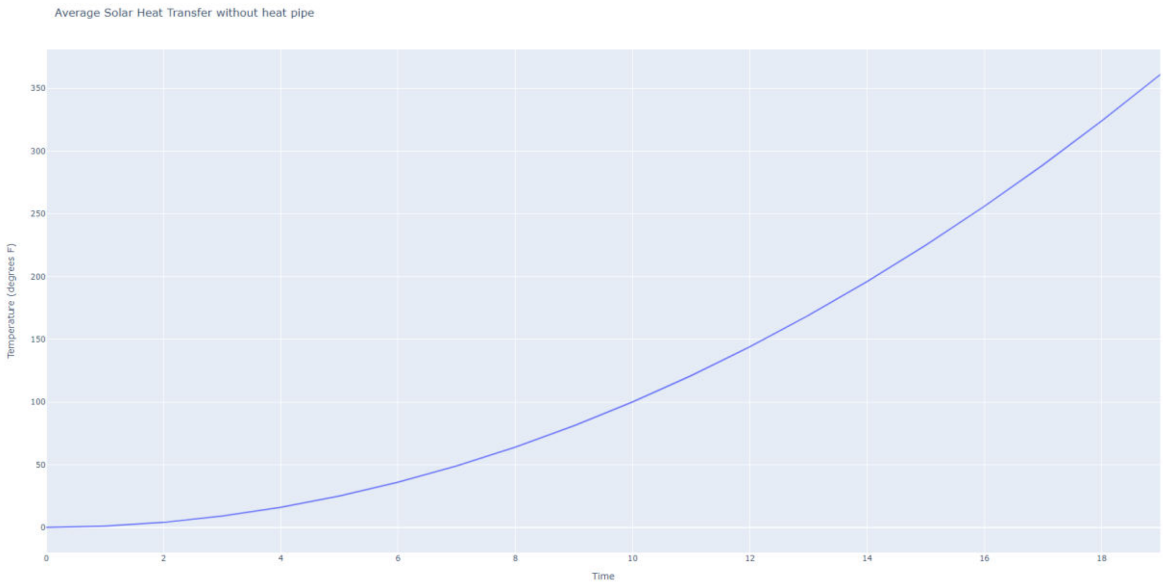

Figure 3 Solar Heat analysiswithout heat pipe

Consider a region that has six surfaces total: the roof, the floor, four walls, and the ceiling. This will serve as an illustration of the procedure. Solar radiation that enters the area via the windows, heat that is transferred through the building's outer walls and roof, and the heat that is gained inside as a result of the lights, the equipment, and the people living there are the sources of energy that enter this area. Heat collector elements (HCEs) often have a glass cover on top of them to help cut down on convective thermal losses and protect the selective absorber from being exposed to the elements outside. It is a glass pipe that is concentric to the metallic absorber pipe, and in order to provide good thermal shock resistance, it needs to have a high solar transmittance and a low thermal expansion coefficient. Additionally, it needs to be relatively close to the thermal expansion coefficient of the metallic absorber pipe at operating temperature. This is done in order to reduce the amount of mismatch between the two linear expansion coefficients. The annulus between the glass and metallic pipes is evacuated to create a vacuum in order to limit the amount of heat lost via conduction and convection and to prevent thermal oxidation of the selective absorber that has been coated on the metallic pipe. This annulus is sealed using a glass–metal welding, and a metallic bellow is used to compensate for the mismatch in expansion coefficient between the glass pipes and the

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metal pipes. Borosilicate glass is required to be the kind of glass material used for the glass cover in HCE. In order to improve the receiver tube's overall optical efficiency, the glass jackets of the tubes are coated on both sides (the inner and the outer) with a film. This coating helps to decrease the reflection losses that occur inside the glass itself.

In order to achieve the destructive interference of light that is reflected at the interface between the glass and the coating as well as the interface between the coating and the air, this film, which is known as ARC, needs to fulfil two requirements related to the coating thickness and the refractive index value. These numbers are the result of calculating the equations of Fresnel's law for normal incidence and for a wavelength that has been established. For solar applications, the wavelength value that is chosen is often somewhere around 600 nm. This is because this wavelength value is located in the zone of the sun spectrum that receives the most irradiance. Therefore, the ideal ARC should have a thickness of around 150 nm and a refractive index value of 1.22. Silicon dioxide (SiO_2) is the substance that is used as ARC on glass the most, and the porosity that is introduced into the coating is what helps to obtain the desired low refractive index value.

This porous quality, which is essential to improve the glass's transmittance, is the material's Achilles' heel as far as its durability is concerned. These holes readily take in water as well as other volatile organic components, which leads to an increase in the coating's refractive index and a decrease in its transmittance. The term "breathing of the coating" refers to this process, which may, in most cases, be reversed. Another negative effect of the porous structure is a low mechanical performance, which is caused by a weak binding force between the silica particles and the substrate as well as between the particles themselves. This effect also applies to the porous structure itself. When the solar receiver is operating at its nominal temperature, the glass cover is attached to the steel pipe using metallic expansion bellows. This is done to compensate for the differing linear thermal expansions of the glass and the steel. The glass cover and the flexible bellows are welded together using a glass-to-metal joint, which is protected from intense sun radiation in order to prevent the thermal and mechanical stress that might compromise the welding's effectiveness and longevity. The heat thermal fluid (HTF) is pumped into the metallic pipe to collect the thermal energy that is being absorbed by the selective absorber. At the same time, a vacuum is created in the annulus to limit the amount of thermal loss. For there to be a solar field system that is both more effective and has reduced operating and maintenance (O&M) expenses, the technology of the parabolic trough has to attain a higher level of performance. The optical and thermal qualities of the collector system, as well as the highest temperature at which the plant can operate, are the primary factors that determine the performance of the STE plant. The effectiveness of the plant as a whole is hindered by the fact that the oil-based HTFs that are most widely employed must be operated at temperatures no higher than 400 degrees Celsius.

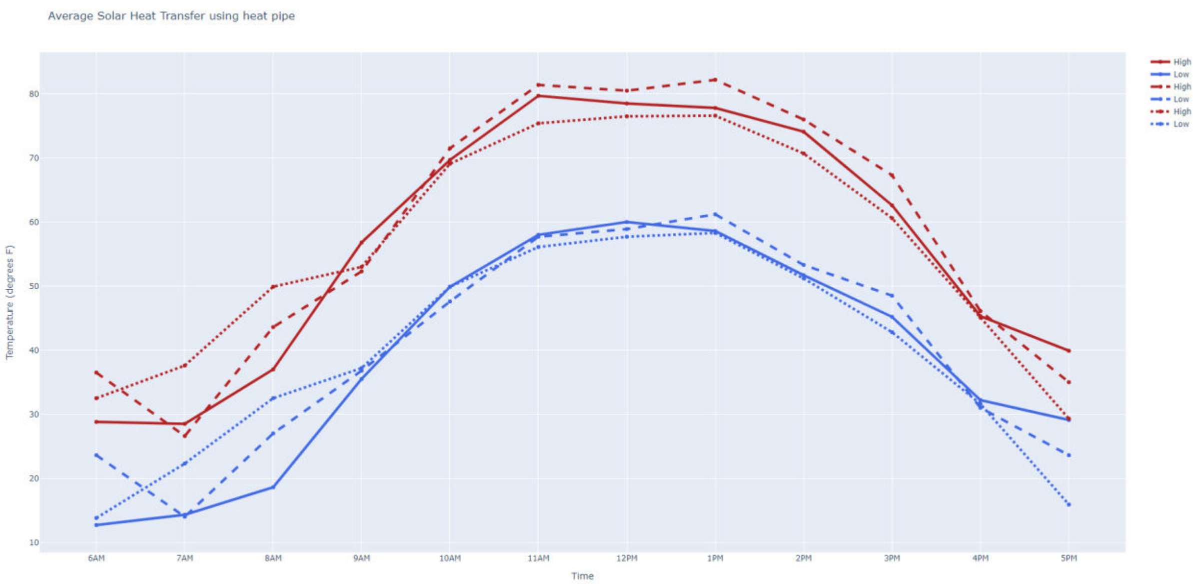

Figure 4 Solar Heat Transfer and its performance improvement

The use of high-temperature HTF, such as molten salts or direct steam generation (DSG), which permits operating temperatures of up to 550 degrees Celsius, is the essential innovation that is required to overcome this constraint. On the other hand, the costs of project execution and solar field construction have the potential to be significantly reduced, with a potential reduction of levelized cost of electricity (LCOE) at higher operational temperatures in a molten salt power plant with thermal storage unit of more than 20% when compared with a no storage standard HTF plant and 15% when compared to an oil-based HTF plant with thermal storage. This reduction in LCOE would apply to a molten salt power plant with thermal storage unit. It is possible to reduce costs in a number of different ways, such as by making use of less expensive materials while maintaining the same level of performance and durability; extending the length of the tube from its current length of 4 metres to a length of 6 metres or even longer; and developing new designs that are more straightforward and inventive, such as re-evaluable tubes or dynamic vacuum systems. Longer pipes provide a greater surface area that may be used, reduce the amount of welding that must be done between pipes, and produce bigger collectors that need for a reduced number of servomotors and controllers, among other benefits. The primary issue of deterioration that is seen in receiver tubes that are used in commercial solar power plants is the loss of vacuum in the inner annulus, which is caused by hydrogen diffusion from oil-based HTF travelling through metal pipe walls. The use of getters has been widespread in an effort to lower the hydrogen partial pressure in vacuum annuli; however the getters have not been able to meet the required endurance. Moving away from oil-based HTF systems and toward those that use molten salts or DSG will lessen the challenges associated with vacuum deterioration and will assist to lower the cost of receiver tubes.

CONCLUSION

The extensive computational analysis that was undertaken in order to examine the performance of SAH was successful. In this investigation, the thermal performance of solar air heaters that have been connected in series in order to enhance the volume of air that can flow through the system units has been analysed. In order to increase the thermophysical characteristics and hence obtain improved performance, SAH has been combined with paraffin wax that has been augmented with copper oxide nanoparticles. The examined computational findings make it abundantly clear that sine wave shape baffles have resulted in the highest possible thermo-hydraulic performance and have been deemed the optimal baffle shape among the several types of baffles that were investigated for this research. Experiments are carried out in order to verify the accuracy of the findings that are computed using sine wave baffles. With the assistance of solar air heater, the level of supply of thermal loads to drying units reached up to 85% on a daily basis. It rapidly warms up and stores heat, can be readily withdrawn from the casing, and has a considerable amount of usage in heating a variety of different kinds of spaces over a long period of time, which contributes to the technical and economic efficiency of the device that has been shown here. The primary thermal engineering parameters of the experimental installation and the operating modes of the SAH with a heat exchanger-accumulator were validated as a result of the experimental tests that were carried out.

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