JOURNAL OF NANO- AND ELECTRONIC PHYSICS
Vol. **16** No 6, 06007(6pp) (2024)

ЖУРНАЛ НАНО- ТА ЕЛЕКТРОННОЇ ФІЗИКИ
Том **16** № 6, 06007(6cc) (2024)

REGULAR ARTICLE

Thermal Performance based Numerical Investigation on Nanofluid Applications with Solar Energy Systems

D. Kumar[1,*], V.V. Upadhyay[2], A. Punia[3], D.P. Singh[4], A.P. Srivastava[5], P.M. Pandian[6], A.K. Khan[7]

[1] *Chitkara Centre for Research and Development, Chitkara University, Himachal Pradesh, 174103, India*
[2] *Department of Mechanical Engineering, GLA University, Mathura- 281406, Uttar Pradesh, India*
[3] *Centre of Research Impact and Outcome, Chitkara University, Rajpura- 140417, Punjab, India*
[4] *Department of Mechanical Engineering, Graphic Era Deemed to be University, Dehradun, Uttarakhand, India*
[5] *Lloyd Institute of Engineering & Technology, Greater Noida, India*
[6] *Department of Chemistry, Saveetha Engineering College, Thandalam, Chennai, Tamil Nadu, India*
[7] *Lloyd Law College, Greater Noida, India*

(Received 28 August 2024; revised manuscript received 21 December 2024; published online 23 December 2024)

Utilizing solar radiation for thermal purposes is a common practice with flat plate solar collectors (FPSCs), but their thermal efficiency is lower. Using it might be one way to fix this problem of nanofluids as working fluids in FPSCs, which have the potential to improve energy-collecting capacities. A new method for measuring the thermal inertia of the various components of glass, trapped air, absorber and nanofluid are the components of FPSC that use nanotechnology has been developed and tested in this work. Water and Al_2O_3 nanoparticles at 1%, 2% and 3% volumetric concentrations are considered in the study. In this study, thermo physical characteristics are examined at heat transfer fluid (HTF) mass different flow rates (0.004 – 0.06 kg/s). According to the findings, in May, the greatest rise in outlet temperature can reach 7.22% under certain circumstances (0.004 kg/s, 3% volumetric concentration). Potential uses for nanofluid-based FPSC are illuminated by this computational analysis, which offers important insights into their thermal performance. The research helps to fill gaps in knowledge of nanofluid dynamics and points the way for future work to maximize the effectiveness of FPSCs in the long-term use of solar power. Importantly, at lower flow rates, nanofluids can improve the FPSCs' thermal efficiency; nevertheless, at a certain point, effectively, the base fluid is transformed into the working fluid. The current study determined that 0.016 kg/s is the essential flow rate.

Keywords: Flat Plate Solar Collectors (FPSCs), Solar Radiation, Nanofluid.

DOI: 10.21272/jnep.16(6).06007 PACS numbers: 47.11. – j, 92.60.Vb

1. INTRODUCTION

The solar electricity concentrated solar power (CSP) has the upper hand in promising future applications. One kind of CSP mechanism that can be used in moderate-temperature environments without requiring a significant initial investment is the linear Fresnel reflector (LFR) system [1]. The cheaper price and wind load could be the result of LFR's planer segmented main mirrors close to the ground. Furthermore, there is a decreased chance of operant liquid leakage with LFR. This is because the LFR receiver remains stationary during the process while the major reflectors rotate independently [2]. LFR has found widespread use in a variety of industrial processes, including drying vegetables, producing electricity and desalination. Hybrid nano liquids are used to increase the rate of a combination of base liquids with nano-scaled polymeric, metallic or non-metallic power for heat transfer in a range of applications [3]. A large body of literature provides computational and empirical evidence that hybrid nano liquids have a higher heat transfer rate than pure liquids. Nanofluids were first characterized by researchers as a mixture of nano-powders and regular liquids and Nanoliquids' overall potential environmental benefit [4]. To guarantee that nano liquids have a good environmental impact on renewable systems, they emphasized areas, which might address these concerns. The avoidance cell's higher temperature is a critical problem that leads to severe heat stress, a shorter lifespan and looking at the difficulties in making nanoliquids available for purchase [5]. When it came to effectively using nanoliquids in the commercial sector, found that consistency over the long period was the most important factor. The heat exchange mechanism to work better and need to make sure the turbulator components is sensible. Enhancing the disruption of the stream border layer and increasing the turbulence of liquids

* Correspondence e-mail: deepak.pec94@gmail.com

Cite this article as: D. Kumar et al., *J. Nano- Electron. Phys.* 16 No 6, 06007 (2024) https://doi.org/10.21272/jnep.16(6).06007

near the wall are both possible with their help. Another benefit of using nanoliquids as the operating fluid in a thermal exchange mechanism is that the turbulator components can prevent the deposition of particles [6]. The device with two height spacing produced the most significant thermal convective development. With each main mirror positioned as a separate concentrator, they achieved optically identical results while enhancing the mechanism's optical efficiency [7]. It became clear to them that the calculation of the useful heat power is crucial. Despite this, they observed that the catoptrics-subset model exhibits a robust form requiring fewer spinning sections. To redirect the sun's rays that had been reflected by the primary reflector to the focal line, they included secondary concentrators in the device [8-9].

The rest of the paper is divided into sections. The Related works of the paper is denoted in section 2. Section 3 shows the materials, procedures and approaches. Section 4 displays the output result analysis together with the discussion. Section 5 shows the conclusion of the paper.

2. RELATED REVIEW

The study [10] examined the flow of hybrid nanofluids across porous media was studied quantitatively in the study. A circular elastic surface was traversed by a water-based hybrid nanofluid and the flow of electrically conducting incompressible water. Because the produced magnetic field has a negligible magnetic Reynolds number, external magnetic fields do not affect it. The article [11] suggested using of mono nanofluids, which had better heat transfer qualities than traditional fluids, as working fluids in solar thermal systems has grown in popularity in recent years. Examining how sheet-and-tube photovoltaic systems function while using hybrid and mono nanofluids as opposed to water is the primary goal of the research. The study [12] examined the models and used them to analyze the flow properties and heat transfer behavior. Afterward, the effects of the layer's location, characteristics and Nanoparticles' influence on collector efficiency were examined. The study [13] suggested the Parabolic Dish Solar Collector (PDSC) concentrated light entering in an absorber chamber, through which a fluid was forced to flow. Across it to heat a heat transfers fluid. Enhancing their efficiency was crucial due to their wide variety of applications. The study [14] improved heat transfers in free, mixed convection and forced using nanofluids in different collector shapes in the presence of transitional, turbulent and laminar flows the subject of several numerical investigations, which were comprehensively reviewed in the work. The study [15] investigated the efficiency of a photovoltaic thermal system (PVT/TE) that incorporated a thermoelectric-producing module the research made use of a computerized framework in three dimensions. The paper [16] presented the results of a numerical investigation on nanofluid-powered solar ponds with a single glazing. The standard shallow-type solar pond was used for the experiment, with nanofluids of aluminum oxide and water can have concentrations ranging from zero to one-hundredth of a percent by volume. To verify the numerical findings, the standard solar pond configuration was used. The study [17] investigated quantitatively how adding obstructions to a parabolic trough collector's (PTC) reception tube affects heat transfer about the apparatus's total thermal efficiency and its use in PTCs.

3. MATERIALS AND METHODS

To evaluate the FPSC with ne-HTF, four sample months (March, May, June and November) are selected for the studies. Monthly averages of daily weather observations serve as the basis for the definition of ambient temperature and transient solar irradiation. Using data obtained from six sources, this research tested the effectiveness of Al_2O_3-water nanofluids in FPSC. Various intelligent models are trained and their predicting abilities are evaluated using this very large experimental database.

3.1 The Flat Plate Solar Collector (FPSC) Model

A temporal FPSC model that is two-dimensional is examined. The problem's boundaries and design of front and side view models are shown in Figure 1. This work used computational methods to examine the unpredictable actions of FPSCs based on Al_2O_3-water nanofluids under various environmental variables along with particle volumetric concentration and mass transfer rate. To reduce the selected surface's radiation and conduction losses, a 3.2 mm thick clear glass cover is used. Because trapped air is see-through, this stops the surface of the absorber from releasing any heat from the surrounding environment. Smothering the absorber is the copper sheet and its outermost layer is coated in a dark tone to increase absorption to make it more selective. Underneath the copper sheet, there are copper tubes that re-circulate the fluid, transferring the absorber's usable heat to the working fluid. The surface of the absorber can have its heat removed using heat transfer fluid (HTF).

3.2 Dynamical Framework

Each part of the FPSC has its own set of energy balance Eq. (1), which is solved using an iterative approach. Very little of the sun's rays reached Earth because of convective heat loss to space and radioactive heat loss to space could reach the operating fluid enters via the outer absorbent plate on the outside of the glass cover.

$$\left(mc\frac{\partial s}{\partial s}\right)_h = \left(kA_d\frac{\partial s}{\partial w}\right)_h + J_{solar}\tau_h\alpha_h B_t - g_\infty B_t(S_h - S_\infty) - \varepsilon_h\sigma B_t\left(S_h^4 - S_{sky}^4\right) + \varepsilon_{abs}\sigma B_t\left(S_{abs}^4 - S_h^4\right) - g_{air}B_t \quad (1)$$

To find the glass's surface convective HT coefficient about the wind speed, the following Eq. (2) is used.

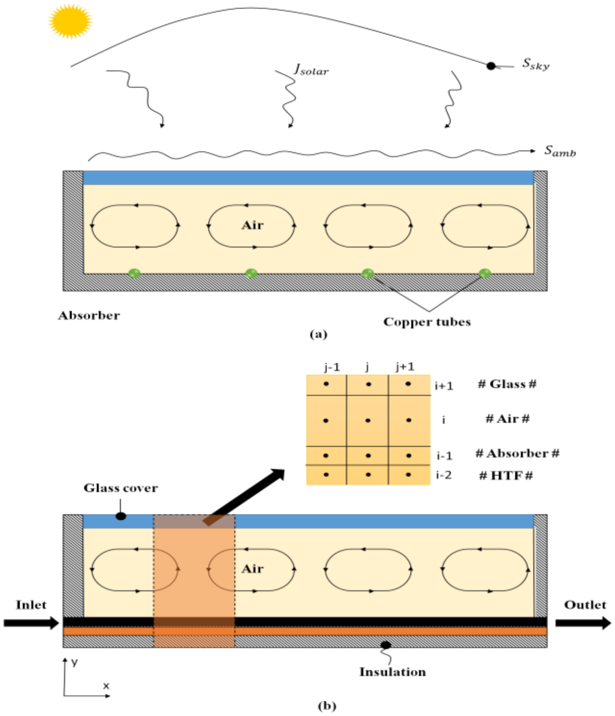

Fig. 1 – FPSE Model

$$g_{\infty} = 3.9u_{wind} + 5.62 \quad (2)$$

When u_{wind} = 3 m/s is the wind speed.

$$S_{sky} = 0.0552S_{\infty}^{1.5} \quad (3)$$

For a particular control amount of air that is trapped above the covering of glass and absorbent, the energy balance Eq. (4) is represented as:

$$\left(mc\frac{\partial S}{\partial s}\right)_{air} = \left(lB_d\frac{\partial S}{\partial w}\right)_{air} + g_{air}B_t(S_h - S_{air}) + g_{air}B_t(S_{abs} - S_{air}) \quad (4)$$

Where g_{air} corresponds to the air thermal transfer of heat ratio that is caught through the plate that absorbs and covers glass.

$$Nu_{air} = \left[0.06 - 0.017\left(\frac{\theta}{90}\right)\right]Gr^{1/3} \quad (5)$$

In which h denotes the collector's angle of inclination. $\theta = 45°$ is the definition of the angle of inclination. However, the nomenclature provides the concept of a dimensionless Gr number.

$$\left(mc\frac{\partial S}{\partial s}\right)_{abs} = \left(lB_d\frac{\partial S}{\partial w}\right)_{abs} + J_{solar}\tau_{abs}\alpha_{abs}B_t - g_{gse}B_t(S_{abs} - S_{gse}) + \varepsilon\sigma B_t(S_h^4 - S_{abs}^4) - g_{air}B_t(S_{abs} - S_{air}) \quad (6)$$

Here mc is the energy Eq. (7) for the water in the riser tubes about the quantity under control:

$$\left(mc\frac{\partial S}{\partial s}\right)_{gse} = \left(lB_d\frac{\partial S}{\partial w}\right)_{gse} + g_{gse}B_t(S_{gse} - S_{abs}) \quad (7)$$

One can figure out HTF's convective transfer of heat ratio by using the correlation. The components of the absorber plate and the surrounding air thermo physical characteristics are detailed in Table 1.

Table 1 – Thermal characteristics of FPSC components

Material	**Glass**	**Air**	**Absorber**
Specific heat, c(J/kg K)	751	1008	386
Density, $\rho\left(\frac{kg}{m^3}\right)$	2501	1.615	8933
Thermal conductivity, k(W/m K)	1.5	0.04	402

In this study, three different ne-HTFs that are soluble in water are examined. The density and specific heat Eq. (8, 9) are used to determine the values for ne-HTFs coupled with the laws of classical mixture.

$$d_{me} = \frac{\phi_o(\rho d)_o + (1-\phi_o)(\rho d)_e}{(1-\phi_o)\rho_e + \phi_o\rho_o} \quad (8)$$

$$\rho_{me} = (1-\phi_o)\rho_e + \phi_o\rho_o \quad (9)$$

Furthermore, the parameters of working fluid viscosity and thermal conductivity are set according to the actual data, rather than using theoretical models. Three different volume fractions of Al_2O_3 1%, 2% and 3% are used in the investigation, with distilled water serving as the base fluid shown in Table 2.

Table 2 – Working fluid physical properties

Material	Water	$Al_2O_3 - H_2O$ (1% vol.)	$Al_2O_3 - H_2O$ (2% vol.)	$Al_2O_3 - H_2O$ (3% vol.)
Specific heat, c	4181	4060.9	3947.7	3840.9
Density, $\rho\left(\frac{kg}{m^3}\right)$	1001	1023.8	1051.9	1078.9
Thermal conductivity, k (W/m K)	0.577	0.621	0.635	0.656
Viscosity, μ(mPa s)	1.01	1.13	1.29	1.58
Pr (-)	7.27	7.34	7.95	9.18

3.3 Data Compression

The following is the Eq. (10) for determining the flat plate solar collector's thermal efficiency:

$$\eta = \frac{r_{useful}}{J_{solar}B_t + X_{pump}} = \frac{mc(S_{out} - S_{in})}{J_{solar}B_t + X_{pump}} \quad (10)$$

When the power required pumping the fluid is determined by the following Eq. (11):

$$X_{pump} = \left(\frac{n}{\rho}\right)\Delta O \quad (11)$$

The pressure drop for a straight, smooth tube can be calculated by drawing the energy balance over the inlet and outlet portions and solving for DP, where $\Delta O = e\left(\frac{K}{U}\right)\left(\frac{\rho U^2}{2}\right)$. Here is the Eq. (12) that gives the rate of exergy gained:

$$Ex = mc\left[S_{out} - S_{in} - S_{\infty}In\left(\frac{S_{out}}{S_{in}}\right)\right] + (ndS)_{abs}\frac{\partial}{\partial s}\Big(1 -$$

$$\left.\frac{S_\infty}{s_{abs}}\right) + (ndS)_{air}\frac{\partial}{\partial s}\left(1-\frac{S_\infty}{S_{air}}\right) + (ndS)_h\frac{\partial}{\partial s}\left(1-\frac{S_\infty}{S_h}\right) \quad (12)$$

A definition of exergy efficiency is:

$$\varepsilon_w = \frac{Ex}{B_t\left[J_{solar}\left(1-\frac{S_b}{S_t}\right)\right]} \quad (13)$$

Where S_t is the apparent sunlight temperature, which is around S_t (3/4) $S^*$and serves as an exergy source. S^* Represents the sun's apparent black body temperature, which is about sun (≈ 6000 K).

4. RESULT AND DISCUSSION

Designed for use in ne-HTF FPSC evaluation, four sample months March, May, June and November are selected for the studies. It is expected to ensure the FPSC continues to receive the operating fluids at a constant temperature all day long at 25°C. The basic fluid is water that takes into account ne-HTFs at 1%, 2% and 3% volume fractions with water. FPSC efficiency the working fluid's mass flow rate is crucial and the HTF mass flow rate is adjusted across a wide range, from 0.004 – 0.06 kg/s, to consider thermo physical qualities at different Reynolds numbers.

4.1 Variation in Outflow Temperature as a Function of Weather

Sunlight hitting the surface, the climate at the HTF's outlet and usable heat changed over four months in Fig. 2. The same image depicts the residual of the system's energy balance at each time step. At each time step, the projected outcomes reasonably meet the first rule of thermodynamics, since the largest divergence from the energy balance is less than 0.8%. The results of this first investigation show that the maximum temperature at which the ne-HTF can be discharged is between 32.9 and 36.7 degrees Celsius. The average temperatures at which the HTF's outlets are open throughout the spring, summer and autumn (i.e., the months of June, May and November) are quite similar. In terms of the average temperatures at the outflow, the difference is less than 1.5 degrees Celsius. With insolation periods of about 13 hours in June, 14 hours in May and 11 hours in November. As things stand, the collector can maintain a constant 30 degrees Celsius for the ne-HTF all year round. As things are, the technology isn't suitable for anything other than providing home hot water. Both the usable heat and the HTF's output temperature are strongly affected by how fast the ne-HTF is flowing through the system. The right working conditions for the actual application can be determined by a design engineer by considering the datasets, which can be experimental or numerical, for the FPSC. An extensive analysis of how various operational and design factors affect the output temperature and usable heat is provided in the following sections.

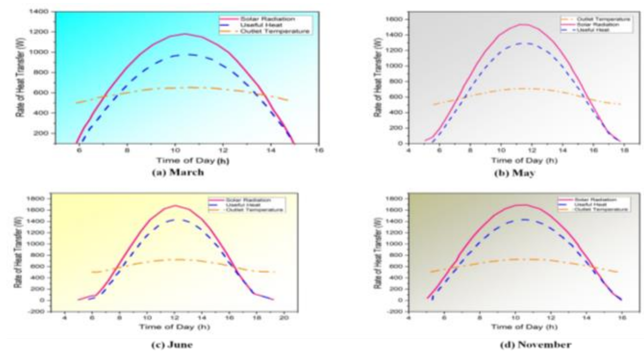

Fig. 2 – FPSC outflow temperature and useable heat

4.2 Influence of Fluid Used

The impact of November affected the efficiency of FPSCs, as do the working fluid and mass flow rates and a well-known property of fluids is that their thermal resistance decreases with increasing fluid Re number when passing heat via narrow tubes. That is, efficiency is type-independent; it grows with mass flow rate. Curiously, at lower mass flow rates, the FPSC containing ne-HTF outperforms pure water in terms of thermal efficiency. Increasing the concentration of nanoparticles inside the ne-HTF improves efficiency at flow rates lower than 0.016 kg/s. Table 2 displays that adding nanoparticles increases the viscosity of ne-HTF and hurts specific heat with increasing nanoparticle concentration. Obtaining the turbulent flow regime requires critical mass flow rates, which vary between working fluids because nanoparticle addition changes their thermo-physical characteristics. A mid storm, the convective transfer of heat ratios of Ne-HTFs is moderate and they are laminar at 0.016 kg/s. Thus, changing water improved performance and a shift from smooth to turbulent flow by about 10%, from 71% to 82%.

In turbulent environments, with flow rates greater than 0.016 kg/s, nanoparticle loading negatively impacts FPSC efficiency. Viscous losses rise with an increased rate of flow for working fluids that have been increased by nanotechnology. Though ne-HTF has better thermal conductivity, it cannot have a substantial effect at higher Reynolds numbers due to reduced relative values of convective and total thermal challenges over the FPSC. Nanofluids achieved the greatest achievement of 74.36% efficiency in May for laminar flow at 3% volume and 0.016 kg/s. Rather than solving for steady-state, the model takes thermal inertia into account for every FPSC part. Thermal inertia accounts for about 30% of the working fluid's contribution. While ne-HTFs work best in regimes of laminar flow, water that is thin and very hot is more efficient at higher flow rates. There is a four-month display of thermal efficiency for different flow rates in Fig. 2. Given the relationship between flow rate and HTF type, it is reasonable to assume that it has similar effects year-round. At lower flow rates, ne-HTF seems to improve daily average efficiency.

The operating fluids and mass flow rate impact

November FPSC performance as per the second law. The exergy efficiency of any mass flow rate increases, causing a decrease in HTF, possibly due to the impact and the effectiveness of exertion is diminished when nanoparticles are present. This occurs because, at greater mass flow rates, the exit temperatures of HTFs are rather constant. The exergy efficiency rises as the concentration of Al_2O_3 nanoparticles rises. Reports of similar conduct were made. An exergy efficiency of 3% was achieved using a velocity of 0.004 kg/s and an Al_2O_3 amount percentage could be increased to 7.13%.

5. CONCLUSION

This study shows nanofluids increase FPSC thermal efficiency. A novel method is proposed for analyzing the thermal inertia of nanofluid-based FPSC components such glass, trapped air, absorber and nanofluid. The study found considerable outlet temperature gains, notably in May, with the maximum rise of 7.22% under specific circumstances. The findings elucidate nanofluid-based FPSC dynamics and suggest thermal performance improvements. The threshold flow rate is 0.016 kg/s, suggesting nanofluids can increase FPSC thermal efficiency at lower flow rates. Due to its superior working qualities, the basic fluid replaces it beyond a certain point. The study improves nanofluid dynamics and informs FPSC long-term solar power use research. The critical flow rate is crucial for nanofluid-based FPSC system design and operation. Future research includes nanofluid composition optimization, nanoparticle material investigation and nanofluid-based FPSC stability along with practical application. Advances in computer modeling and experimental methods can help to understand these systems' complex interactions. This research can improve solar thermal energy system efficiency and sustainability, helping the globe switches to greener energy.

REFERENCES

1. A. Palacios, C. Barreneche, M.E. Navarro, Y. Ding, *Renewable Energy* **156**, 1244 (2020).
2. J. Jacob, A.K. Pandey, N. Abd Rahim, J. Selvaraj, M. Samykano, R. Saidur, V.V. Tyagi, *Journal of Energy Storage* **45**, 103369 (2022).
3. H. Adun, D. Kavaz, M. Dagbasi, *Journal of Cleaner Production* **328**, 129525 (2021).
4. A.H. Pordanjani, S. Aghakhani, M. Afrand, M. Sharifpur, J.P. Meyer, H. Xu, H.M. Ali, N. Karimi, G. Cheraghian, *Journal of Cleaner Production* **320**, 128573 (2021).
5. O. Mahian, E. Bellos, C.N. Markides, R.A. Taylor, A. Alagumalai, L. Yang, C. Qin, B.J. Lee, G. Ahmadi, M.R. Safaei, S. Wongwises, *Nano Energy* **86**, 106069 (2021).
6. J.E. Salhi, T. Zarrouk, A.A. Merrouni, M. Salhi, N. Salhi, *Journal of Energy Storage* **46**, 103813 (2022).
7. L. Wang, Z. Yuan, Y. Zhao, Z. Guo, *Journal of Thermal Science* **28**, 929 (2019).
8. A. Vouros, E. Mathioulakis, E. Papanicolaou, V. Belessiotis, *Renewable Energy* **156**, 68 (2020).
9. X. Li, G. Zeng, X. Lei, *Solar Energy Materials and Solar Cells*, **206**, 110323 (2020).
10. M.M. Bhatti, R. Ellahi, M.H. Doranehgard, *Journal of Molecular Liquids* **361**, 119655 (2022).
11. I. Karaaslan, T. Menlik, *Solar Energy* **224**, 1260 (2021).
12. M. Siavashi, M.V. Bozorg, M.H. Toosi, *Sustainable Energy Technologies and Assessments* **45**, 101179 (2021).
13. A.A. Alnaqi, J. Alsarraf, A.A. Al-Rashed, *Journal of the Taiwan Institute of Chemical Engineers* **124**, 238 (2021).
14. Y. Menni, A.J. Chamkha, G. Lorenzini, N. Kaid, H. Ameur, M. Bensafi, *Mathematical Modelling of Engineering Problems* **6** No 3, (2019).
15. A. Salari, A. Parcheforosh, A. Hakkaki-Fard, A. Amadeh, *Renewable Energy*, **153**, 1261 (2020).
16. M. Appadurai, E.F.I. Raj, I. Jenish, *Process Integration and Optimization for Sustainability* **6** No 1, 211 (2022).
17. T. Fahim, S. Laouedj, A. Abderrahmane, S. Alotaibi, O. Younis, H.M. Ali, *Nanomaterials* **12** No 3, 419 (2022).

Чисельне дослідження застосування нанофлюїдів у системах сонячної енергії на основі теплових характеристик

D. Kumar[1], V.V. Upadhyay[2], A. Punia[3], D.P. Singh[4], A.P. Srivastava[5], P.M. Pandian[6], A.K. Khan[7]

[1] *Chitkara Centre for Research and Development, Chitkara University, Himachal Pradesh, 174103, India*
[2] *Department of Mechanical Engineering, GLA University, Mathura- 281406, Uttar Pradesh, India*
[3] *Centre of Research Impact and Outcome, Chitkara University, Rajpura- 140417, Punjab, India*
[4] *Department of Mechanical Engineering, Graphic Era Deemed to be University, Dehradun, Uttarakhand, India*
[5] *Lloyd Institute of Engineering & Technology, Greater Noida, India*
[6] *Department of Chemistry, Saveetha Engineering College, Thandalam, Chennai, Tamil Nadu, India*
[7] *Lloyd Law College, Greater Noida, India*

Використання сонячного випромінювання для теплових цілей є звичайною практикою для плоских сонячних колекторів (FPSC), але їх теплова ефективність нижча. Його використання може бути одним із способів вирішити проблему нанофлюїдів як робочих рідин у FPSC, які мають потенціал для покращення здатності накопичувати енергію. У цій роботі було розроблено та випробувано новий метод вимірювання теплової інерції різних компонентів скла, захопленого повітря, поглинача та нанорідини, які є компонентами FPSC, які використовують нанотехнології. У дослідженні розглядаються вода та наночастинки Al_2O_3 в об'ємних концентраціях 1%, 2% та 3%. У цьому дослідженні теплофізичні характеристики досліджуються при різних витратах маси теплоносія (ТРТ) (0,004 – 0,06 кг/с). Згідно з отриманими даними, у травні найбільше підвищення температури на виході за певних умов може досягати 7,22% (0,004 кг/с, об'ємна концентрація 3%). Потенційне використання FPSC на основі нанофлюїдів висвітлено цим обчислювальним аналізом, який пропонує важливе розуміння їх теплових характеристик. Дослідження допомагає заповнити прогалини в знаннях динаміки нанофлюїдів і вказує шлях для майбутньої роботи, щоб максимізувати ефективність FPSC у довгостроковому використанні сонячної енергії. Важливо, що при меншій швидкості потоку нанофлюїди можуть підвищити теплову ефективність FPSC; проте в певний момент основна рідина фактично перетворюється на робочу. Поточне дослідження показало, що 0,016 кг/с є основною витратою.

Ключові слова: Плоскі пластинчасті сонячні колектори (FPSC), Сонячне випромінювання, Нанорідина.