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PERFORMANCE ANALYSIS OF SOLAR FLAT PLATE COLLECTOR AT DIFFERENT RADIATIONS AND WIND SPEEDS

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Abstract : Solar Flat Plate Collectors are widely employed for water heating purpose. The present study investigates how solar flat plate collectors (FPCs) perform under different conditions, particularly focusing on the impact of solar radiation levels and wind speeds on their efficiency. Through experimental methods, FPC was exposed to varying radiation levels and wind speeds, in thermosyphonic mode as well as in forced modes and collector performance was studied. The findings suggest a correlation between these factors and the FPCs' thermal efficiency. Notably, forced circulation mode demonstrated 6% higher efficiency compared to thermosyphon mode. This study aims at establishment of more efficient and cost-effective solar energy systems, contributing to the global transition towards sustainable energy sources

***IndexTerms* – Flat Plate Collector, Thermal Efficiency, Forced mode, Natural mode.**

I. INTRODUCTION

A flat plate collector is the simplest means available for solar energy utilization. They do involve advanced technology, but at the same time, a good efficiency can be obtained in the temperature range up to 100°C. It has, therefore, been widely employed for applications like water heating, building air-conditioning (heating and cooling), crop drying, and electrical generation through an organic Rankine cycle engine which can also be used for irrigation pumping.

The performance of a flat plate collector is highly influencedby its orientation and its angle of tilt with the horizontal. It can be mainly attributed to the fact that both the orientation and tilt angle change the solar radiation reaching the surface of the absorber and the overall heat losses.

2. LITERATURE SURVEY

Abubakkar et.al [1] studied the performance of a flat collector under various conditions in a laboratory under controlled environment. Halogen lamps were used to heat the water in the collector tubes instead of actual solar radiation. The effect of wind and the placement of a reflector near the collector studied experimentally. The reflector was introduced to improve the performance of the solar collector. Their study revealed that heat transfer rate and the collector efficiency are strongly dependent on solar radiation. The maximum collector efficiency without reflector was 32 % and with reflector was 67%.

Nassir D. Mokhlif et.al[2] investigated experimentally the integrated storage solar collector coupled with reflectors. The reflectors were insulated from the back side when working during the day hours and as insulated cover during the night hours. While comparing the combined collector-storage solar water heater with and without insulated reflectors, their studies revealed that the insulated reflectors increased the thermal efficiency by 23%. Furthermore, on the coldest day, the stored water reached a high of 82 degrees Celsius, though it was only 46 degrees Celsius that same morning.

Vikram Singh et.al [3] in their experimental study on a solar water heater system, to increase further the thermal performance of solar collectors the interaction between the radiation and mass flow rate was investigated. In their research work, experimental analysis has been carried out at different levels of solar irradiance and at different mass flow rates. Results indicate that efficiency decreases with an increase in solar irradiance levels in all considered cases. **Yaning Zhang et al** [4]; conducted Experimental study and numerical analysis of thermal performance of corrugated plate solar collector. Both results revealed that the sinusoidal corrugation provides an increased outlet temperature and reduced plate to fluid temperature difference and thereby an enhanced efficiency of the collector. The experimental and numerical results of collector outlet temperature and collector efficiency proved to be in a good agreement. **Saadbin Choudhary et al** [5]; conducred experiment on Flat plate collector using nano fluid. which exhibits enhanced thermal conductivity and has larger convective heat transfer coefficient compared to the base fluid. It was observed that the efficiency of flat plate solar collector was increased by using nano fluid compared to using solely water as circulating fluid. The objective of this project is to investigate the performance and analyze the behavior of a flat plate collector under varying wind speeds and different radiation levels

NOMENCLATURE

C = Ratio of diffuse radiation to direct normal radiation, F_R = Collector heat removal factor
I_r = Total solar radiation falling on collector surface (kJ/h m^2),m_w = Mass flow rate (kg/s)
n = Refraction index of glass,N = Number of glass covers ,T = Time (h),

T_a T_{fi}, T_p, = Temperature; atmospheric, fluid inlet, mean plate (K), U_L = Collector loss coefficient; overall (kJ/h m^2 C)
V = Mean wind velocity (m/s) β= Collector tilt angle (degrees

3. MATERIALS AND METHODOLOGY.

In our methodology, working principle, various tools and components used for carrying out the experimental work has been discussed along with their specifications and the working procedure.

The Sun's rays fall on the collector plate (a component of solar water heating system). A black absorbing surface (absorber) inside the collector absorbs solar radiation and transfers the heat energy to water flowing through it. Heated water is collected in a tank which is insulated to prevent heat loss. Circulation of water from the tank through the collectors and back to the tank continues either automatically due to thermosiphon effect (Natural effect) or through a circulation pump (external force).

Absorption of Solar Radiation: Solar flat plate collectors consist of a dark-colored, flat surface known as the absorber plate, typically made of metal. This absorber plate is coated with a selective coating, which enhances its ability to absorb sunlight. When sunlight strikes the absorber plate, it absorbs solar radiation, converting it into heat energy.

Conversion of Solar Energy to Heat: The absorbed solar energy heats up the absorber plate, increasing its temperature. Heat transfer fluid, usually water or a mixture of water and antifreeze, flows through pipes or channels attached to the absorber plate. As the heat from the absorber plate is transferred to the fluid flowing through the collector, the temperature of the fluid rises.

Circulation of Heat Transfer Fluid: The heated fluid is then circulated through the collector by a pump or natural convection, depending on the system design. As the fluid circulates through the collector, it continuously absorbs heat from the absorber plate, further increasing its temperature.

Transfer of Heat Energy: The hot fluid leaving the collector is directed to a heat exchanger or storage tank. In the case of a domestic hot water system, the hot fluid passes through a heat exchanger, transferring its heat to water stored in a storage tank. In space heating systems or industrial applications, the hot fluid may be used directly or passed through additional heat exchangers for specific purposes.

Utilization of Heat Energy: The heat energy transferred to the water or other heat transfer fluid can be used for various purposes, including space heating, domestic hot water production, industrial process heating, or electricity generation through a heat engine

Fig.1 Solar Thermal Training System

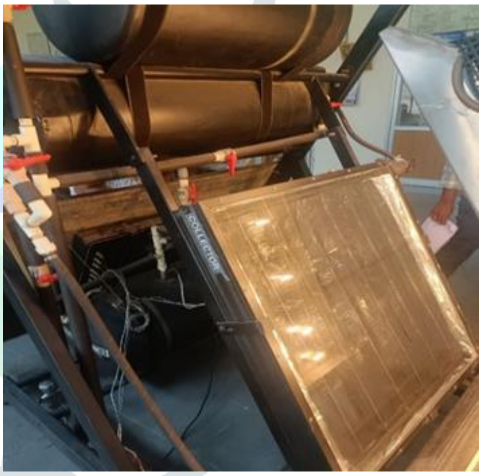

Fig.2 Solar Flat Plate Collector

Fig.3 Halogen Bulbs

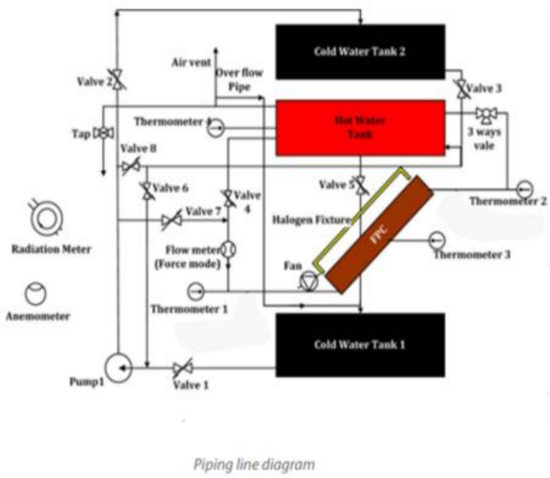

Fig.4 Piping Diagram

4. 1 PROCEDURE FOR THERMOSYPHON MODE

Keep all valves closed. Fill cold water tank number 2. Open the valves 1 and 2 and fill cold water tank 1 by using the pump. Once the cold-water tank 1 is full, open valve 3 and 4 and allows the water to flow into the hot water tank andthe collector by gravity. Once the hot water tank over flows and water comeback to the cold-water tank 2 close the valves1, 2 and 3.Switch ON the wind generating fan. Measure the wind speed at different locations of the collector by using theAnemometer. Use an average value for calculation. Similar to the wind speed measure the ambient air temperature by using the same anemometer at different locations around theexperimental setup. Use an average value for calculation. Connect all the meters and note all the readings. Switch ON the Halogen system and set the regulator for maximum radiation level. Measure the radiation level at different locations on the collector glazing by using the radiation meter. To get the radiation levels at the desire value apply theregulator. Use an average value for calculation. Note the values shown by different meters after every 5 minutes. To know the mass flow rate, open the three ways valve and notethe time required to fill a desire amount of water in the waterlevel marking bottle. Repeat the above step at least threetimes during the whole experiments. Use an average vale forcalculation. Keep the halogen system ON until the outlet water achieved a stable temperature. Once the experiment is over drain the hot water to the cold-water tank 2 by opening valve 5.

4.2 PROCEDURE FOR FORCED CIRCULATION MODE

Fill the cold-water tank 2. Close all valves except valve no. 3 and 4. Once water overflows the hot water tank close allvalves except valve no.6 and 7. Switch ON the pump and setthe regulator at the middle position. See the flow rate on the flow meter screen (forced mode). To get the required flow rate first open the valve No. 8 completely and then adjust the valve No. 7. Wait for some time to get a stable flow rate reading. Once flow rate is set note all the readings. Switch ON the wind generating fan and set the speed at the desire level. To know the wind speed and ambient air temperature use same methodology as in experiment No 1.Switch ON thehalogen system and set the radiation at the desire level. To know the radiation level use same methodology as in thermosyphon mode. Note all the readings after every 5 minutes. Keep the pump on throughout the experiment.

Heat Loss Coefficient (U_L):

UL is the overall heat transfer coefficient from the absorber plate to the ambient air. It is a complicated function of the collector construction and its operating conditions. In simple term it can be expressed as

$U_L = U_t + U_b + U_e$

$$U_L = \left\{ \frac{\frac{1}{N}}{\frac{C}{T_p}\left[\frac{T_p - T_a}{N+f}\right]^{0.88} + \frac{1}{h_a}} \right\} + \left\{ \frac{\sigma(T_p + T_a)(T_p^2 + T_a^2)}{(\varepsilon_p + 0.05N(1-\varepsilon_p))^{-1} + \frac{2N+f-1}{\varepsilon_g} - N} \right\}$$

Where,

$C = 365.9*(1-0.00883ß + 0.001298ß^2)$ $h_a = 5.7 + 3.8(v)$; $f = (1 + 0.04ha – 0.005ha^2) * (1+ 0.091N)$

$U_b = k_b / X_b$ $U_e = U_b* (A_e/A_c)$

Heat Removal Factor (F_R):

Heat removal factor represents the ratio of the actual useful energy gain to the useful energy gain if the entire collector were at the fluid inlet temperature. It depends upon the factorslike inlet and outlet water temperature, the ambient temperature, area of the collector etc. The importance of heatremoval factors remains with the efficiency of the system. Forhighly efficient system, a higher value of heat removal factoris must.

$$F_R = \frac{m`Cp[To-Ti]}{Ac[I\tau\alpha - UL(Ti-Ta)]}$$

Thermal Efficiency of the collector(η):

Efficiency is the most important factor for a system. This factor determines the system's output. For a flat plate collectorbased solar water heater system the efficiency is define as the ratio of the useful energy delivered to the energy incident on the collector aperture. The value of efficiency is dominated by parameters like product of glazing's transmittance and absorbing plate's absorption, intensity of global radiation falling on the collector, water inlet temperature and ambient air temperature

$$\eta = Fr[(\tau\alpha)-U_l(Ti-Ta) / I]$$

5. RESULT ANALYSIS.

The results obtained from the experiments conducted to study the Performance of solar flat plate collector with different angles of incidence of radiation are presented here. From Fig 5,which shows variation of efficiency with radiation in thermosyphon/ natural mode. it is evident that the efficiency increases as the amount of radiation increases. This can be easily understood, because more radiation means more heat is being absorbed by the system,which increases the circulation and heat transfer. From this graph it is evident that as the solar flux increases, the heat absorbed by the collector increases, thereby performance of the collectors improves i.e, efficiency increases.

Fig 6. shows the variation of efficiency of solar flat plate collector at different radiation levels in Forced mode. From this graph it is observed that as the radiation increases there is an increase in efficiency. In forced circulation a pump actively circulates the heat transfer to the fluid. .This allows for a much higher flow rate compared to thermosyphonic mode. Forced circulation promotes better heat transfer from the absorber plate to the working fluid due to the increased flow rate. This reduces the temperature difference between the absorber plate and the fluid, minimizing loss of heat back to the environment

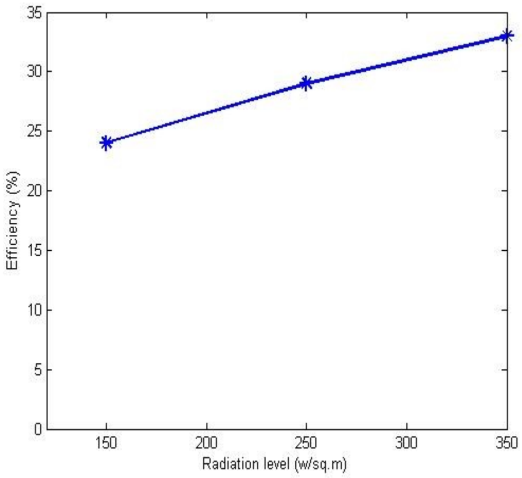

Fig.5–Variation of efficiency with radiation in natural mode

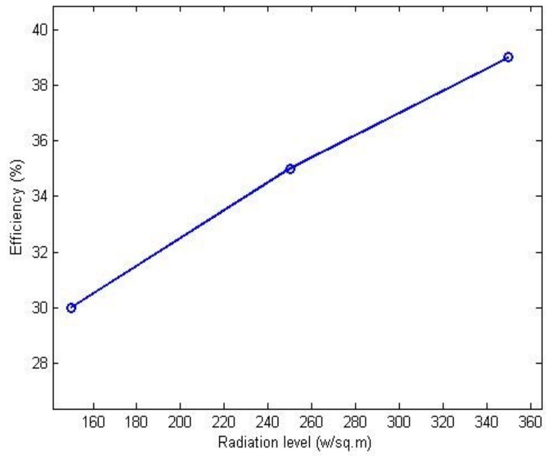

Fig 6–Variation of Efficiency with radiation in forced mode

Fig 7 shows the variation of efficiency of solar flat plate collector at different radiation levels in thermosyphonic mode . From the Graph 6 we can observe that there is no significant change in the efficiency of solar flat plate collector with the variation in wind speeds such that atthe radiation intensity level 350w/m^2 with wind speed of 2.5 m/s efficiency is 28.8%, at wind speed of 3.5m/s efficiency is observed as 28.3% and at wind speedof 4.5m/s efficiency is observed as 27.8%. Wind is mostly negligible for glazed collectors, the cover reduces the heat losses from the collector by creating a greenhouse effect, trapping the infrared radiation emitted by the plate

Fig 8, we can observe that there is no significant change in the efficiency of solar flat plate collector with the variation in wind speeds such that atthe radiation intensity level 350w/m^2 with wind speed of 2.5 m/s efficiency is 34.3%, at wind speed of 3.5m/s efficiency is observed as 33.9% and at wind speedof 4.5m/s efficiency is observed as 33.2%And also we can observe Efficiency of flat plate collector is more in Forced mode compared to Thermosyphonic mode

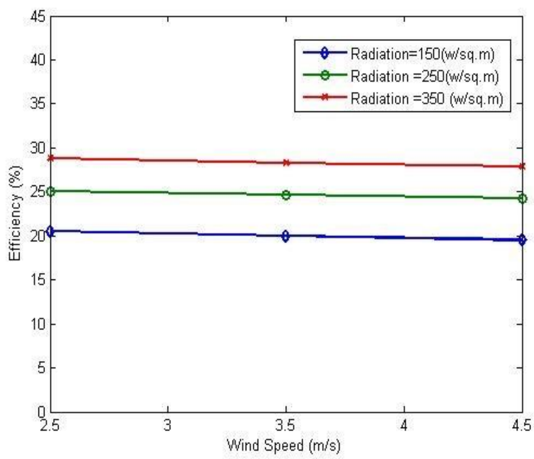

Fig.7. Efficiency v/s Wind speed (Thermosyphonic mode)

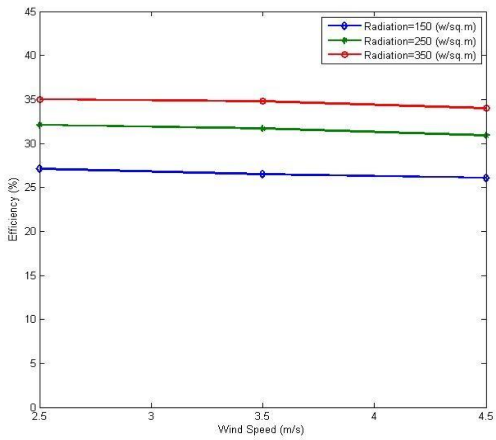

Fig.8 Efficiency v/s Wind speed (forced mode)

In Fig 9, it's clearly depicted that the temperature of thesolar flat plate collector is directly proportional to the duration of time in thermosyphon mode. This implies that asthe duration of time increases, the temperature of the collectoralso increases. This relationship underscores the thermal dynamics at play within the thermosyphon mode, whereprolonged exposure to solar radiation leads to enhanced heatabsorption and retention by the collector

Fig 9 indicates with the change in radiation levels a decreasing trend is observed as explained in the graphs plotted using experimental observations. As the level of radiations is reduced from 350, then 250 and then to 150 (all values in W/sq m) .We are reducing the incident solar energy on the collector plates to be available for water heating in the riser tubes. Thus in the nutshell we conclude that the efficiency levels obtained in the graphs are reducing with reduction in available solar radiation levels (which are varied using halogen regulator).Thus the curves are justified in showing a decreasing trend with reduction in solar radiation level. With the increase in value of ΔT the efficiency of solar flat plate collector decreases gradually.

From the Fig 10 solar irradiance levels for a mass flow rate of 0.5 LPM From , it is observed that efficiency increases with an increase in solar irradiance levels. This suggests that the efficiency of the system depends on ΔT, i.e., efficiency decreases with an increase in the value of ΔT. Also, at higher solar irradiance levels, the collector may absorb more heat than it can effectively transfer to the working fluid (water). This can result in higher heat losses through conduction, convection, and radiation, reducing the overall efficiency. For this graph, max. efficiency is achieved at a higher solar irradiance value and ΔT is 40% to 30%.

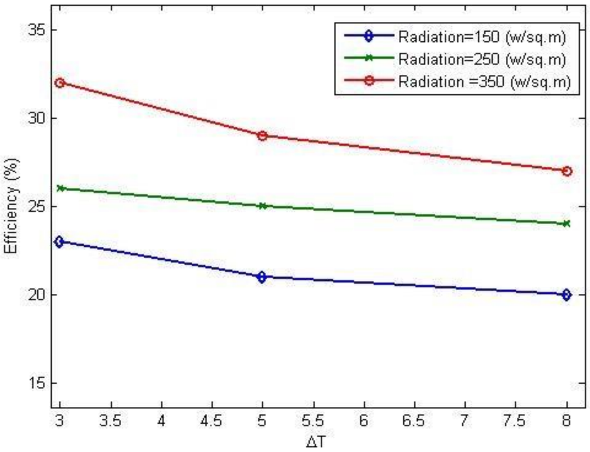

Fig.9 Efficiency v/s ΔT (Thermosyphonic mode)

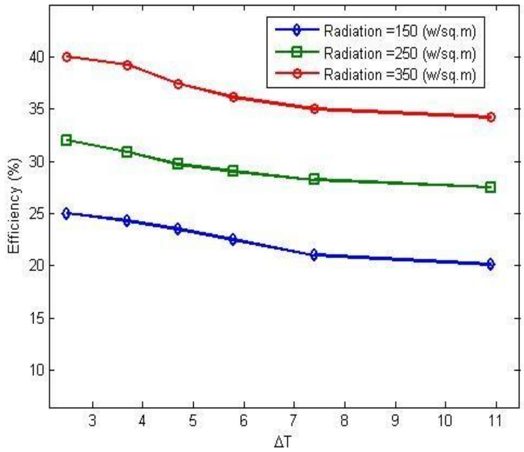

Fig.10 Efficiency v/s ΔT (forced mode 0.5 lpm)

From the Fig 11 and Fig.12 solar irradiance levels for a mass flow rate of 0.7LPM and 1 LPM ,it is observed that efficiency increases with increase in solar irradiance levels. This suggests that the efficiency of the system depends on ΔT, i.e., efficiency decreases with an increase in the value of ΔT. Also, with increased solar irradiance, the collector plate temperature can rise significantly. If the temperature of the collector plate becomes too high, it can lead to higher thermal losses due to increased heat transfer to the surroundings. From graph 8, max. efficiency is achieved at a higher solar irradiance value and the ΔT value is 34% to 30% For graph 7.8, max. efficiency is achieved at a higher solar irradiance value is 30.9% to 27.1%.

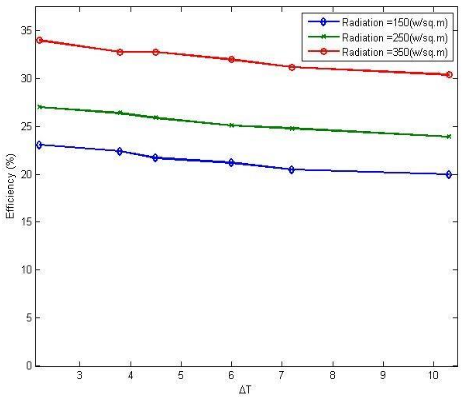

Fig.11 Efficiency Vs ΔT (Forced Mode 0.7LPM)

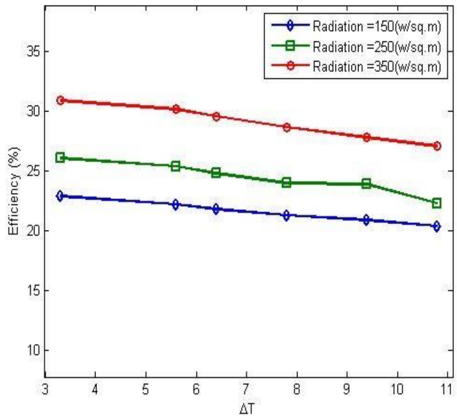

Fig.12 Efficiency Vs ΔT (Forced Mode, 1LPM)

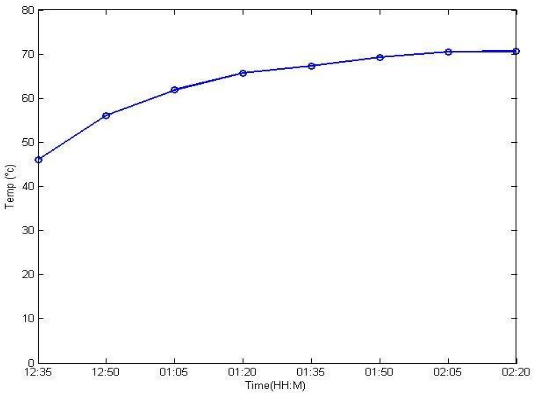

Fig.13.Variation of plate temperature wrt to time in Forced circulation mode.

From the Fig 13 we can observe that as time increases the temperature of plate increases because more amount of heat is absorbed by the flat plate collector as time passes.

6. Conclusions and Future Scope

The following conclusions were drawn after conducting studies on flat plate collector by varying different radiation levels and wind speeds as discussed

• The study revealed that the efficiency of solar flat plate collectors fluctuates significantly with changes in radiation levels. Higher radiation levels generally correspond to increased collector efficiency, while lower radiation levels result in decreased performance.

• It is observed that Forced circulation mode has 6% more efficiency when compared to thermosyphon mode.

• Efficiency increases with increase in solar radiation levels.

• There is no significant change in efficiency of solar flat plate collector with varying wind speeds.

• With the increase in change of difference between fluid inlet temperature in collector and ambient temperature the efficiency of Solar flat plate collector decreases

• In conclusion, the performance analysis of solar flat plate collectors across varying radiation levels provides valuable insights into their efficiency and effectiveness under diverse environmental conditions.

Here are some potential areas of future scope of work,

1. Advanced Materials and Coatings: Investigate the use of advanced materials and coatings that can enhance the absorption of solar radiation across a broader range of angles. Developing materials with improved spectral selectivity could increase the efficiency of solar flat plate collectors.

2. Adaptive and Autonomous Tracking Systems: Research and develop adaptive tracking systems that can automatically adjust the angle of the collector in real-time to maximize energy capture throughout the day. These systems could use artificial intelligence and machine learning algorithms to optimize the angle based on local weather conditions and the position of the sun.

3. Geographic and Climate-Specific Optimization: Conduct studies to determine the most effective angles for solar flat plate collectors in different geographic locations and climate conditions. Understanding how latitude, climate, and local weather patterns affect optimal angles can lead to more efficient energy harvesting strategies.

4. Integration with Energy Storage: Explore the integration of solar flat plate collectors with energy storage solutions, such as advanced batteries or thermal storage systems. Optimizing the angle of incidence in conjunction with storage can enable continuous energy generation, even during cloudy periods or at night.

7. References.

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