International Journal of Power and Energy Systems, Vol. 44, No. 10, 2024
An Open Access Paper

COMPARISON OF THE PERFORMANCE OF DIFFERENT SOLAR RECEIVERS BASED ON THEIR GEOMETRY AND DIMENSIONS

Samane Karimi,* Amir Torabi,* Behzad Ghasemi,* and Afrasiab Raisi*

Abstract

In this study, the thermal performance of a solar spherical concentrator located in a sample city of Shahrekord, Iran, with different cavity receivers has been investigated. For this purpose, various receivers, such as disk, hemisphere, incomplete sphere, cylindrical, conical, and spherical receivers with different sizes have been simulated. The receivers are located at the focal point of the concentrator. The amount of energy received by each receiver is calculated for various geometric sizes based on software calculations. Among the obtained results, the geometry configuration that had the highest efficiency was reported as the most appropriate condition, and then the location for the best performance of the most suitable thermally receivers in each type is found by changing the position of each receiver around the foci. A tubular heat exchanger with thermal oil as a working fluid is considered. Then, the effect of the diameter and pitch of heat transfer pipes on the temperature rise of the output working fluid is investigated by a three-dimensional CFD simulation, and then the best diameter and pitch of the pipe are calculated. Study results show that for a spherical concentrator, the highest absorption of solar energy is achieved by receivers with spherical, cone, cylindrical, and imperfect sphere geometry, respectively. The heat exchanger pipe with a 5 mm diameter and 20 loops have the best performance and can rise the temperature of thermal oil to 440 K. The geometries were drawn in CAD software and the analyses were done with Fluent software.

Key Words

Solar energy, spherical concentrator, cavity receiver, thermal analysis, CFD

* Shahrekord University, Faculty of Technology and Engineering, Rahbar Street, Sharekord, Iran; e-mail: s.karimi6485@gmail.com; {torabi, ghasemi, raisi}@sku.ac.ir
Corresponding author: Amir Torabi

Recommended by Partha Sarathi Subudhi
(DOI: 10.2316/J.2024.203-0491)

Abbreviations

Receiver height (mm)	L	Aperture area (mm^2)	A_a
Flow rate (m^3/s)	Q	Receiver thickness (mm)	d
Receiver radius (mm)	R	Diameter of receiving pipe (mm)	D
Environment temperature (C)	T_{amb}	Diameter of concentrator (mm)	D_{con}
Density (kg m^{-3})	ρ	Focal length (mm)	f
Dynamic viscosity (N s m^{-1})	μ	Acceleration of gravity (m s^{-2})	g
		Thermal conductivity (W $m^{-1}K^{-1}$)	k

1. Introduction

The sun is the most significant source of energy in the universe. Earth gets 170 trillion kWh of solar power. About 30 % of this energy is reflected in space, and less than half will be converted into thermal energy at a low temperature [1]. Solar energy is one alternative and renewable energy, which has a very high potential for placement in the energy basket, because the intensity of radiation in Iran is at a high level. In this technology, a concentrator focuses the solar radiation at its focal point to make a high-temperature region. The concentrator has two axes to follow the sun. Solar energy is concentrated in a device called a receiver located at the focal point of the concentrator [2]. Solar receivers are a special type of heat exchangers that convert solar radiation energy into thermal energy. Due to the energy conversion, it can be said that the most important part of the solar system is its receiver. The receiver absorbs the solar energy and transfers it to a working fluid. Thermal energy can be delivered to a heat engine.

Potential control strategies for an impinging receiver-based dish-Brayton system have been presented for protecting the key components from the risks of overheating when the solar irradiation exceeds its design value. A rope-pulley shading device is developed for controlling the shading area in the centre of the dish, and the change of the inlet temperature is achieved by applying a bypass at the cold side of the recuperator for reducing the heat transfer rate. Both control strategies can manage the peak temperature on the absorber surface within 1,030°C with an outlet temperature fluctuation between -4.1 and 15.1°C. Furthermore, the temperature differences on the absorber surface are between 137.1°C and 163.8°C [3].

The proper design of the cavity receiver geometry to achieve high thermal performance is a key step in optimising the solar concentrator dish system. Many studies have been conducted on cavity receiver design [4]–[12]. In the selection of cavity receivers, in addition to the efficiency of the receiver, the possibility of construction should also be considered. Bellos *et al.* [13] investigated the cylindrical, rectangular, spherical, conical, and conical cylindrical shapes of receivers. The results of this study showed that the best geometry is conical cylinders and the most unsuitable geometry in terms of thermal efficiency is rectangular geometry. Loni *et al.* [14] also examined the thermal performance of cubic, cylindrical, and hemispherical cavities to select the best receiver geometry. They concluded that the most effective cavities for receiving solar energy are cubic, hemispherical, and finally cylindrical, respectively. Daabo *et al.* [15] compared the optical efficiency of three spherical, conical, and cylindrical geometries. The results of this study showed that the conical receiver absorbed more of the reflected flux energy than other forms. The optical efficiency at 85% adsorption reached 75/3%, 70/1%, and 71/5% for conical, spherical, and cylindrical shapes, respectively. Alvarado-Juárez *et al.* [16] analysed the numerical and experimental heat transfer of a solar receiver with a square hole in different Re numbers. Zou *et al.* [17] calculated the heat losses of the cylindrical cavities in different dimensions and concluded that by increasing the diameter of the cylinder, the heat loss increases significantly. In another study, Venkatachalam and Cheralathan [18] investigated the thermal performance of conical cavity receivers. In a paper, Lin *et al.* [19] investigated the power loss reduction, hybrid system reliability, voltage profile, the optimal size of distributed generation unit, and finally improvement of the construction cost of combined wind and solar power plants. To achieve this goal in this study, the IEEE standard 30-bus network is examined. The results of the system simulation show the reduction of total system losses after DG installation compared to the state without DG and the improvement of other variable values in this network. This loss index after installing DG in the desired bus has a reduction of about 200 kWh during the year and has a value equal to 126.42 kWh per year. Shaikh *et al.* [20] did an economic study of the hybrid network connected to the wind. The main objective of the study is to design a grid-connected hybrid (PV–wind) microgrid system using an NM facility. The meteorological data collected from NASA were placed into HOMER to evaluate the availability of RE sources. The load profile of the building was calculated to measure energy consumption for 24 h/day. The on-grid PV–wind hybrid system has been analysed before and after using the NM facility. The simulation results before NM have obtained NPC, COE, payback period, and CO2 as 125,158 $, 0.0700 $/kWh, 2.86 years and 20,175 kg/year, respectively. These same constraints by using the NM facility have been estimated as 50,521 $, 0.0238 $/kWh, 2.79 years, and 14,733 kg/years, respectively. The NM strategy is most preferable due to its feasible outcomes and accomplishment of distinct energy demands adequately. The tactics, availability, prospects, potential, and achievements of solar energy in India are discussed in this study by Prakash *et al.* [21]. The authors compared the barriers to solar energy acceptance and examined the topic of social dissimilarity from a broad theoretical perspective. The study states that solar energy could meet higher than 50% of the electricity sector demand in India in 2040. This study determined that solar energy incidence in India is around 5,000 trillion kWh (kilowatt-hours) each year. The solar energy accessible in a single year surpasses the energy output from the petroleum derivative. The average energy from the solar power plant is 0.30 kWh per m^2 equal to the 1,400–1,800 peak-rated capacity. India has many solar power facilities, making it one of the top producers of renewable energy power. Jahangiri *et al.* [22] in an article, a hybrid system has been evaluated based on solar energy in ten tourism target villages in Iran using HOMER software. This study investigated the design of the system with real and up-to-date data on equipment and fossil fuel prices taking into account transportation costs as well as a comprehensive study of energy-economic-environmental with electricity generation approach to the development of rural tourism. The results demonstrated that for the studied stations, the LCOE parameter was in the range of $0.615–0.722, the percentage of power supply by solar cells was in the range of 90–99%, and the prevention of pollutants was 33.9–277 kg/year. According to the results, Meymand village is the most suitable, and Mazichal village is the unsuitable station in the field of energy supply required by solar cells. The production pollution in the studied stations is mainly CO_2 and results from the operational phase of the project and its amount is 979.5 kg/year. In a study, Aldawoud *et al.* [23] developed a motorised curtain to cover the PV module surface during nights and dust storms. This system successfully reduced the impact of the condensation and the accumulation of soiling that could affect the performance of the PV panels and reduce their efficiencies. This study also experimentally investigates utilising a superhydrophobic (laboratory-prepared nano-coating) and a superhydrophobic coating on the PV module surface to reduce the impact of soiling. These two proposals could heavily reduce the frequency of cleaning the PV panel, therefore, reducing water consumption, particularly for areas with limited water supply. This study uses experimental data as a method to demonstrate the impact of dust, humidity, and nano-coating on the performance of PV panels. In addition, PVsyst was used to demonstrate and verify the soiling impact on the performance of PV modules.

As it is clear from the research records, different geometries with different properties and in different conditions can show different thermal behaviours. Therefore, in this research, the effect of geometric parameters and flow on the thermal performance of cavity receivers with different geometries has been investigated. To be able to choose the most suitable geometry from among the suggested geometries. In this study, the energy efficiency, exergy efficiency, and total heat loss coefficient of receivers were compared. The results of this study showed that by increasing the aspect ratio, thermal performance decreases. Among the received receivers, the receiver with an image ratio of 0.8 showed the highest performance. The mentioned studies show that the best geometry of receivers depends on the size of the system, site location, *etc.* In this study, by using meteorological data of Shahrekord city of Iran, various receiver geometries have been investigated. At first, the average reflectance of a spherical concentrator with a diameter of 4 m in different months and the optimal concentrating angle with the sun's rays have been calculated. The cavity receivers studied in this paper include cylindrical and conical at three different heights, spherical, and spherical–cylindrical geometries. The results of the mentioned geometries are compared and the most appropriate type of receivers in terms of the amount of solar radiation absorption is introduced. Finally, a tubular heat exchanger is designed to fit the cavity and also deliver as large an amount of concentrated energy to the working fluid. The purpose of this work is to investigate the thermal performance of the cavity receiver and to select the most suitable design.

2. Models

2.1 Radiation Model

The radiation data is the best source of information to estimate the average incidence of contact with the surface. During the scarcity of these data or data from adjacent locations with similar weather conditions, it is possible to use empirical relations to estimate the amount of radiation received from the Sun in an hour and even the radiation received in overcast weather. The results of radiation data for the Shahrekord are presented in Table 1 according to the meteorological data.

2.2 The Concentrator and the Receiving Model

Point-focusing concentrators generally use for a much higher density of radiation. Paraboloid and spherical reflectors are an example of these point-focus concentrators. Due to construction considerations, a spherical dish is generally used. The spherical solar collector is an attractive method to concentrate direct beam radiation. The receiver geometry is shown in Fig. 1. The receiver geometry was drawn with CAD software and analysed with Fluent software.

Table 1
Reflection Energy from the Concentrated Spherical Dish With the Reflection Coefficient One for Shahrekord

Month	Reflection (W)	Month	Reflection (W)
April	1,093/8	October	3,378/9
May	1,063/9	November	2,622/8
June	1,038/3	December	1,420/7
July	1,038/3	January	1,009/4
August	3,378/9	February	9,28/9
September	3,661/1	March	1,366/0

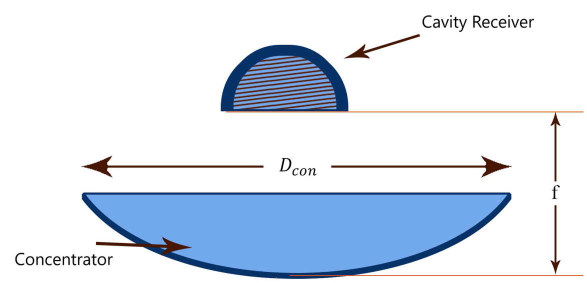

Figure 1. The geometry of the spherical concentrator dish.

Table 2
Solar System Characteristics

Parameter	Symbol	Amount
Diaphragm area	A_a	5×10^7mm^2
Concentrator diameter	D_{con}	4×10^3mm
Focal length	f	2×10^3mm
Receiver thickness	d	3×10^{-3}mm
Environment temperature	T_{amb}	21°C

The reflected rays are concentrated in the receiver, which is a heat exchanger that transfers the radiation energy received from the sun to the working fluid flowing in the tubes embedded in its wall. The receivers are made in different shapes.

The receivers examined in this study consist of a simple disc, spherical, incompressible spherical, and conical sections in three different dimensions. The shapes of the receivers are shown in Fig. 2 and the general parameters are listed in Table 2.

3. Mathematical Formulation

Reynolds number is defined as follows:

$$Re = \frac{\rho \mathrm{VD}}{\mu} = \frac{4\rho Q}{\pi \mathrm{D}\mu} \tag{1}$$

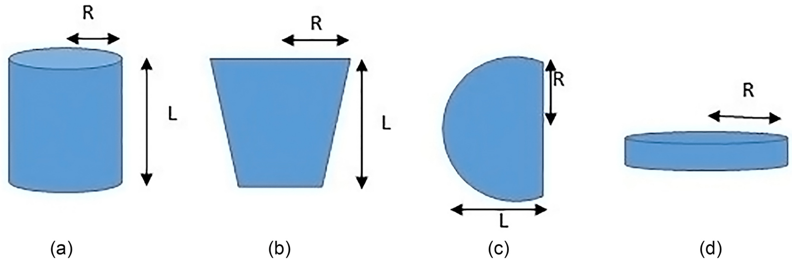

Figure 2. Receivers geometry: (a) disk; (b) sphere; (c) incomplete cone; and (d) cylinder.

Table 3
Comparison of Energy Absorbed by the Cylindrical Receiver of Reference [19] With Data Calculated With the Present Model

Focal length (mm)	Reference results [19] (W)	Results of the present study (W)	Percentage of difference
510	393	365	7/6%
540	370	345	7/2%
570	374	350	6/8%
600	335	315	6/3%

Continuity, momentum, and energy equations of nanofluid for laminar flow can be considered as follows:

$$\nabla . V = 0 \tag{2}$$

$$\rho \frac{\mathrm{dV}}{\mathrm{dt}} = \rho g - \nabla p + \mu \nabla^2 V \tag{3}$$

$$\rho c \frac{\mathrm{dT}}{\mathrm{dt}} = \nabla . (k \nabla T) \tag{4}$$

4. Rays Model Validation

The Trace pro software is used to calculate the solar radiation and estimate the concentrated solar heat flux in the receiver. For this purpose, the concentrator and receivers are first designed in CAD software. Then, the solar energy source is defined with the variable intensity obtained from meteorological radiation data, according to Table 1 is defined with the help of Trace Pro software, and the results of the collected heat flux are extracted from each receiving surface. To validate our results, the amount of energy absorbed by the cylindrical receiver of the system introduced by Liu *et al.* [24] was recalculated here and the difference is reported in Table 3. The results show that our model has an agreement with their data with less than an 8 percent difference.

5. Results

5.1 Choosing the Most Suitable Geometry Based on Radiation Absorption

With an absorption coefficient of 1 and its outer surfaces are insulated. To receive the maximum radiation, first, obtain the maximum amount of radiation by changing the distance between the receiver and the concentrator around the foci. The distance for the highest ray incidence is closer than the centre of the sphere and is about 1,900 mm from the concentrator. The ratio of heat flux absorption of each receiver per that of the disk receiver in terms of the radius of the receiver in September is presented in Table 4. The receiver is placed at the mentioned position.

The most suitable dimensions of the receivers studied according to heat absorption are given in Table 5.

5.2 Choosing the Most Suitable Geometry Based on the Heat Exchanger Surface of the Receiver

Receiver transfers the concentrated solar radiation heat flux to the working which flows through the coil located in the receiving chamber. The heat transfers to the fluid through the tubes embedded in the receiver. When the rays are concentrated in a very small area, the heat exchanger surface is not sufficient to have a considerable heat flux to the flow. The rays must have concentrated on a suitable area that provides a large enough area to reach the maximum temperature of working fluid. Therefore, to obtain a wider radiation distribution on the receiver surfaces, the distance between the receiver and the concentrator is changed so that the higher percentage of receiver heat exchanger area is opposite to the heat flux. Figure 3 shows the radiation distribution on the receiver surface in the form of an incomplete sphere receiver.

Heat exchanger tubes that deliver solar radiated heat to the working fluid also have an appropriate heat transfer surface. If the heat concentrates on a point where the heat flux is very high around this point, but most part of the heat exchanger surface will not receive any flux and its thermal performance will be negligible. According to the results presented in these plots as well as a similar study for the other receivers in this study, the optimal distance between the receivers and the concentrator is shown in Table 6. As shown in the table for some geometries cylinder,

Table 4
Comparison of Radiation Absorption of Different Receivers Compared to Disk Receivers in Terms of Radius in September

Radius (mm)	Cylinder	Cone 1	Cone 2	Cone 3	Sphere	In-Sphere
100	1/008	0/405	0/421	0/138	1/0.005	0/365
120	0/556	0/556	0/556	0/145	1/0.005	0/476
140	0/968	0/976	0/984	0/206	1/0.005	0/697
160	1/000	1/000	1/000	0/286	1/0.005	0/786
180	1/000	1/000	1/000	0/349	1/0.005	0/976
200	1/000	1/000	1/000	0/627	1/0.005	1/000
220	1/000	1/000	1/000	1/000	1/0.005	1/000

Table 5
The Suitable Geometric Dimensions of Receivers

In-Sphere	Sphere	Cone 3	Cone 2	Cone 1	Cylinder	Geometry
200	100	220	160	160	100	Radius (mm)
300	100	200	150	100	200	Height (mm)

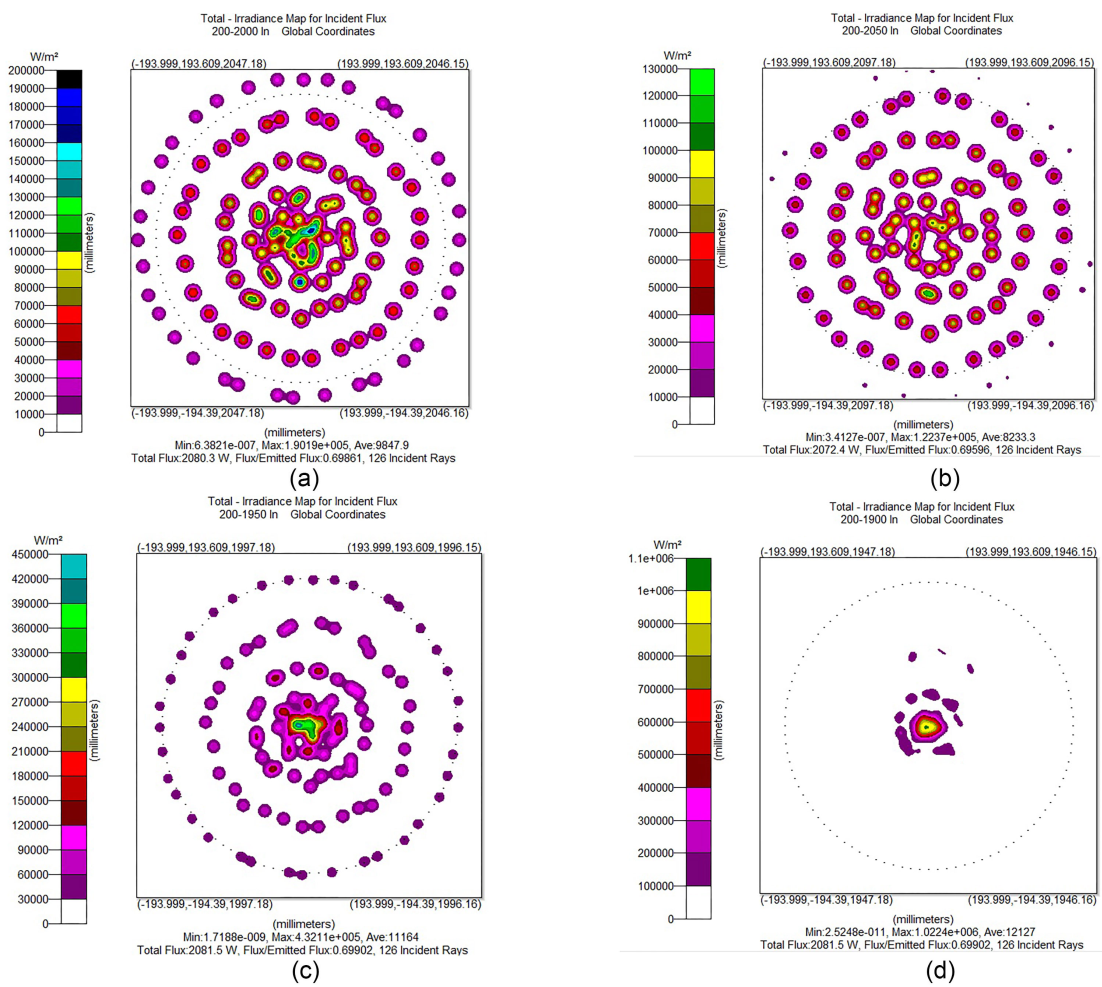

Figure 3. Incomplete sphere with a radius of 200 mm and different focal lengths: (a) distance of 1,900 mm from the concentrator with 0.4 % of the irradiated surface; (b) distance of 1,950 mm from the concentrator with 2.11% of the irradiated surface; (c) distance 2,000 mm from the concentrator with 9.39% of the irradiated surface; and (d) distance 2,050 mm from
AQ2 the concentrator with 7.18% of the irradiated surface.

Table 6
The Most Appropriate Position of the Receiver Relative to the Concentrator

Cone 3	Cone 2	Cone 1	Incomplete Sphere	Sphere	Cylinder	Disk	Geometry
1,700	1,750	1,850	2,000	1,900	1,700	1,950	Distance (mm)

Table 7
The Effect of Pipe Diameter and Number of Coils of Heat Exchanger on the Output Fluid Temperature at Re = 1,000

Outlet fluid temperature (K)	Number of rings	Pipe diameter (mm)	Outlet fluid temperature (K)	Number of rings	Pipe diameter (mm)
423/54	8	12	316/35	3	25
403/81	8	10	327/16	6	25
403/81	10	10	331/94	8	25
440/46	12	10	351/67	5	20
390/54	6	8	376/21	6	20
438/71	12	8	391/25	8	20
463/12	16	8	366/61	10	16
464/02	10	5	395/57	13	16
472/94	12	5	337/42	3	12
576/27	17	5	378/22	5	12

the receiver should become closer and for some other, *i.e.* incomplete sphere should go farther from the foci.

5.3 Choosing the Most Suitable Geometry Based on the Pipe Diameter and Pitch

Since the medium temperature is expected from a small concentrator, Therminol is considered as working fluid that has a practical maximum temperature of 393°C. The properties of Therminol can be found in several references, such as Heller [24]. The higher temperature of the working fluid output is considered as criterion for better performance of the system. To find the best of these conditions, we investigated the effect of pipe diameter and the number of loops of heat exchanger with a fixed Reynolds number for smooth flow. The other surface of the receiver is considered as insulation and the inner wall have a heat distribution obtained in the previous section. The results of this study are shown in Table 7.

The above results show that with a constant diameter, the outlet temperature increases by the increase in the number of rings. The highest temperature of the working fluid outlet occurs in the condition of 5 mm diameter with 17 rings. Also, reducing the diameter of the receiver improves the output results.

Increasing the number of receiving rings will lead to an increase in the length of the flow-carrying tube and an increase in the heat transfer time, so the fluid inside the tube will have a chance to absorb more heat.

5.4 Reynolds Number Effect

The higher temperature of the working fluid output means improving the performance of the designed system. To find the best condition, the appropriate flow regime and the most suitable Reynolds number is the next step. For this purpose, we change the speed of the flow entering the coil and so the Reynolds number, then check the temperature of the fluid flowing from it. The results related to the outlet temperature are given in Fig. 4.

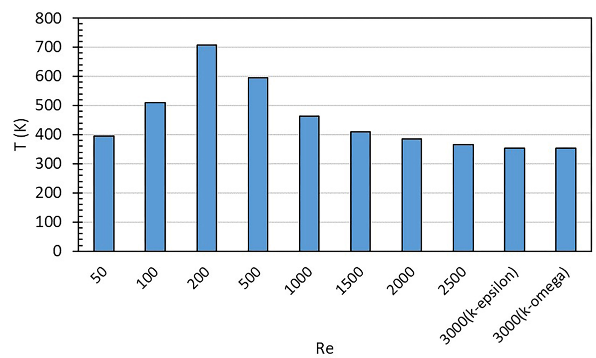

Figure 4. The effect of flow velocity on receiver outlet temperature.

The results of Fig. 4 shows that the highest fluid outlet temperature occurs at a Reynolds number equal to 200. In the case of a laminar flow regime, the outlet fluid temperature is higher than the outlet fluid temperature in a turbulent flow regime. Choosing a different type of turbulence model in Reynolds number 3,000 shows that the temperature of the outlet fluid with k-epsilon and k-omega models does not affect the outlet temperature of the fluid. Figure 5 shows the temperature distribution of the fluid in the receiving heat exchanger tubes. These temperature contours were calculated and drawn by Fluent software.

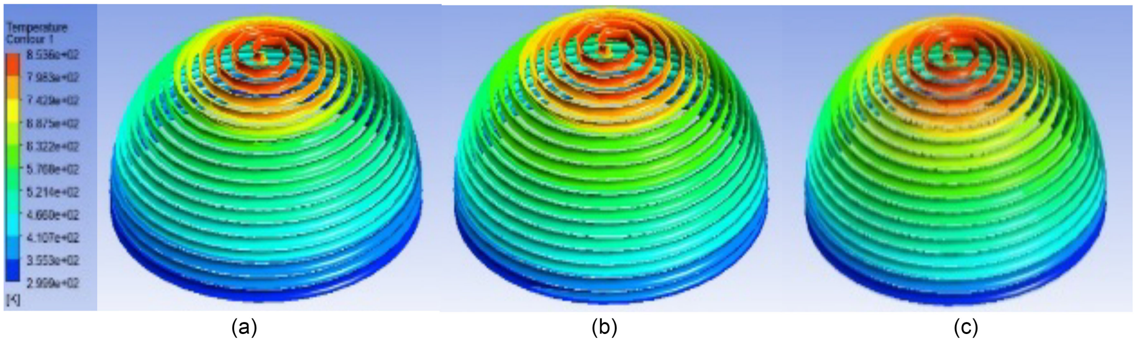

Figure 5. Temperature distribution for different Reynolds numbers: (a) Re = 1,000; (b) Re = 100; and (c) Re = 200.

This temperature distribution shows that at lower velocities (lower Reynolds numbers), along the length of the tube, the fluid has more heat absorption from the receiving cavity wall, and as a result, the temperature rises. This phenomenon can occur due to enough time for heat transfer.

6. Conclusion

In this study, according to the monthly solar radiation data of Shahrekord, the reflection heat flux from the spherical concentrator and the amount of radiation absorbed by the receivers were determined. Different geometries, such as disks, spheres, incomplete spheres, cylinders, and incomplete cones in different dimensions are considered as receivers and the situation in which the maximum amount of radiation is absorbed by the receiver. The results show that the highest amount of radiation absorption occurs in cylindrical and conical receivers with a height of 100 and 150 mm in a diameter of 140 mm. This result is different for disc and cone receivers with a length of 200 mm. The maximum amount of radiation absorption in these receivers occurs in a radius of 220 mm. The minimum radius of the receiver in the form of a sphere, which has the highest amount of radiation absorption, is 100 mm. Also, the maximum amount of radiation absorption in the receiver occurs in the form of an incomplete sphere with a radius of 220 mm. The highest radiation absorption occurs in the form of an incomplete sphere receiver with a length of 200 mm and a diameter of 220 mm. The lowest amount of radiation absorption occurs in the cylinder receiver. For the most appropriate design of the receiver, increasing the surface of heat transfer along with the intensity of the received heat is considered. Therefore, the position of the receiver was changed from the foci and the heat flux distribution on them was obtained. The results showed that the position of the receiver between 5 to 10% should have deviated from the main focus. Comparing the performance of the receivers with each other leads to the conclusion that among the studied receivers, the receiver in the form of hemispheres and imperfect spheres shows the best performance against radiation absorption. The maximum outlet temperature of the working fluid occurs in the arrangement of a pipe with a diameter of 5 mm with 20 coils. The flow velocity is also investigated and the results show that the laminar flow and especially Reynolds number of 200 has the highest working fluid temperature outlet. The important key point in the design of the receiver is creating enough area and time for heat transfer and receiving the maximum reflected solar heat flux. The set of parameters that were suggested in this article, *i.e.* focal distance, tube size, and Reynolds number, provide the conditions to obtain the optimal receiver. For future work, it is suggested to investigate other methods of increasing the heat transfer, such as adding nanoparticles to the working fluid, creating grooves inside the pipe, different absorption coating on the outside of pipes, *etc.* Also, radiation from multi-collector and surrounding radiation can affect the performance of receivers. This suggested studying these articles for all days of the year.

References

[1] A.B. Meinel and M.P. Meinel, Applied solar energy: An introduction, *NASA STI/Recon Technical Report A, 77*, 1977, 33445.

[2] S.A. Kalogirou, Solar energy engineering: processes and systems (Cambridge, MA: Academic Press, 2013 Oct 25).

[3] W. Wang, A. Malmquist, and B. Laumert, Comparison of potential control strategies for an impinging receiver based dish-Brayton system when the solar irradiation exceeds its design value, *Energy Conversion and Management, 169*, 2018, 1–2.

[4] Y. Wang, X. Dong, J. Wei, and H. Jin, Numerical simulation of the heat flux distribution in a solar cavity receiver, *Frontiers of Energy and Power Engineering in China, 4*(4), 2010, 571–576.

[5] L. Weinstein, D. Kraemer, K. McEnaney, and G. Chen, Optical cavity for improved performance of solar receivers in solar-thermal systems, *Solar Energy, 108*, 2014, 69–79.

[6] A. Fleming, C. Folsom, H. Ban, and Z. Ma, A general method to analyze the thermal performance of multi-cavity concentrating solar power receivers, *Solar Energy, 150*, 2017, 608–618.

[7] K. Wang, Y.L. He, P. Li, M.J. Li, and W.Q. Tao, Multi-objective optimization of the solar absorptivity distribution inside a cavity solar receiver for solar power towers, *Solar energy, 158*, 2017, 247–258.

[8] S. Pavlovic, R. Loni, E. Bellos, D. Vasiljević, G. Najafi, and A. Kasaeian, Comparative study of spiral and conical cavity receivers for a solar dish collector, *Energy Conversion and Management, 178*, 2018, 111–122.

[9] J. Garrido, L. Aichmayer, A. Abou-Taouk, and B. Laumert, Experimental and numerical performance analyses of Dish-Stirling cavity receivers: Radiative property study and design, *Energy, 169*, 2019, 478–488.

[10] A. Kasaeian, A. Kouravand, M.A. Rad, S. Maniee, and F. Pourfayaz, Cavity receivers in solar dish collectors: A geometric overview, *Renewable Energy, 169*, 2021, 53–79.

[11] C. Ophoff, M. Abuseada, N. Ozalp, and D. Moens, Systematic approach for design optimization of a 3 kW solar cavity receiver via multiphysics analysis, *Solar Energy, 206*, 2020, 420–435.

[12] R. Alvarado-Juárez, M. Montiel-González, H.I. Villafan-Vidales, C.A. Estrada, and J. Flores-Navarrete, Experimental and numerical study of conjugate heat transfer in an open square-cavity solar receiver, *International Journal of Thermal Sciences, 156*, 2020, 106458.

[13] E. Bellos, E. Bousi, C. Tzivanidis, and S. Pavlovic, Optical and thermal analysis of different cavity receiver designs for solar dish concentrators, *Energy Conversion and Management: X, 2*, 2019, 100013.

[14] R. Loni, E.A. Asli-Areh, B. Ghobadian, A.B. Kasaeian, S. Gorjian, G. Najafi, and E. Bellos, Research and review study of solar dish concentrators with different nanofluids and different shapes of cavity receiver: Experimental tests, *Renewable Energy, 145*, 2020, 783–804.

[15] A.M. Daabo, S. Mahmoud, and R.K. Al-Dadah, The effect of receiver geometry on the optical performance of a small-scale solar cavity receiver for parabolic dish applications, *Energy, 114*, 2016, 513–525.

[16] R. Alvarado-Juárez, M. Montiel-González, H.I. Villafan-Vidales, C.A. Estrada, and J. Flores-Navarrete, Experimental and numerical study of conjugate heat transfer in an open square-cavity solar receiver, *International Journal of Thermal Sciences, 156*, 2020, 106458.

[17] C. Zou, Y. Zhang, H. Feng, Q. Falcoz, P. Neveu, W. Gao, and C. Zhang, Effects of geometric parameters on thermal performance for a cylindrical solar receiver using a 3D numerical model, *Energy Conversion and Management, 149*, 2017, 293–302.

[18] T. Venkatachalam and M. Cheralathan, Effect of aspect ratio on thermal performance of cavity receiver for solar parabolic dish concentrator: An experimental study, *Renewable Energy, 139*, 2019, 573–581.

[19] M.H. Lin, J.H. Lin, M. El Haj Assad, R. Alayi, and S.R. Seyednouri, Optimal location and sizing of wind turbines and photovoltaic cells in the grid for load supply using improved genetic algorithm, *Journal of Renewable Energy and Environment*, *10*(2), 2022, 9–18.

[20] A. Shaikh, P.H. Shaikh, L. Kumar, N.H. Mirjat, Z.A. Memon, M.E.H. Assad, and R. Alayi, Design and modeling of a grid-connected PV–wt hybrid microgrid system using net metering facility, *Iranian Journal of Science and Technology, Transactions of Electrical Engineering, 46*(4), 2022, 1189–1205.

[21] O. Prakash, A. Ahmad, A. Kumar, R. Chatterjee, S. Sharma, R. Alayi, and H. Monfared, The compressive study of energy security prospects in India through solar power, *International Journal of Low-Carbon Technologies, 17*, 2022, 962–979.

[22] M. Jahangiri, F. Raeiszadeh, R. Alayi, A. Najafi, and A. Tahmasebi, Development of rural tourism in Iran using PV-based system: Finding the best economic configuration, *Journal of Renewable Energy and Environment, 9*(4), 2022, 1–9.

[23] A. Aldawoud, A. Aldawoud, Y. Aryanfar, M.E.H. Assad, S. Sharma, and R. Alayi, Reducing PV soiling and condensation using hydrophobic coating with brush and controllable curtains, *International Journal of Low-Carbon Technologies, 17*, 2022, 919–930.

[24] L. Heller, Literature review on heat transfer fluids and thermal energy storage systems in CSP plants, *STERG Report*, 2013 May 31.

Biographies

Samane Karimi is currently pursuing the Ph.D. degree in mechanical engineering with the Department of Technology and Engineering of Shahrekord University, Shahrekord, Iran. Her research interests include solar energy, nanofluid, and heat transfer. She works on novel increasing heat-receiving technique, such as micro-channel heat exchangers, and nano-fluid applications.

Amir Torabi received the Ph.D. degree in mechanical engineering from Isfahan University of Technology, Isfahan, Iran. He is currently working as an Assistant Professor with the Mechanical Engineering Department of Technology and Engineering of Shahrekord University, Shahrekord, Iran. His research interests include tribology and renewable energy. He works on friction and wear-reducing techniques, such as textured surfaces and nano-size surface patterns. He also works on solar heat energy applications for low-capacity power plants.

Behzad Ghasemi received the Ph.D. degree in mechanical engineering from Isfahan University of Technology, Isfahan, Iran. He is currently working as a Professor with the Mechanical Engineering Department of Technology and Engineering of Shahrekord University, Shahrekord, Iran. His research interests include heat transfer, natural convection, forced convection, computational heat, and fluid flow, nanofluids, and magnetohydrodynamic convection.

Afrasiab Raisi received the Ph.D. degree in mechanical engineering from Isfahan University of Technology, Isfahan, Iran. He is currently working as a Professor with the Mechanical Engineering Department of Technology and Engineering of Shahrekord University, Shahrekord, Iran. His research interests include heat transfer, natural convection, forced convection, non-newtonian fluids, nanofluids, conduction heat transfer in small scales, and magnetohydrodynamic convection.