The thermal efficiency of the heat receiving panels of solar collectors and CFD analysis of a screw duct collector

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Abstract. The designs of heat-receiving panels, which are the main absorbing elements of solar collectors, as well as new designs of heat-receiving panels of solar collectors, are considered and studied in order to organize production based on local raw materials. The CFD analysis of the solar spiral collector was performed using the SolidWorks software. The initial 3D drawing of the panel was developed and the project was developed in Flow Simulation and certain results were obtained. The obtained results were compared with the results of previously published articles. These results are detailed in the Results and Discussion section of the article.

1 Introduction

Solar thermal systems are at the forefront of renewable energy technology due to the increased focus on sustainable energy solutions worldwide [1–6]. Among them, solar collectors are essential for utilizing solar energy for a range of purposes, including industrial operations, space heating, and water heating. At the same time, even in solar fruit and vegetable dryers [7-11]. One important factor affecting solar collectors' functionality and sustainability as an energy source is their thermal efficiency. Raising the heat-receiving panels' thermal efficiency coefficient in solar collectors will greatly increase their overall efficacy, which will help save energy and lessen the need for fossil fuels [12–17]. New paths for improving the functionality and appearance of solar collectors have been made possible by recent developments in computational fluid dynamics, or CFD. Researchers can detect and reduce inefficiencies by using CFD analysis to simulate fluid flow and heat transfer in the collector in great detail. The screw duct collector, which uses a helical shape to enhance fluid dynamics and heat transfer rates, is one interesting invention in this area. This new method has demonstrated the ability to increase the uniformity of temperature distribution and decrease thermal losses, hence improving the thermal efficiency of solar collectors [1, 12-13, 16-20]. Research has indicated that thermal performance of solar collectors may be significantly enhanced by adjusting their design and flow patterns. To optimize heat

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absorption and reduce heat loss, for example, researchers have experimented with different absorber plate, fluid channel, and surface coating arrangements [21-22]. Using the concepts of increased surface area and turbulence to increase heat transfer rates, the incorporation of screw ducts into the collector design is a major advancement [23]. In this optimization process, computational fluid dynamics (CFD) analysis is a potent tool that offers insights that are difficult to gain with purely experimental approaches. CFD models are able to forecast the performance of various design alterations and operating situations by predicting the interactions between fluid flow and thermal gradients [24-25]. This method enables iterative testing and improvement, resulting in designs of solar collectors that are more effective and efficient.

2 Governing Equations

The governing equations for mass, momentum, and energy conservation are resolved by the CFD analysis:

Continuity Equation:

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho u) = 0 \tag{1}$$

Momentum Equation (Navier-Stokes):

$$\frac{\partial (\rho u)}{\partial t} + \nabla \cdot (\rho u u) = -\nabla p + \nabla \cdot (\mu \nabla u) + F \tag{2}$$

Energy Equation:

$$\frac{\partial (\rho E)}{\partial t} + \nabla \cdot \big(u(\rho E - p)\big) = \nabla \cdot (k \nabla T) + S \tag{3}$$

where ρ is the density, u is the velocity vector, p is the pressure, μ is the dynamic viscosity, E is the total energy, k is the thermal conductivity, T is the temperature, and S represents source terms [26].

3 Results and Discussion

The model of the heat exchange panel with a twisted channel was developed in SolidWorks 2020 with a 3D view. The project was developed and simulated in the Flow Simulation interface of the SolidWorks software. The simulation time was set to 3600 s and the interval was 20 s. The following results were obtained from the CFD analysis. The obtained results are considered for the conditions of Tashkent city on May 5, 2023. The boundary conditions for the city of Tashkent on this day were determined from the NASA website https://weather.com. Solar radiation was determined using SolmetricPVAnalyzer [www.solmetric.com]. Table 1 shows the following initial conditions:

Table 1. Finite elements used in the calculation.

Symbol	Measurement	Value	Units
$\dot{m}$	Mass flow	0,005	$\mathrm{kg/s}$
c_{water}	Relative specific heat	4200	$\mathrm{kg \cdot J^{-1} \cdot K^{-1}}$
c_{copper}	Relative specific heat	420	$\mathrm{kg \cdot J^{-1} \cdot K^{-1}}$
$T_{ambient}$	Ambient temperature	293,15	K

$I_{radiation}$	Solar radiation	800	W/m^2
P_A	Atmospheric pressure	101315	Pa
k_{copper}	Coefficient of thermal conductivity	401-391 [a*]	$W \cdot m^{-1} \cdot K^{-1}$
h_{∞}	Convective heat transfer coefficient for copper surface	15,6 [b*]	$W \cdot m^{-2} \cdot K^{-1}$

a* - http://al-vo.ru/teplotekhnika/koefficient-teplootdachi-poverhnost-vozduh.html

b* - http://thermalinfo.ru/svojstva-materialov/metally-i-splavy/svojstva-medi-plotnost-teploemkost-teploprovodnost

Based on the values in Table 1, the following results were determined (Fig. 1).

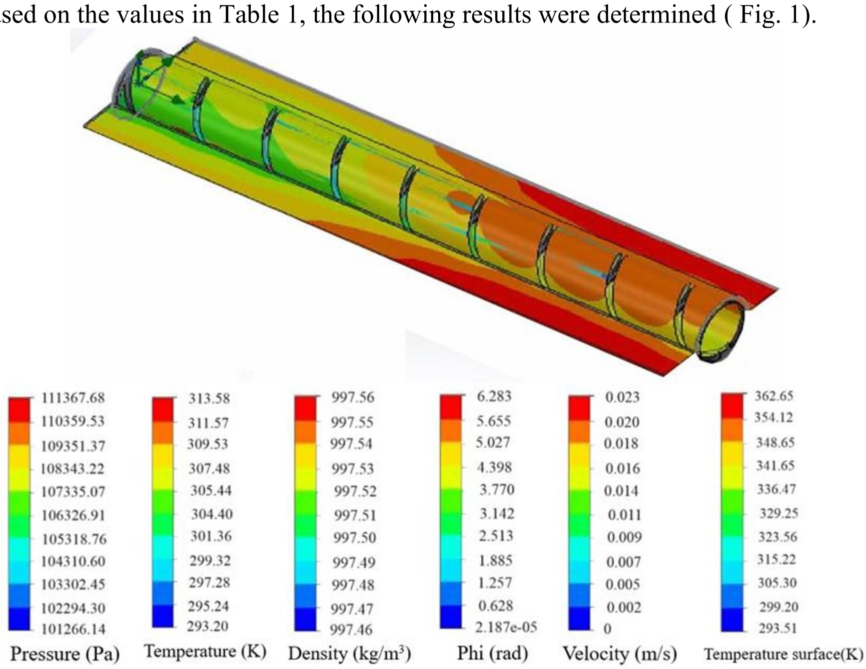

Fig.1. Pressure, temperature, density of water flowing through a pipe of a helical hot water collector, parameter of a spherical wave created by water, change in water velocity and pipe temperature.

The results in Fig. 1, Fig. 2 and Fig. 3 above apply to the hourly interval between the blue and red lines in Figure 4, with irradiances reaching around 800 W/m^2.

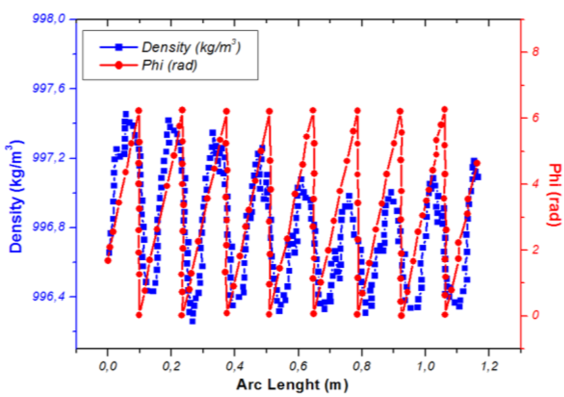

Fig.2. Harmonic variation of water density (in very small amounts, $\Delta\rho \leq 1$), variation of spherical wave parameter.

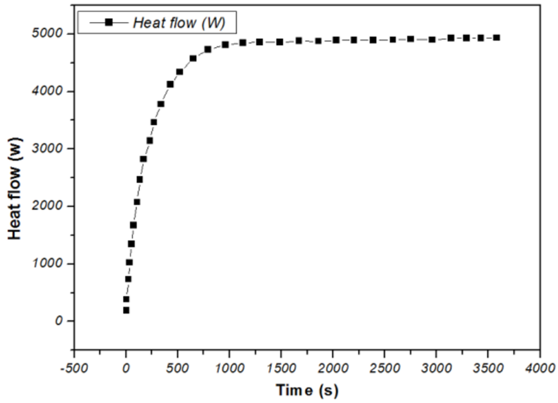

Fig.3. Variation of heat flow over time.

The obtained results were compared with the following article [27-28]. This article is experimental, a flat solar collector made with and without PCM was investigated, and it was considered appropriate to compare the obtained results with and without PCM in this article (Fig. 5). (PCM is a phase change material).

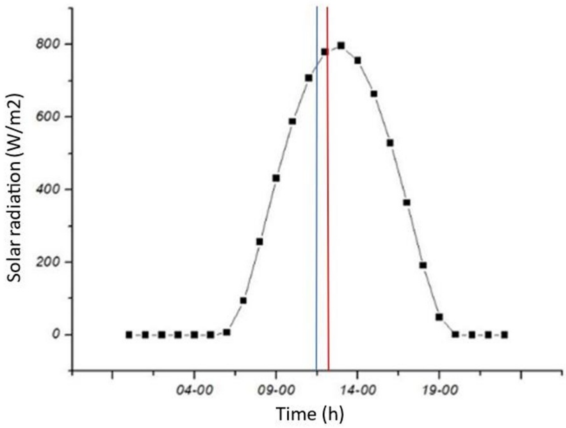

Fig.4. Change in the amount of solar radiation during the day.

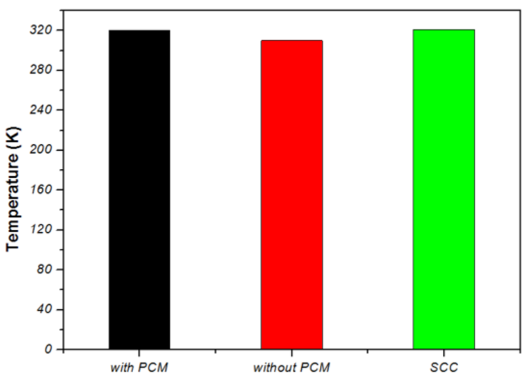

Fig. 5. The water heating temperatures of a collector with a phase change, a conventional flat collector and a screw channel collector (SCC) were compared.

In solar collectors, phase change materials (PCMs) are utilized to improve thermal energy storage and stable temperature. The substance absorbs a large amount of heat without rising in temperature as it changes phases, such as from solid to liquid. This heat may be released when the material solidifies.

Screw Channel Collectors (SCC) are more efficient at absorbing and using solar energy than flat-plate versions because they have a special channel design that improves fluid mixing and heat transfer efficiency.

4 Conclusions

The developed design of the heat-receiving panel with a twisted heat-dissipating channel for the coolant is advanced, relative to heat-receiving panels with smooth heat-dissipating channels (HDC). The heat transfer coefficient of heat-receiving panels with developed heat-dissipating channels increases up to several times and fluctuates from 2.0 to 3.0 times, where as a result of this, the efficiency of the heat-receiving panel of the solar collector and the efficiency of the collector as a whole increase. The temperature of the water supplied to the collector with a temperature of 20 ºC is heated and fluctuates to a temperature of 70 ºC - 90 ºC, which is acceptable for the consumer. The pressure inside the pipe changes insignificantly, the water temperature at the inlet changes from 293.15 K to 314 K, and when comparing this result with the experimental results from, it is found that the results are very close to each other. The heat-removing channel of the screw design has been tested for a short time, while the collector can heat water to 80-90 ºC if heated under direct sunlight. A CFD analysis of the solar spiral heat-receiving panel of the solar collector has been performed, which is made in the SolidWorks program, where the initial 3D drawing of the panel was developed and a project was developed in Flow Simulation and certain results were obtained. The results obtained were compared with the results of previously published articles.

References

1. N. Rakhimov, Kh. Akhmadov, A. Komilov, K. Rashidov, L. Aliyarova, E3S Web of Conferences, **498**, 01012 (2024)
2. Kh.S. Akhmadov, N.M. Nazarova, G.T. Zaripov, S.S. Muxlisov, E3S Web of Conferences (2024)
3. S.A. Boltaev, K.S. Akhmadov, U.R. Gapparov, M.K. Kurbanov, D.S. Saidov, Applied Solar Energy (English translation of Geliotekhnika), **58(1),** 116–120 (2022)
4. J.S. Akhatov, K.S. Ahmadov, Applied Solar Energy (English translation of Geliotekhnika), **58(6),** 889–894 (2022)
5. Kh.S. Akhmadov, N.M. Nazarova, A.R. Juraev and I.Y. Avezov, , E3S Web of Conf. **524** (2024)
6. Ahror Kayumov, Muslimjon Sobirov, Khurshid Musayev, E3S Web of Conferences **538**, 04015 (2024)
7. Z.S. Iskandarov, Applied Solar Energy (English translation of Geliotekhnika), **35** (1) 24-27
8. Z.S. Iskandarov, Applied Solar Energy (English translation of Geliotekhnika), **33** (2), 27-29
9. Z.S. Iskandarov, Geliotekhnika, **(2),** 89-96
10. Z.S. Iskandarov et al, Applied Solar Energy (English translation of Geliotekhnika), **47 (1),** 24-26

11. Iskandarov, Z.S., Soliev, A.S., Dzhuraev, I.I., Saidkhuzhaeva, S.S. Applied Solar Energy (English translation of Geliotekhnika), **40 (4)**, 10-13
12. J.S. Akhatov, Kh.S. Akhmadov, N.I. Juraboyev, UNEC J. Eng. Appl. Sci. **3(2)**, 5-13 (2023)
13. N.Z. Rakhimov, A.V. Novik, E.O. Germanovich, Kh.S. Akhmadov, S. A. Boltaev, S.I. Khamraev, CFD Analysis of Solar Water Desalination Plant with an External Camera, Energetika. Proc. CIS Higher Educ. Inst. and Power Eng. Assoc., **67 (4),** 377–387 (2024)
14. K.S. Akhmadov, S.A. Boltaev, T.S. Hojiev, J.H. Hamraev, S.H. Dustova, T.T. Safarov, Advancements in Solar Thermochemical Reactors: Integrating Experimental Validation and Modelling Techniques for Enhanced Performance and Scalability, **1**, 1 (2024)
15. T.S. Hojiev, K.H. Akhmadov, A.S. Halimov, J.S. Akhatov, Advancements in Solar Thermochemical Reactors for Sustainable Hydrogen Production. International Conference on Thermal Engineering, Volume 1, Issue 12024 15th International Conference on Thermal Engineering: Theory and Applications, ICTEA 2024 Tashkent 28 May 2024through 1 June 2024 Code 314379.
16. N.I. Juraboev, Kh.S. Akhmadov, A.A. Kuchkarov, A Comparative Study on Thermal Analysis of Latent Heat Energy Storage Systems Using Phase Change Materials, International Conference on Thermal Engineering, Volume 1, Issue 12024 15th International Conference on Thermal Engineering, Theory and Applications, ICTEA 2024 Tashkent 28 May 2024 through 1 June 2024, Code 314379.
17. J.S. Akhatov, N.I. Juraboev, Kh.S. Akhmadov, Enhancing Thermal Performance of Solar Parabolic Through Collector by using Corrugated Absorber Tube, International Conference on Thermal Engineering, **1**, 12024 (2024)
18. Kh.S. Akhmadov, N.I. Juraboev, S.A. Boltaev, J.S. Akhatov, CFD Analysis for Receiver Tube of Solar Parabolic Through Collector, (under review). https://10.21203/rs.3.rs-4617576/v1.
19. U. Sharopov et al, Exploring electron energy dependencies in the formation of surface charge on ZnO crystals, **227**, 113395 (2024)
20. O. Abdurakhmonov et al, Journal of Magnetism and Magnetic Materials, **600**, 172130 (2024)
21. S.A. Kalogirou, Progress in Energy and Combustion Science, **30(3)**, 231-295 (2004)
22. G.L. Morrison, I. Budihardjo, Solar Energy, **76(1-3)**, 135-140 (2004)
23. E. Zambolin, D. Del Col, Solar Energy, **84(8),** 1382-1396 (2010)
24. G. Mohan, C. Balaji, Energy Conversion and Management, **52(10),** 3162-3168 (2011)
25. J. Facao, A.C. Oliveira, Energy, **35(10),** 3867-3874 (2010)
26. I.U. Shadmanov, Simulation and experimental studies of heat and moisture transfer processes during the storage and drying of heterogeneous porous products in open areas under solar influence, Fifteen International Conference on Thermal Engineering: Theory and Applications, 28 June, **1** (2024)
27. Mario Palacio, Anggie Rincon, Mauricio Carmona, Solar Energy **206**, 708–721(2020)
28. V.A. Sednin, R.S. Ignatovich, Proceedings of CIS Higher Education Institutions and Power Engineering Associations, **66(4)**, 354–373 (2023)