Power System Technology
ISSN:1000-3673

Received: 16-01-2024 *Revised: 12-02-2024* *Accepted: 07-03-2024*

Enhancing Parabolic Trough Solar Collector Efficiency through Absorber Tube Rotation: A Computational Study

Umamaheshwar Hebbal[1], Bhimasen Soragaon[2], Abdulrajak buradi[3], Mohan Das A N[4], Sudeep Kumar T[5]

[1, 2]Department of Mechanical Engineering, JSS Academy of Technical Education, Bengaluru-560060, (Affiliated to Visvesvaraya Technological University, Belagavi), Karnataka, India.
[1]uhebbal789@gmail.com, [2]bsoragaon@gmail.com
[3]Department of Mechanical Engineering, Nitte Meenakshi Institute of Technology (NMIT), Yelahanka, Bangalore -560064, Karnataka, India.
arbnitk@gmail.com
[4]Department of Mechanical Engineering, Dayananda Sagar College of Engineering, Bengaluru-560111, Karnataka, India.
mohandas-me@dayanandasagar.edu
[5]Mechanical Engineering department, Siddaganga Institute of Technology, Tumkur-572103, Karnataka, India.
sudeepkumart@sit.ac.in

Abstract

This work uses CFD simulations to examine how absorber tube rotation affects parabolic trough solar collector performance, including output temperature, thermal efficiency, and surface temperature distribution. Simulation results are closely matched to experimental data, with variances ranging from 0.54% to 4.63%. It examines how mass flow rates (0.01 kg/s, 0.015 kg/s, and 0.02 kg/s) and input temperatures (32°C to 38°C) affect system performance in stationary and rotational modes at 1 and 2 rpm. Tube rotation considerably improves thermal mixing in the heat transfer fluid (HTF), resulting in more equal temperature distribution and possibly improved heat transfer efficiency. Increased rotational speed causes complicated dynamics that slightly impair thermal efficiency due to centrifugal forces affecting fluid flow patterns. The study shows that thermal efficiency peaks in the morning, emphasizing the importance of climatic and operational factors on collector performance.

Keywords: Parabolic trough collector, Receiver tube Rotation, Radiation Model, Discrete Ordinates, Surface Temperature.

1. INTRODUCTION:

Energy is an essential element of everyday existence, powering almost all actions worldwide. The development, consumption, and conservation of energy have become crucial topics due to the pressing issues of climate change, pollution caused by the usage of fossil fuels, and the increasing expenses associated with these finite resources. Sustainable energy practices are crucial for the advancement of any nation, serving as a pivotal measure of quality of life. In the past, energy production heavily depended on traditional, non-renewable sources such as coal, oil, and gas.

Power System Technology
ISSN:1000-3673
Received: 16-01-2024 Revised: 12-02-2024 Accepted: 07-03-2024

Nevertheless, the exponential growth in demand over time has resulted in escalatedutilisation of these limited resources, intensifying environmental problems such as pollution and global warming, and adding to the upsurge in oil prices. The current circumstances have required a transition towards renewable energy sources (RES) such as solar, wind, biofuels, and geothermal power. These sources provide alternate means of generating energy while minimisingharm to the environment.

Although non-renewable sources are essential, incorporating renewable energy sources (RES) into our energy systems offers a practical option to distribute the energy burden and reduce adverse environmental and societal impacts. The renewable methods mentioned are primarily devoid of pollutants and encompass technology such as solar photovoltaics (PV) and solar thermal collectors. The vast availability, lack of pollution, and unobtrusive production methods make solar energy an optimum choice. Photovoltaic (PV) technology directly turns sunlight into electricity by utilising the visible spectrum, whereas solar thermal collectors capture solar energyfor heating purposes by harnessing a wider range of sunlight.

The shift towards renewable energy sources (RES) is not only environmentally responsible, but also economically advantageous. The breakthroughs in solar PV and thermal technology have led to considerable reductions in costs and improvements in efficiency. As a result, solar energy has become increasingly competitive with traditional fossil fuels [1] Furthermore, the worldwide allocation of funds towards renewable energy sources highlights the transition towards a more environmentally friendly energy outlook, with wind and solar power taking the lead in mitigatingcarbon emissions and addressing climate change [2].

Moreover, the dispersal of energy generation via renewable energy sources (RES) might improve energy stability and availability, especially in distant and less developed areas. Generating renewable energy locally decreases reliance on imported fuels, fostering energy autonomy and ensuring economic stability [3].

In their study, Devander Kumar et al. [4] conducted an experimental investigation on the performance of a parabolic trough collector (PTC) under various flow rates. The study focused on a non-evacuated receiver and examined several situations, including south-facing and tracking orientations, as well as glazing and non-glazing setups. The findings indicated that the performance is primarily contingent upon the mass flow rates. Additionally, it was discovered that the performance of small-sized PTC is somewhat superior while facing south compared to when in tracking mode. In their study, A.M. Narouzi et al. [5] examined how the efficiency of aparabolic trough collector can be improved by applying rotational effects to the receiver of the collector. In addition, they conducted research on the impact of the volume percentage of nano particles and the contribution of tube material on the performance of the collector.

Power System Technology
ISSN:1000-3673
Received: 16-01-2024 Revised: 12-02-2024 Accepted: 07-03-2024

The researchers determined that the rotation of the tube resulted in a consistent distribution of temperature over its surface. Additionally, the average surface temperature of the tube decreasedby 60 K. The collector's efficiency can vary based on the chosen rotational speed for each Reynold's number, either increasing or decreasing.

In their research, N. Sreenivasalu Reddy et al. [6] conducted an experimental study on the performance of a parabolic trough collector with a rotating motion applied to the receiver tube. The tube is subjected to two distinct speeds: 2 revolutions per minute (rpm) and 4 rpm, in additionto a study where the tube remains motionless. The greatest temperature differences at 4 rpm, 2 rpm, and 0 rpm are determined to be 18.5 °C, 12.5 °C, and 4.0 °C, respectively. Additionally, they discovered that the average surface temperature of the tube lowers in comparison to the stationary tube. The utilization of a rotary receiver tube led to an enhancement in the thermal efficiency of the collector. The recorded values for this improvement were 190.3% and 158.6% at 4 rpm and 2 rpm correspondingly, according to their findings.

In their study, A. Mwesigye et al. [7] examined the ideal thermal and thermodynamic efficiencyof the receiver component in a parabolic trough collector. Three distinct forms of nano fluids, namely copper-Therminol VP-1, silver-Therminol VP-1, and aluminium-Therminol VP-1, were employed as heat transfer fluids. An investigation was carried out to examine various concentration ratios ranging from 88 to 113. The results indicate that the thermal efficiency increased by 13.9%, 12.5%, and 7.2% for silver-Therminol VP-1, copper-Therminol VP-1, and aluminium-Therminol VP-1, respectively, at a concentration ratio of 113. An increase in the concentration ratio resulted in a corresponding improvement in thermal efficiency. Specifically,a 5% increase in thermal efficiency was seen when comparing a concentration ratio of 113 to 88.

A study conducted by A. Ozcan et al. [8] investigated the performance of parabolic trough collectors for water heating applications using both numerical and experimental methods. For their examination, they have examined various flow rates ranging from 0.0017 to 0.0083 kg/s. Copper and aluminum are frequently utilized as tube materials. An analysis was conducted on several factors, including thermal efficiency, intake and output temperatures, and heat loss and exergy efficiency. The numerical outcomes of the collector were compared to the experimental results. The copper and aluminum tubes achieved maximum thermal efficiencies of 74.5% and 72.7% respectively. The copper tube had the highest exergy efficiency of 15.64% when the massflow rate was 0.0017 kg/s.

In their study, V.K. Jebasingh et al. [9] evaluated the efficiency of a newly constructed elliptical absorber tube in comparison to a circular absorber in a parabolic trough collector. The experiment was conducted using several flow rates, specifically 0.014, 0.021, and 0.028 kg/s. The performance has been concentrated on several metrics, including usable heat transfer rate, temperature gradient, overall heat transfer rate, outlet temperature of the fluid, and collector efficiency.

Received: 16-01-2024 Revised: 12-02-2024 Accepted: 07-03-2024

The average collector efficiency had a 9% improvement. The new collector's enhanced surface area resulted in an 82.86% enhancement in the usable heat transfer rate. The innovative collector achieved a perfect vacuum condition, resulting in a reduction of heat lossesby 89.05% compared to a circular tube.

In their study, K. Basha et al. [10] examined the efficiency of a parabolic trough collector using two heat transfer fluids, namely Hytherm 600 and Therminol 55. These fluids were mixed with water in modest volumes every hour, in incremental fractions. Essentially, the experimental setup involved the utilization of a copper tube with a glass cover, as well as an evacuated copper tube. Hytherm 600 outperforms Therminol 55, according to the results. The evacuated tube setup achieved a higher average heat gain compared to the standard tube, with an increase ofapproximately 32%.

In their research, U. Allauddin et al. [11] performed a numerical investigation on a roughened absorber used in a parabolic trough collector. A comparative analysis is conducted to assess theefficiency of the PTC, with and without turbulators, in relation to a smooth absorber tube. This assessment involves the calculation of several key metrics, including the Nusselt number (Nu), the friction factor (f), and the performance evaluation criterion (PEC). When inclined ribs are used, a PEC value of 1.46 is seen at an absorber tube inlet temperature (Tin) of 500 K and a massflow rate ($\dot{m}$) of 0.5 kg s^{-1}. On the other hand, when dimpled protrusions are used, a PEC value of 1.18 is observed under the same conditions. Utilizing inclined rib turbulators leads to a noteworthy enhancement in the thermohydraulic performance of the PTC. In their study, S. Ebrahim Ghasemi et al. [12] conducted a simulation to analyze the turbulent flow of the Syltherm heat transfer fluid in the absorber tube of a solar system that was fitted with turbulators. The findings demonstrated that the heat transfer properties of the solar parabolic trough collector were improved by including porous rings into the tubular solar absorber. Furthermore, it was noted that decreasing the spacing between the porous rings leads to an augmentation in heat transmission, whilst enlarging the inner diameter of the porous rings leads to a decrease in the Nusselt number. Hebbal et al. [13] investigated the multielement airfoil with CFD for the enhancement of lift and drag on the airfoil. They had varied the angle of attacks and studied its effect on pressure co-efficient, lift and drag. In their study, A. Raheem et al. [14] investigated the impact of helical screw inserts on the efficiency of the absorber tube in parabolic trough collectors. The use of helical screw inserts inside the absorber tube of the collector holds the capacity to augment its efficiency. The optimal value of performance evaluation criteria (PEC) is attained while using an insert thickness of 1 mm, a helix angle of 90 degrees, and an inner diameter of 3.5 mm. In addition, the incorporation of apertures or protrusions in the altered inserts results in a rise in pressure differential accompanied by a minor enhancement in Nusselt number. The tapered-helix design provides the benefit of a 12% reduction in pressure drop, but with a 5% fall in Nusselt number. In general, improving the PEC is a productive step in advancing a pollution-free environment for PTC.

Power System Technology
ISSN:1000-3673
Received: 16-01-2024 *Revised: 12-02-2024* *Accepted: 07-03-2024*

In the light of the above, the present work investigates the detailed impacts of absorber tube rotation in parabolic trough solar collector systems. This is done by conducting meticulous simulations that are cross-validated with experimental data from previous research. This work isnotable for its thorough analysis of how rotational dynamics, in combination with different flowrates, impact important performance measures of the solar collector. The uniqueness of the studyrests in its meticulous examination of the thermal consequences caused by tube rotation, providing fresh perspectives on enhancing the efficiency of solar collectors.

2. Methodology

The methodology employed in the current study is numerical in nature. Computational Fluid Dynamics Software (CFD) was employed to examine the efficiency of the collector in both stationary and rotational modes of the tube, considering various mass flow rates and intake temperatures. The model is validated by comparing its results with those obtained from the experimental investigation conducted by Devender Kumar et al. [4]. After confirming the validation of the model, a parametric investigation is conducted on the model, both with and without rotation. Subsequently, the findings are succinctly outlined and deliberated upon. The key characteristics taken into account for performance study include input and output temperatures, heat transfer rate, and thermal efficiency.

Heat Transfer rate is calculated with the relation

$$Q_u = m\, C_p\, (T_{fo}\text{-}T_{fi}) \quad \text{.............(1)}$$

And Thermal Efficiency is useful heat gain by the HTF from direct solar irradiance (G_b) falling on the plane aperture area (A_a) of the collector i.e

$$\square_{th} = \{m\, C_p\, (T_{fo}\text{-}T_{fi})\}/(G_b * A) \quad (2)$$

where ‘m’ is the mass flow rate (kg/s) and ‘C_p’ specific heat (J/kgK) of heat transfer fluid, T_{fo} and T_{fi} outlet and inlet temperatures (K) of the fluid, ‘A’ is aperture area (m^2) and ‘G_b’ is solar irradiance (W/ m^2) falling on the collector.

Power System Technology
ISSN:1000-3673

Received: 16-01-2024 *Revised: 12-02-2024* *Accepted: 07-03-2024*

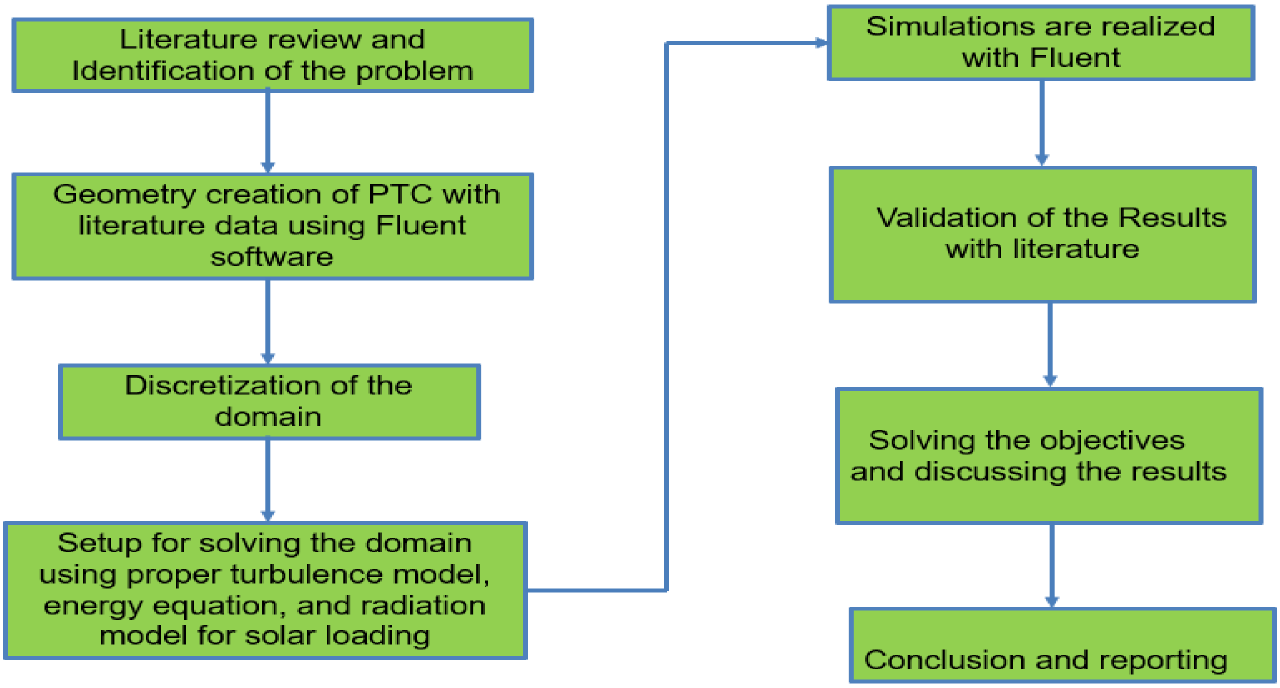


Fig.1: Layout of the Methodology adopted in this work

3. PTC Model and Numerical approach

For the numerical investigation of the model, the simulation of the collector is performed in ANSYS 2023 R2 Fluent as shown in Fig.2

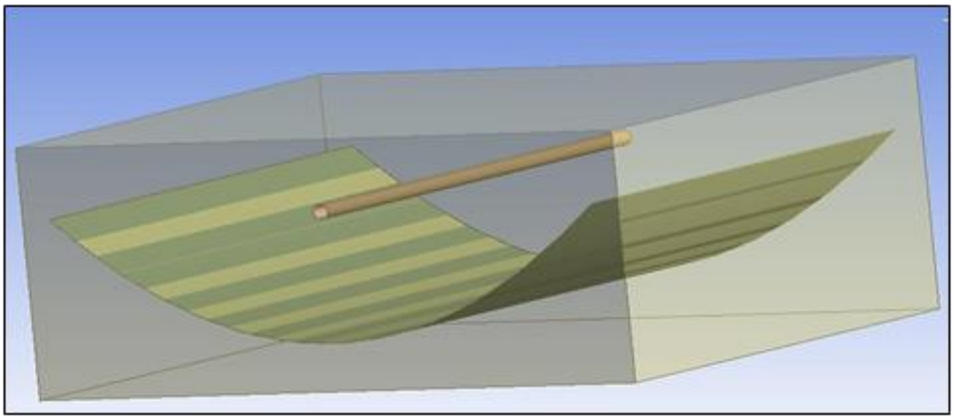


Fig.2: 3D Model of the collector

The copper tube, with inner and outer diameters of 0.0284 m and 0.0318 m respectively, is positioned at the focal point of the reflector. The dimensions of the reflector are 1.09 metres in width and 1.22 metres in length. The reflector consists of an aluminium sheet. Table 1 presents the additional dimensions of the model under investigation.

Power System Technology
ISSN:1000-3673
Received: 16-01-2024 Revised: 12-02-2024 Accepted: 07-03-2024

Water serves as a heat transmissionmedium, while the collector is presumed to be enclosed by air and depicted as a rectangular box encompassing the collector. The thermal and physical properties of water and air are measured as follows (Ref. Table 2).

Table 1: Parameters of the investigated model

Parameters	Dimensions with units
Aperture width of concentrator (Wa)	1.09 m
Concentrator Length (L)	1.22 m
Focal Length (F)	0.273 m
Aperture area of collector (Aa)	1.33 m^2
Concentration ratio (C)	10.60
Absorber Tube Inner Diameter (Dai)	0.0284 m
Absorber Tube Outer Diameter (Dao)	0.0318 m
Arc Length (Sa)	1.255 m
Copper receiver tube absorptance (α)	96%
Reflectivity of the collector (ρr)	80%
Transmittance of the collector (□)	95%

Table 2: Thermal and physical characteristics of water and air

Properties	Water	Air
Density (kg/m^3)	998.2	1.225
Specific heat (J/kgK)	4182	1006.43
Thermal Conductivity (W/mK)	0.6	0.0242

3.1 Considerations of assumptions:

1. Specific heat of the fluids is considered as constant
2. Losses from the side of the tube are considered as minor.
3. Throughout the circumference of the tube, the uniform sun intensity is considered,
4. Results are applicable to Indian geographical conditions.

Power System Technology
ISSN:1000-3673
Received: 16-01-2024 Revised: 12-02-2024 Accepted: 07-03-2024

3.2 Governing Equations:

Flow inside the tube obeys Navier Stoke's equations along with energy and continuity equations.

3.3 Boundary conditions:

For the validation of our study, we utilised the boundary conditions established in the experimental research conducted by Devender Kumar et al. The specified parameters for our inquiry are as follows: The outside wall of the receiver's tube experienced a non-uniform distribution of heat flux. We ensured a consistent mass flow rate and temperature at the entrance of the absorber tube, while allowing the water inlet temperature to fluctuate between 305 K and
310.5 K. The mass flow rates were adjusted to 0.01 kg/s, 0.015 kg/s, and 0.02 kg/s. In order to replicate varied levels of solar exposure, the solar loading was modified at specific times during the day: 11:00, 11:40, 12:30, 13:05, 13:43, and 14:15. These times corresponded to distinct mass flow rates. In addition, a pressure outlet boundary condition was set at the entrance of the absorber tube, with the ambient temperature ranging from 293 K to 300 K. All receiver walls were subjected to no-slip and no-penetration boundary conditions in order to appropriately represent the fluid dynamics within the system during physical modelling. The parabolic trough collector was constructed using galvanised aluminium sheet, while the receiver tube was made of copper. These materials were selected based on their thermal qualities and their compliance with the operational needs of the system.

3.4 Mesh Generation:

The current inquiry involves the modelling of turbulence, which is carried out by taking k-□ into consideration. The model is attainable. In the event where the residuals of continuity are smaller than 10-3, the solutions are said to have converged. During the iterations, the rate of heat transfer is also monitored, and it is seen that the solution has converged when the rate of heat transfer remains constant for a number of iterations that are more than one thousand. The collector, the receiver tube, and the air walls are all constructed out of tetrahedral mesh construction. With a growth rate of 1.20, the element size that was taken was 0.05 metres. It was decided to use the Discrete Ordinates model in Ansys 2023 R2 Fluent for the radiation analysis. The mesh generation for the PTC model that was studied is seen in Figure 3.

Power System Technology
ISSN:1000-3673
Received: 16-01-2024 Revised: 12-02-2024 Accepted: 07-03-2024

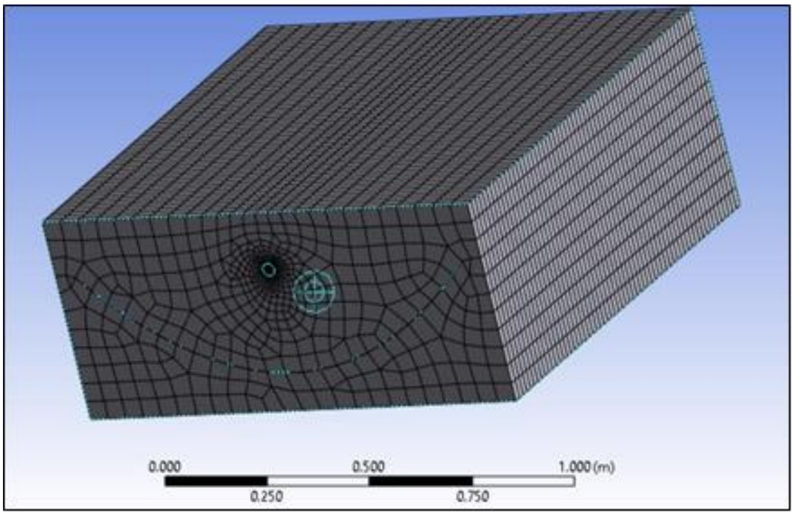


Fig.3 Meshing of the PTC Model of the collector

4. Results and Discussions

In this work, the simulation results obtained are compared to those of the experimental work of Devender kumar et.al [4]. Then the effect of rotation of the receiver tube on the performance parameters are discussed for different flow rates and speeds as follows.

4.1 Comparison with Experimental Results

One of the most important aspects of this investigation is the complex simulation framework that was constructed with the help of ANSYS software. This software is an effective instrument for computational fluid dynamics and finite element analysis. In an effort to provide a realistic representation of the experimental setup, this framework has been built to incorporate a wide variety of models that replicate the behaviour of fluid flow, energy conversion and transfer, sun irradiance, and radiation impacts. The simulation takes into account the precise geometric configuration of the receiver tube of the PTC as well as the thermophysical parameters of the working fluid. This ensures that the simulation provides an accurate depiction of the physical processes that occur inside the system.

Discrepancies between the findings of the simulation and the experimental data range from a meagre 0.54% to 4.63%, indicating that there is a high degree of consistency between the two collections of information. Having this variance indicates that the simulation is capable of closely replicating the results of the experiment, which in turn validates the correctness and dependability of the numerical model. Nevertheless, these differences, despite their relatively minor nature, highlight the intrinsic difficulties that are associated with accurately representing physical processes using computer models.

Power System Technology
ISSN:1000-3673
Received: 16-01-2024 Revised: 12-02-2024 Accepted: 07-03-2024

As a result of the differences being within a small band, they also indicate to the resilience and precision of the numerical technique that was used.This further demonstrates that the model is useful in forecasting the actual performance of PTCsystems.

Several research have investigated the thermal performance and fluid dynamics inside PTC systems by making use of a variety of simulation tools. These investigations have been conductedwithin the framework of the existing body of literature. As an illustration, Bellos et al. [15] carried out an exhaustive analysis on the performance enhancement strategies for PTC systems. They emphasised the need of realistic simulation models in order to forecast the behaviour of the system under a variety of various operating situations. Montes et al. [16] focused on the optimisation of PTC design through simulations, emphasising the possible inconsistencies between simulated and real-world outcomes owing to simplifications and assumptions in the models. In a similar manner, Montes et al. [16] focused on the optimisation of PTC design.

This particular work contributes to the advancement of the discipline by presenting a comprehensive analysis of these disparities, which in turn provides insights into the mechanisms that are responsible for the observed trends and deviations. It makes a contribution to the

continuing topic on the accuracy of simulation models in reproducing experimental data, as described in works such as Zhang et al. [17] who investigated the influence of various modellingassumptions on the fidelity of PTC simulations. This conversation on the quality of simulation models is ongoing.

As an additional point of interest, the outcomes of this study highlight the significance of continuously improving both experimental settings and simulation models. Researchers have the potential to develop their methods by determining the elements that contribute to the observed differences. This allows them to improve the precision and applicability of simulations when it comes to forecasting the performance of thermal systems such as PTCs.

Table 3: Comparison of present results with Devender kumar et., al [4] (outlet temperature)

Time of the day (hours)	Inlet Temperature (°C)	Numerical Outlet Temperature (°C)	Expt. Outlet Temperature (°C)	Deviation (%)
11:00	32	51.27	49	4.63
11:40	33	51.49	50	2.98
12:30	36	42.73	42.5	0.54
13:05	37	43.12	42	2.67

Power System Technology
ISSN:1000-3673
Received: 16-01-2024 Revised: 12-02-2024 Accepted: 07-03-2024

13:43	38	42.18	41.5	1.64
14:15	37.5	41.94	41.23	1.72

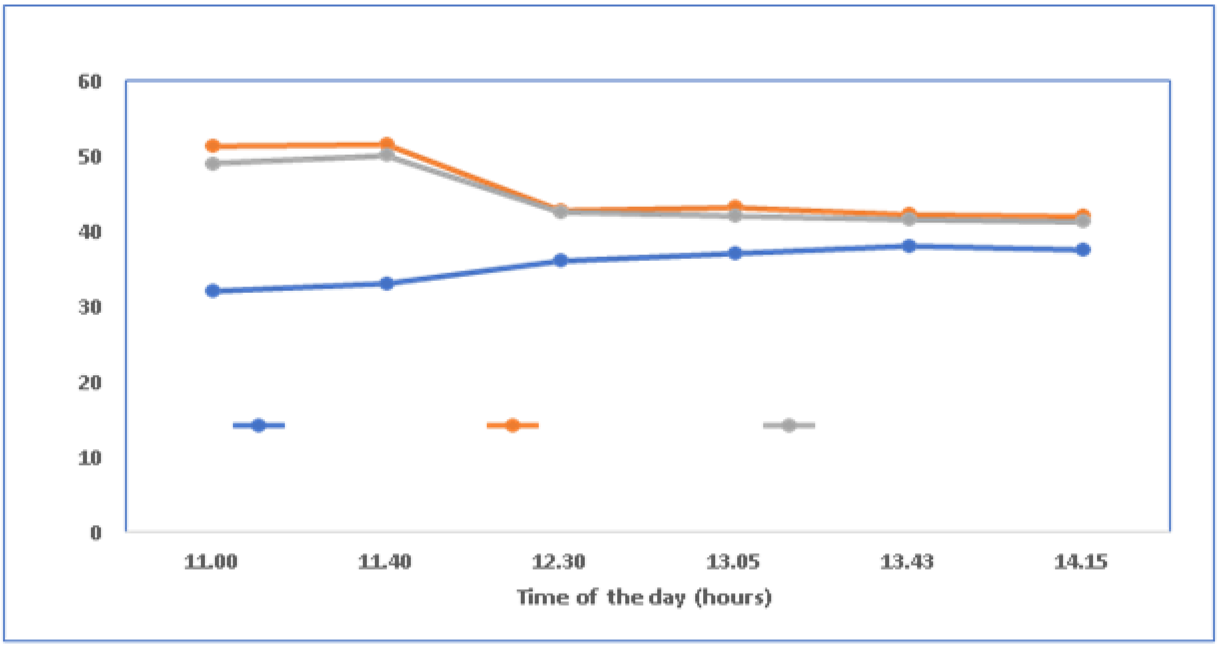


Fig.4 Comparison of present study results with Devender kumar et., al [4] (outlet temperature)

4.2 Effect of rotation of tube on various performance parameters

The simulation study of the model is carried out at different mass flow rates of 0.01 kg/s, 0.015 kg/s and 0.02 kg/s and at the speeds of 1 rpm and 2 rpm. The results obtained are analyzed as follows.

4.2.1 Effect of rotation of the tube on HTF outlet temperature

Figure 5 depicts the influence of different mass flow rates on the outlet temperature of the heat transfer fluid (HTF) in a collector system. The intake temperatures are set at 32°C, 33°C, 36°C,37°C, 38°C, and 37.5°C. The assessment of the collector's performance relies heavily on this parameter, as it directly affects the system's capacity to transmit heat from the solar collector tothe HTF. The analysis differentiates between the performance of fixed and rotational tubes withinthe collector, emphasizing their individual efficiencies in heat transfer.

The outlet temperatures of the HTF in the stationary tube arrangement range from a minimum of 39.19 °C to a maximum of 44.83 °C. This range represents the thermal capacity of the collectorsystem when it is not in motion, and the heat transfer dynamics are mainly affected by the thermalcharacteristics of the heat transfer fluid (HTF).

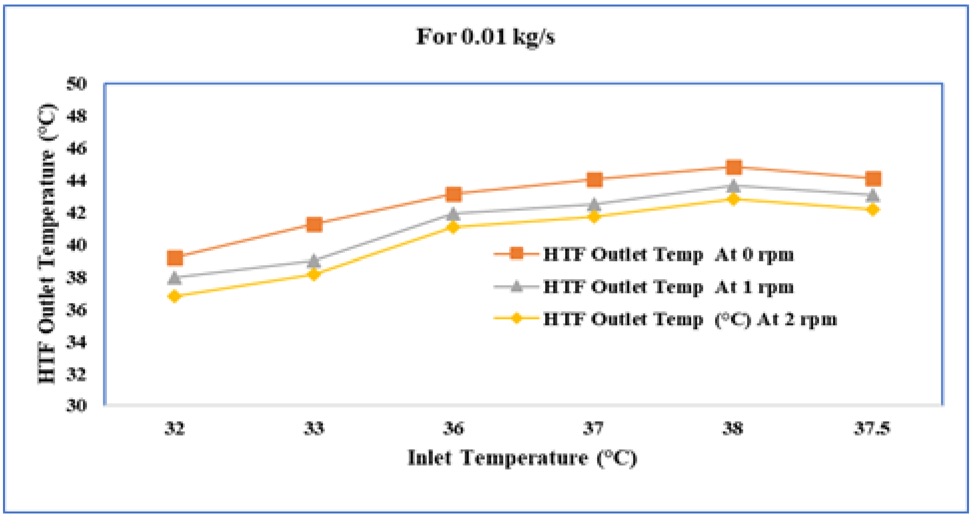
Power System Technology
ISSN:1000-3673

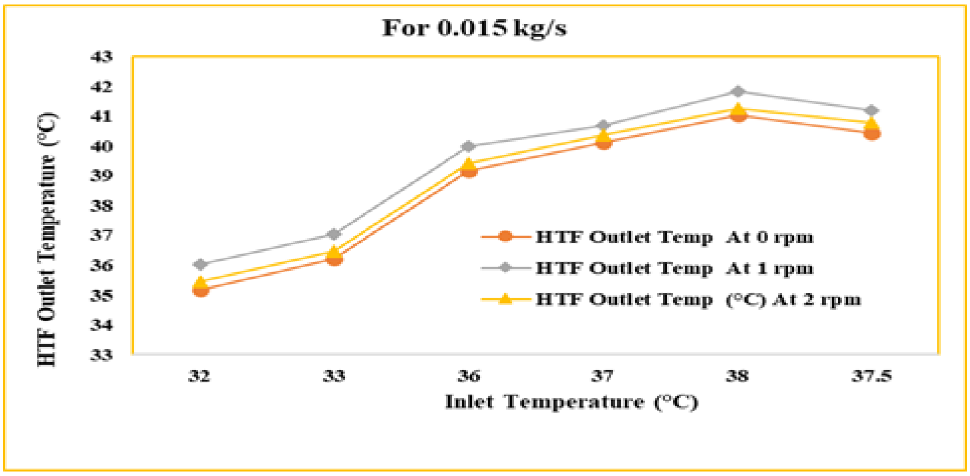
Received: 16-01-2024 *Revised: 12-02-2024* *Accepted: 07-03-2024*

The surface area of the tube that is exposed to solar radiation, and the temperature at which the fluid enters the system.

By contrast, the thermal characteristics of the rotating tube configuration differ slightly, as evidenced by outlet temperatures that range from a minimum of 36.8 °C to a maximum of 43.67
°C. The rotation of the tube incorporates dynamic phenomena into the heat transfer process, including enhanced thermal mixing within the heat transfer fluid (HTF) and perhaps more uniform exposure of the tube surface to solar radiation. The thermal efficiency of the system can be influenced by these factors, as seen by the differences in outlet temperatures when comparedto the stationary arrangement.

The disparity in output temperatures between fixed and rotating tubes highlights the impact of tube motion on the thermal efficiency of the collector. Rotating the tube can improve heat transferby decreasing thermal resistance and facilitating uniform heating of the fluid. This can result in lower maximum outlet temperatures and reduce the likelihood of extremely low temperatures, indicating a more consistent and potentially more efficient heat transfer process.





Power System Technology
ISSN:1000-3673

Received: 16-01-2024 *Revised: 12-02-2024* *Accepted: 07-03-2024*

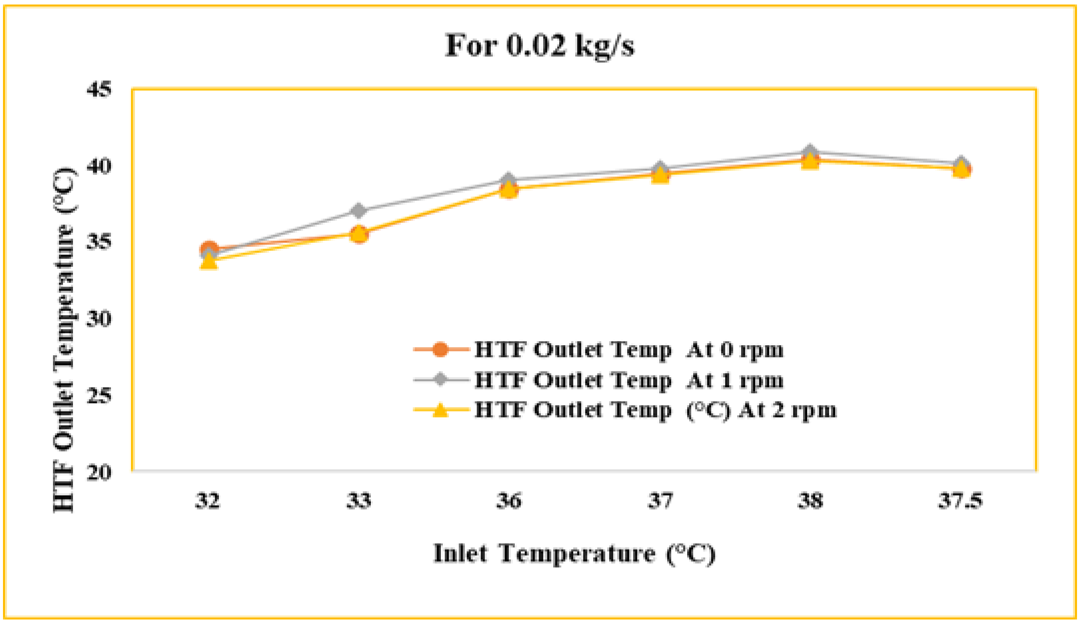


Fig.5 Effect of mass flow rate on HTF outlet temperature at different speeds

4.3 Effect of Rotation of The Tube on Surface Temperature

The investigation of the impacts of mass flow rates on the temperature distribution of the heat transfer fluid (HTF) along the absorber tube of a solar collector system, as seen in Figure 6, assists in shedding light on crucial thermal dynamics that are necessary for optimising the collection of solar thermal energy. This inquiry is centred on determining how the effectiveness of heat transfer mechanisms within the system is affected by variations in mass flow rates,

ranging from 0.01 kg/s to 0.02 kg/s, as well as the introduction of rotational dynamics at 1 rpm and 2 rpm, in comparison to a stationary configuration.

One of the most important findings from the research is that there was a significant drop in the surface temperature of the absorber tube when the HTF mass flow rate was increased substantially. The faster flow is responsible for this tendency, which may be attributed to the shortened contact time between the heat transfer fluid (HTF) and the inner surface of the absorbertube. This allows the HTF to absorb less heat, which in turn reduces the temperature at which itexits the absorber tube. The findings of Petela [18], who emphasised the relevance of flow rate modifications in optimising the efficiency of solar thermal collectors, are consistent with this approach. In addition, the examination of the stationary tube scenario, which displays temperature changes ranging from 320.69 K to 313.14 K, highlights the fact that heat transmission is a static process that is dependent on the thermal parameters of the tube material and the HTF.

Received: 16-01-2024 ***Revised: 12-02-2024*** ***Accepted: 07-03-2024***

When compared to this, the implementation of tube rotation results in the creation of a dynamic heat transmission mechanism. Enhanced thermal mixing is fostered within the HTF as a result of the rotation, which in turn reduces the creation of thermal boundary layers along the internal surface of the tube. According to Sarafraz and Hormozi [19] this impact improves the efficiency of heat transmission by encouraging a more uniform temperature distribution within the HTF. This effect is described in further detail further down. The rotating situations, which show a temperature range from 319.77 K to 310.84 K, highlight the influence that this phenomenon hason boosting the efficiency of heat exchange.

The findings gained from this study are contextualised even further by drawing analogies with previously published literary works. In his study of solar collectors with a parabolic trough, for instance, Zavoico [20] emphasised the significant part that fluid dynamics plays in influencing the efficiency of the collector. The findings of the current study on the influence of rotating speed on heat transfer efficiency are in agreement with Zavoico's focus on the importance of developingnovel techniques to improve heat transfer processes in solar thermal systems.

Furthermore, the observed drop in surface temperatures with greater mass flow rates and the inclusion of rotational dynamics makes a convincing argument for the possibility of these tacticsin enhancing the thermal performance of solar collector systems. This is because both of these factors have been shown to significantly reduce surface temperatures. The findings of Xu et al.[21], who explored the effect of fluid flow rates and rotation in boosting the heat transfer rates of solar receivers, lend credence to this conclusion. They suggested that such alterations might considerably increase the performance of the system.

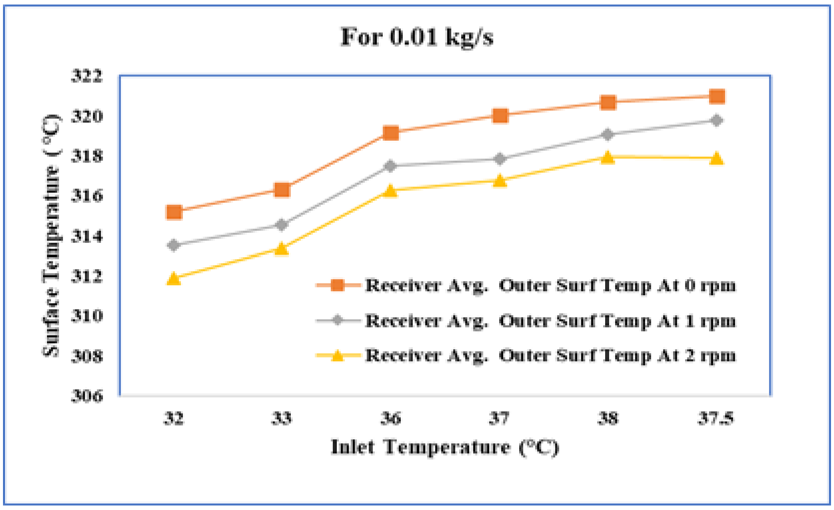
This investigation not only provides evidence that mass flow rates and rotational dynamics playa crucial role in maximising the thermal efficiency of solar collector systems, but it also contributes to the advancement of the conversation regarding efficient methods of thermal energycollecting. It is possible to acquire a thorough knowledge of the thermal behaviour of HTF in solar collectors by combining these findings with those of prior research. This opens the door forfuture thermal system simulations that are more accurate and applicable to real-world situations.

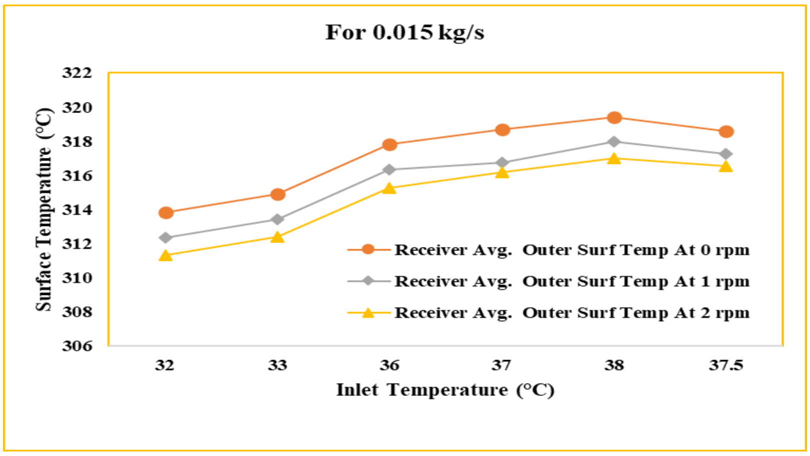
In Parabolic trough collectors, the Sun's radiations are concentrated at the bottom of the tube which is placed at the focal axis of the collector. Hence, there is a high temperature compared to the top surface of the tube. This high temperature results in the severe thermal stresses and could lead to failure of the tube. The rotation of the tube, besides improving the thermal efficiency, also helps in resolving the mentioned issue. The Fig.8 shows the temperature contours obtained for different speeds of the receiver tube along the length of the tube. The tube is given three different speeds such as 1, 2 and 3 rpm at constant mass flow rate of 0005 kg/s at 12:30 pm and simulation results are shown in the Fig. 7.

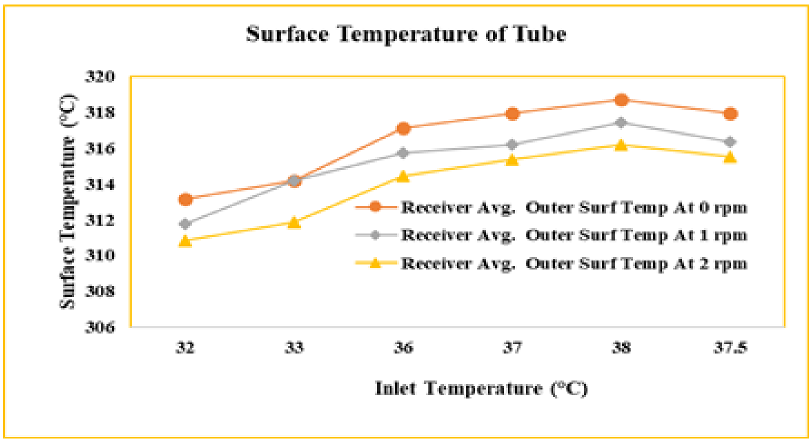
Power System Technology
ISSN:1000-3673

Received: 16-01-2024 *Revised: 12-02-2024* *Accepted: 07-03-2024*

It is observed that the minimum and maximum surface temperatures for 1 rpm, 2 rpm and 3 rpm of the tube are 317 K to 322 K, 314 K to 319 K and 316 K to 321 K respectively. As the speed of the tube increase, there is little time available for the heat transfer fluid to absorb the radiations falling on it and hence the surface temperature decrease.







Power System Technology
ISSN:1000-3673
Received: 16-01-2024 *Revised: 12-02-2024* *Accepted: 07-03-2024*

Fig.6 Effect of mass flow rate on surface temperature at different speeds

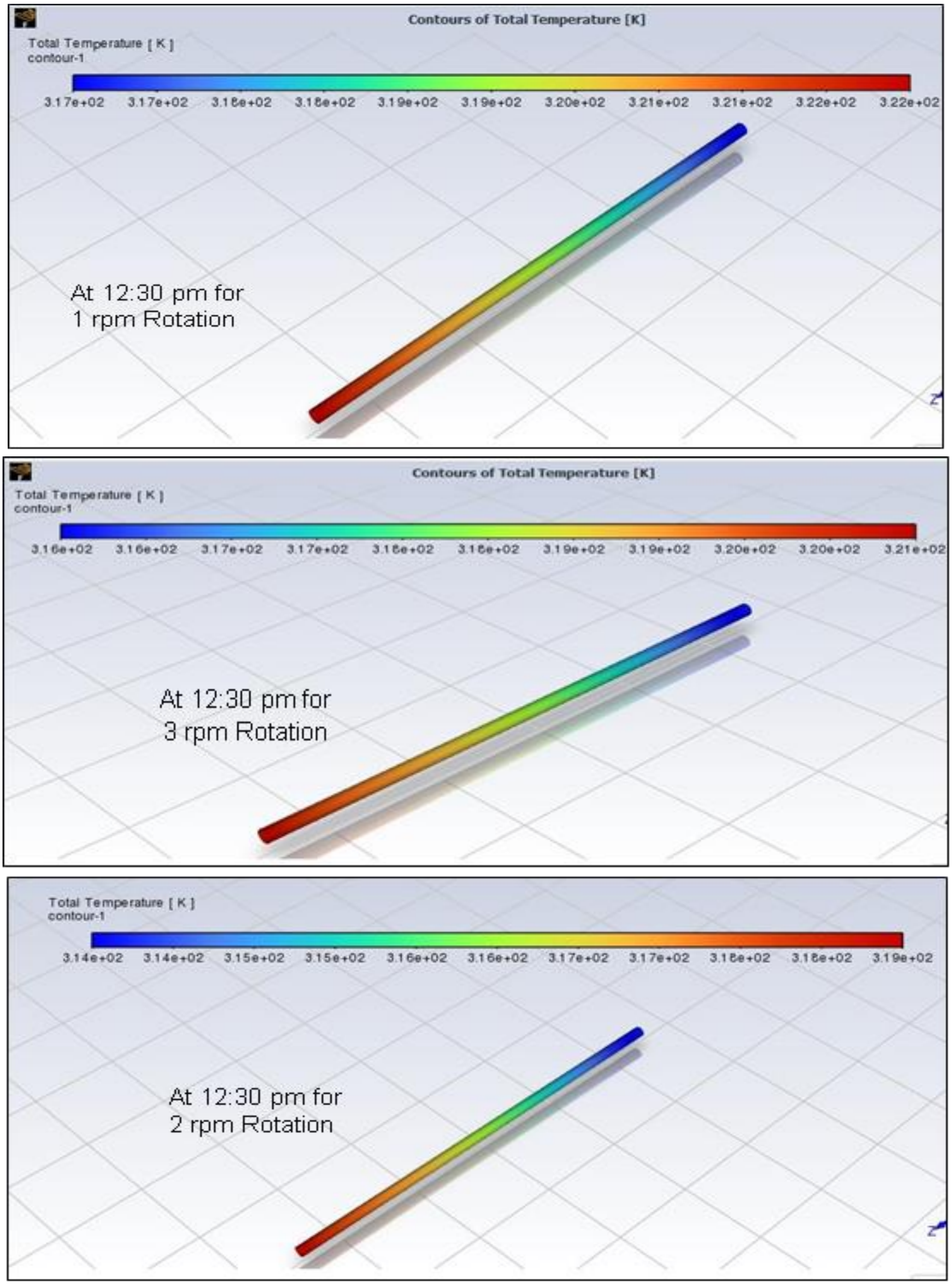


Fig.7 Contours of surface temperatures at different speeds

Power System Technology
ISSN:1000-3673
Received: 16-01-2024 Revised: 12-02-2024 Accepted: 07-03-2024

4.4 Effect Of Rotation of The Tube on Thermal Efficiency

The thermal efficiency of the solar collector is shown to be affected by the rotation of the absorber tube, as shown in Figure 8. When analysing the performance of the system, thermal efficiency is an essential metric to take into consideration. A number of factors, including the intake and outlet temperatures of the heat transfer fluid (HTF), the specific heat of the fluid, the amount of solar irradiation, and the aperture area of the collector, all play a role in determining the thermal efficiency of a solar collector. This study provides a detailed understanding of the connection between tube rotation and thermal efficiency. It shows that the efficiency remains relatively stable overall, although there is a minor decline at higher rotational speeds, which is linked to a fall in output temperature.

The decline in thermal efficiency observed at higher rotational speeds can be explained scientifically by analysing the dynamics of heat transport and fluid mechanics within the revolving tube. At increased velocities, the rotation promotes improved thermal mixing and potentially a more even distribution of temperature inside the heat transfer fluid (HTF).

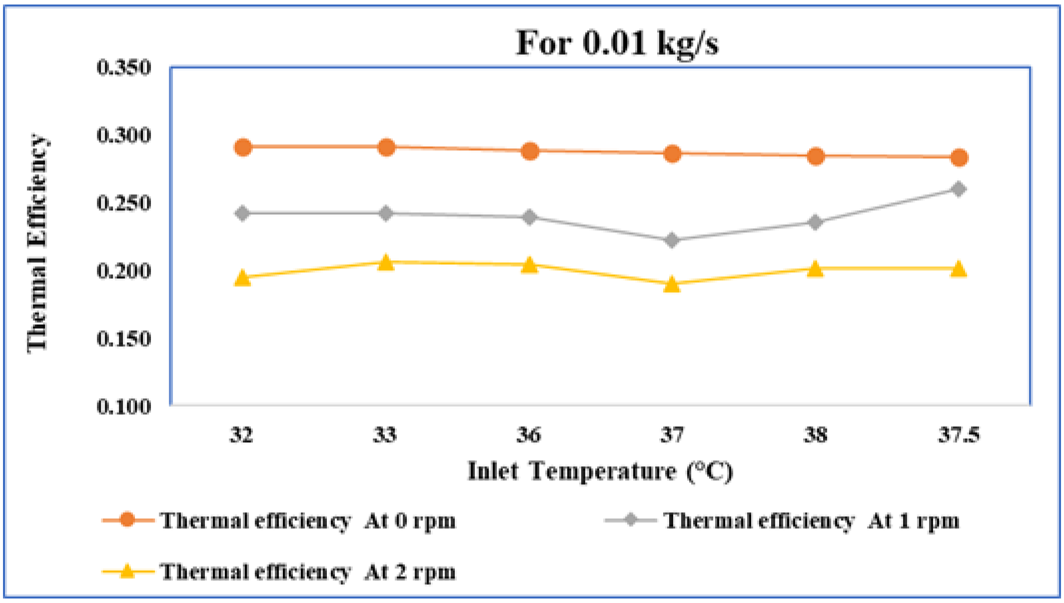
However,it also introduces centrifugal forces that can impact the pattern of fluid flow. These forces may result in a reduced efficiency of heat absorption from the surface of the solar collector to the fluid, particularly if the increased mixing does not offset the rapid migration of fluid particles away from the area of the tube surface where heat transfer is at its highest. Furthermore, the modest decline in output temperatures observed at higher speeds indicates that the fast flow of the heat transfer fluid (HTF) through the collector may not provide enough time for the fluid to absorb heat adequately. As a result, this slightly diminishes the overall thermal efficiency of thesystem.

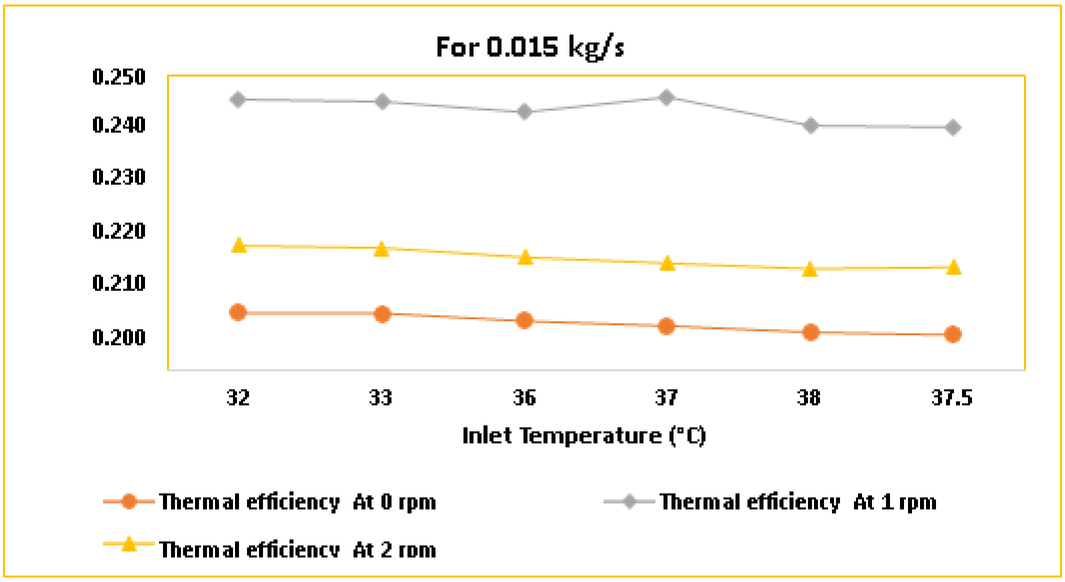
Additionally, the study emphasises the fluctuations in thermal efficiency across time, with the highest efficiency occurring during the morning hours in contrast to later in the day. The primary cause of this variance is the daily cycle of solar radiation and surrounding temperatures. During the morning, cooler ambient temperatures can increase the temperature difference between the heat transfer fluid (HTF) and the surrounding environment. This results in improved heat collection and less thermal losses. In contrast, as the day goes on and temperatures increase, the ability to transmit heat from the collector to the heat transfer fluid (HTF) declines. This results in reduced thermal efficiencies during the later hours of the day.

The highest efficiencies achieved were 29.2% at 11:00 AM with an inlet temperature of 32 °C for the stationary tube, and 27.5% for the rotational tube with an input temperature of 37.5 °C. These data suggest that rotation has positive impacts on heat distribution within the HTF due todynamic effects. However, its impact on thermal efficiency is complex and can be influenced by the interaction between improved mixing and the speed of heat transmission. The little difference in effectiveness between stationary and revolving tubes highlights the intricate interplay of fluid dynamics, thermal characteristics, and operational circumstances in maximising the performanceof solar collectors.

Power System Technology
ISSN:1000-3673
Received: 16-01-2024 *Revised: 12-02-2024* *Accepted: 07-03-2024*

The work provides unique insights into the intricate rotational effects, which have significant implications for the design and management of solar thermal systems. It emphasises the necessity of optimising rotational speed and comprehending diurnal changes to get maximum thermal efficiency.





Power System Technology
ISSN:1000-3673
Received: 16-01-2024 Revised: 12-02-2024 Accepted: 07-03-2024

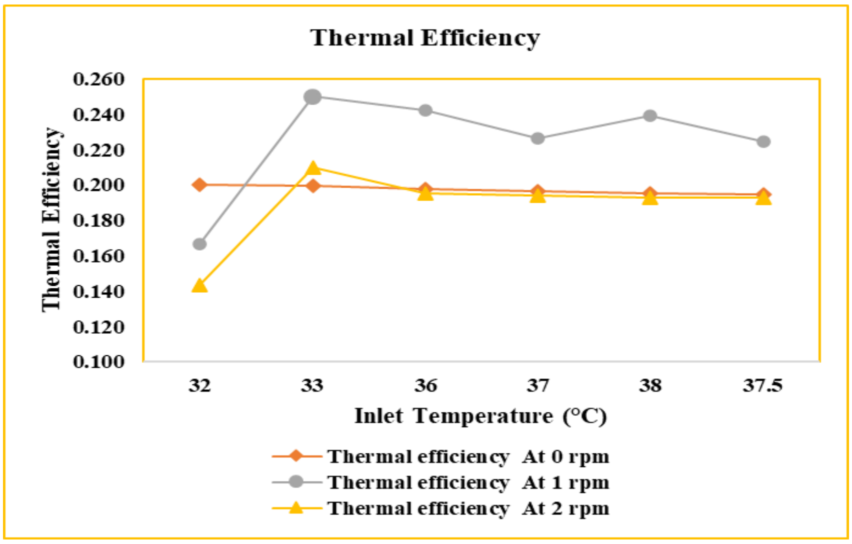


Fig.8 Effect of mass flow rate on thermal efficiency at different speeds

5. Conclusions

The effect of rotating the parabolic trough collector tube on its performance characteristics, such as outlet temperature, thermal efficiency, and surface temperature of the tube, was investigated through the use of computational fluid dynamics (CFD) simulations. Mass flow rates of 0.01 kg/s, 0.015 kg/s, and 0.02 kg/s, as well as inlet temperatures of 32°C, 33°C, 36°C, 37°C, 38°C, and 37.5°C, are the values for the tube. Listed below are the significant findings that emerged from the research.

1. The study demonstrates that the rotation of the tube has a notable impact on both the outlet temperature of the heat transfer fluid (HTF) and the distribution of surface temperatures along the absorber tube. Rotation specifically improves thermal mixing in the HTF, resulting in a more even distribution of temperature and potentially increasing heat transfer efficiency. This discovery suggests that the use of rotational dynamics has the ability to enhance the efficiency of solar collectors by optimising the thermal interactions within the system.
2. The analysis reveals a marginal decline in thermal efficiency as rotational speeds increase, which can be attributed to the intricate interaction between improved thermal mixing and the impact of centrifugal forces on fluid flow patterns. The intricate comprehension of how rotational speed affects efficiency emphasises the significance of meticulously choosing operational parameters to strike a balance between the advantages of enhanced mixing and potential decreases in heat absorption efficiency.
3. The study reveals notable fluctuations in thermal efficiency throughout the day, with the highest efficiencies observed during the morning hours. The variation is associated with fluctuations in solar irradiance and ambient temperature, highlighting the importance of designing and operating solar collector systems while considering environmental and temporal aspects in order to optimise efficiency throughout the day.

Received: 16-01-2024 *Revised: 12-02-2024* *Accepted: 07-03-2024*

4. The comparative examination of stationary and rotating tubes demonstrates that while rotation adds advantageous dynamics for heat dispersion, the overall effect on thermal efficiency is intricate and requires additional investigation. The disparities in effectiveness between fixed and spinning tubes imply that meticulous optimisation of rotational velocity and operational parameters could result in substantial enhancements in solar collector efficiency.

REFERENCES:

[1]. Kabir, E., Kumar, P., Kumar, S., Adelodun, A. A., & Kim, K. H. (2018). Solar energy: Potential and future prospects. Renewable and Sustainable Energy Reviews, 82, 894-900.

[2]. REN21. (2020). Renewables 2020 Global Status Report. Paris: REN21 Secretariat.

[3]. International Renewable Energy Agency (IRENA). (2019). Renewable Energy Benefits: Leveraging Local Capacity for Solar PV. Abu Dhabi: IRENA.

[4]. Kumar, D., & Kumar, S. (2018). Thermal performance of the solar parabolic trough collector at different flow rates: An experimental study. International Journal of Ambient Energy, 39(1), 93-102.

[5]. Norouzi, A. M., et al. (2020). Efficiency enhancement of the parabolic trough solar collector using the rotating absorber tube and nanoparticles. Renewable Energy, 145, 569-584.

[6]. Reddy, N. S., Subramanya, S. G., Vishwanath, K. C., Karthikeyan, M., & Kanchiraya, S. (2022). Enhancing the thermal efficiency of parabolic trough collector using rotary receiver tube. Sustainable Energy Technologies and Assessments, 51, 101941.

[7]. Mwesigye, A., & Meyer, J. P. (2017). Optimal thermal and thermodynamic performance of a solar parabolic trough receiver with different nanofluids and at different concentration ratios. Applied Energy, 193, 393-413.

[8]. Özcan, A., Devecioğlu, A. G., & Oruç, V. (2022). Experimental and numerical analysis of a parabolic trough solar collector for water heating application. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 44(2), 4184- 4203.

[9]. Jebasingh, V. K., Divya Johns, J., & Arunkumar, T. (2022). Assessment of circular and elliptical absorber tube in solar parabolic trough collector. International Journal of Ambient Energy, 43(1), 873-878.

[10]. Basha, S. K., & Behura, A. K. (2023). Investigation of thermal performance of a parabolic trough solar collector using different heat transfer fluids. Energy Sources, Part A: Recovery, Utilization, and Environmental Effects, 45(3), 7198-7221.

[11]. Allauddin, U., Rafique, M. U., Malik, O., Rashid, O., Waseem, A., King, P., & Almond, H. (2023). Investigation of the Thermo-hydraulic performance of a roughened Parabolic trough collector. Applied Thermal Engineering, 219, 119523.

Received: 16-01-2024 *Revised: 12-02-2024* *Accepted: 07-03-2024*

[12]. Ghasemi, S. E., & Ranjbar, A. A. (2017). Numerical thermal study on effect of porous rings on performance of solar parabolic trough collector. Applied Thermal Engineering, 118, 807-816.

[13]. Hebbal, U., Venkatesh, B. N., Swamy, G. M., & Soragaon, B. Numerical Analysis of Multielement airfoil with Computational Fluid Dynamics.

[14]. Raheem, A., Siddique, W., Farooqui, Z. H., Salameh, T., Haq, I. U., Waheed, K., & Qureshi, K. (2021). Performance evaluation of adding helical- screw tape inserts in parabolic solar trough collectors as a source of cleaner energy production. Journal of Cleaner Production, 297, 126628.

[15]. Bellos, E., Tzivanidis, C., Antonopoulos, K. A., & Gkinis, G. (2016). A review on the thermal performance and optimization of parabolic trough collectors. Renewable & Sustainable Energy Reviews, 62, 580-595.

[16]. Montes, M. J., Abánades, A., Martínez-Val, J. M., & Valdés, M. (2015). Optimization of parabolic trough collector designs. Solar Energy, 118, 280-290. [17]. Zhang, H., Baeyens, J., Degrève, J., & Cacères, G. (2017). Concentrated solar power plants: Review and design methodology. Renewable and Sustainable Energy Reviews, 22, 466-481.

[18]. Petela, R. (2003). Optimum parameters of solar thermal collectors. Solar Energy, 74(6), 469-480.

[19]. Sarafraz, M. M., & Hormozi, F. (2014). Experimental investigation on heat transfer augmentation of a mini double-pipe heat exchanger using Al2O3/water nanofluid. Applied Thermal Engineering, 62(2), 591-598.

[12]. Zavoico, A. B. (2001). Solar power tower design basis document, Sandia National Laboratories, Report SAND2001-2100.

[21]. Xu, B., Li, P., & Chan, C. L. (2016). Enhanced heat transfer in cylindrical solar water heaters with rotating collector. Energy Conversion and Management, 117, 398-405.