OPTICAL SIMULATION OF A SOLAR PARABOLIC COLLECTOR AND CAVITY RECEIVERS USING RAY-TRACING SOFTWARE TRACEPRO WITH NATIVE CONDITIONS OF IRAN FOR SOLAR DRYERS

/

شبیه سازی نوری کلکتور بشقابی به وسیله دریافت کننده های استوانه ای و کروی بهینه *شده با استفاده از نرم افزار*
با شرایط بومی ایران برای خشک های خوردشیدی ***TRACEPRO***

Hosseinzadeh J. [1)], **Mohhebi A.*** [1)], **Loni R.** [2)] [1]

[1)] Urmia University, Department of Mechanical Engineering of Biosystems / Iran;
[2)] Tarbiat Modarres University, Department of Mechanical Engineering of Biosystems / Tehran
Tel: +98 914 441 2042; E-mail: arash.mech@gmail.com, a.mohebbi@urmia.ac.ir
DOI: https://doi.org/10.35633/inmateh-59-22

Keywords: *Parabolic dish collector, ray-tracing simulation, TracePro software, Monte Carlo method*

ABSTRACT

This paper proposes the design and optical evaluation of a solar dish collector with changeable structure using TracePro software with native conditions of Iran for solar dryers. The designed dish concentrator has a diameter of 1.5m. TracePro's goal is to design and evaluate complex optical systems. Modeling a parabolic concentrator in TracePro can be achieved using several methods. All segments of dish collectors are made of glass (perfect parabolic mirror with a reflection coefficient of 95%). In the ray-tracing simulations, the two cavity receiver model (cylindrical and semi-sphere) is added to study the influence of physical parameters of the cavity. The simulation result shows that semi-spherical receiver is better and it has got better optical performance. Thereby it is highly recommended for various types of solar dryers such as direct drying (solar box dryer), or indirect drying (solar cabinet dryer).

چکیده:

این مقاله طراحی و شبیه سازی اپتیکی یک کلکتور بشقابی خورشیدی با ساختار متغیر را با استفاده از نرم افزار *TracePro* برای شاریط بومی ایران برای استفاده در خشک کن های خورشیدی ارائه می نماید.قطر بشقاب بررسی شده 1.5 متر می باشد. هدف نرم افزار *TracePro* مدل سازی اپتیکی سیستم های پیچیده برای سامانه های خورشیدی وآنالیزس نوری آنها می باشد. روشهای مختلفی می توان برای مدل سازی کلکتور بشقابی در نرم افزار *TrcePro* استفاده کرد. در این مقاله شبیه سازی های نوری واحد کلکتور بشقابی پارابولیک با استفاده از نرم افزار پرتوی ردیابی *TracePro* ارائه شده است. بخش های کوچکی از کلکتور بشقابی پارابولیک از شیشه ساخته شده اند (آینه پارابولیک کامل با ضریب بازتاب 95٪). دو مدل گیرنده (استوانه ای و نیمه کروی) به منظور بررسی تأثیر پارامترهای فیزیکی حفره در شبیه سازی های ردیابی پرتویی اضافه شده است. نتیجه شبیه حاکی از این می باشدکه گیرنده نیمه کروی بهتر است و عملکرد نوری بهتری دارد. بدین ترتیب برای انواع مختلفی از خشک کن های خورشیدی مانند خشک کردن مستقیم (خشک کن جعبه خورشیدی) ، خشک کردن غیرمستقیم (خشک کن کابین خورشیدی) بسیار توصیه می شود.

INTRODUCTION

As the primary source of energy, solar energy is one of the best alternatives to fossil fuels because it is green, it is environmentally-friendly and it can be used in systems requiring minimal maintenance and operating costs. Solar energy use is critical to tackle recent energy problems such as global warming, the fossil fuel depletion and high electricity prices *(Stijepovic M.Z., Papadopoulos A.I. et al., 2017)*. The abundance is the key advantages of solar energy *(Jamil and Akhtar, 2017)* and possibility of direct heat conversion *(Kasaeian A., Daneshazarian R. et al., 2017)*. The production of solar thermal energy can be carried out with concentrating technologies such as parabolic trough collectors, linear Fresnel reflectors, solar plates and solar towers *(Kaushika N. and Reddy K., 2000)*.

In tropical and semi-tropical areas, the use of solar energy for thermal applications such as cooking, heating and drying is well established *(Bal L.M., Satya S. et al., 2010)*. In Iran, conventionally, open sun drying (OSD) is used to dry agricultural products. The disadvantage of OSD is the uncontrolled heat transfer to the product and slow drying rate. As a result, the quality of the products is very poor and they aren't able to compete on the international market.

[1] *Hosseinzadeh J., Ph.D. Stud. Eng.; Mohhebi A., Lect. Ph.D. Eng.; Loni R., Lect. Ph.D.*

To improve the product quality, drying should be performed in controlled conditions in order to maintain a constant temperature and a low relative humidity. It can be done by means of hot air (produced either using electric energy or biomass), or by means of infrared radiation.

Such methods, however, require a lot of investment and also consume a lot of energy. One of the cleanest and simplest options is to dry using renewable energy sources.

Karthikeyan and Murugavelh have developed a solar tunnel dryer for turmeric drying integrated with a solar flat plate collector. They conducted drying kinetics experiments and found that the Verma model is best suited to represent the drying behaviour of turmeric *(Karthikeyan A. and Murugavelh S., 2018)*.

José Vásquez et al., proposed a novel solar dryer for agricultural products with thermal energy storage system. The dryer's mathematical model included three stages: a solar panel, a solar accumulator and a drying chamber *(Vásquez J, Reyes R. et al., 2019)*. Kumar et al. modeled a greenhouse dryer with modifications to define temperature distribution with wind speed variability. They reported a better drying rate for forced circulation compared to natural convection in accordance with the available experimental results *(Kumar R., Gupta V. et al. 2017)*. Compared to linear technologies, solar dishes have high concentration ratios and are therefore promising for high-temperature applications. In recent years, substantial theoretical and experimental work has been carried out on solar dish concentrators for a wide range of industrial applications *(Reddy K. and Kumar N.S., 2009; Wang M. and Siddiqui K., 2010; Wu Xiao et al., 2010; Wu Xiao et al., 2010; Wu Z., Caliot C et al., 2010; Li Tang et al., 2011; Lovegrove K., Burgess G. et al., 2011)*. In solar collectors, the receiver plays the most important role in improving the efficiency of the solar system and it must be designed to result in high optical efficiency and low heat loss.

In the literature, the shape and dimensions of the receivers have been investigated to achieve a design that absorbs as much solar energy as possible while having a low external area to reduce heat loss. In past years, a lot of research has centered on solar collectors as compact technologies that can generate heat at high temperatures and also different absorber shapes, such as conical, cylindrical and rectangular, have been investigated. Roux et al. designed a rectangular absorber for solar thermal Brayton cycle in which the air was used as working fluid. They suggested a method for determining temperatures of the receiver surface and performance of various cavity receiver *(Le Roux W.G., Bello-Ochende T. et al. 2014)*. Thirunavukkarasu and Venkatachalam performed an experimental analysis on the thermal efficiency of the cavity receiver with specific aspect ratios. They found that the temperature of the receiver's surface was decreased by increasing the aspect ratio *(Venkatachalam T. and Cheralathan M., 2019)*.

Evangelos Bellos et al. investigated different cavity receivers (cylindrical, rectangular, spherical, conical and cylindrical-conical) under different operating temperature levels. They reported that cylindrical-conical shape receiver has the best optical, thermal and exergy efficiency *(Bellos E., Bousi E. et al., 2019)*. Song Yang et al. suggested a new model of a heat-pipe cavity receiver for a two-stage dish concentrator. They found that improved dish concentrator configuration shows superior performance compared to the conventional one, especially in terms of compact structure, flux and temperature distribution uniformity, and solar to thermal efficiency. Moreover they stated that there are fewer scale limitations such as weight and volume on the new receiver with overlapped configuration *(Yang S., Wang J. et al., 2018)*.

ZhouSi-Quan et al., created a three-dimensional model to investigate the spherical cavity receiver's optical and thermodynamic performance. They found that when the spherical receiver moves away either positively or negatively from the focal plane, the distribution of the radiation flux is more uniform *(Si-Quan Z., Xin-Feng L. et al., 2019)*. Sara Soltani et al. experimentally and theoretically studied a helically baffled cylindrical cavity receiver and they investigated the effect of certain mathematical, structural and functional parameters on the thermal performance of the system. Their results showed that the optimal selection of the above parameters could improve the system's thermal performance by up to 65% *(Soltani S., Bonyadi M. et al. 2019)*. Huang et al., suggested a novel method to optimize the system to provide maximum solar energy for net heat output under typical conditions for specific optical errors *(Huang W., Huang F. et al. 2013)*.

A revised hybrid computational approach was proposed by Li Zhang et al. to investigate the thermal performance of the steady-state three-dimensional molten salt cavity models. They found that when only the lengths of the back walls next to the side walls were raised, the thermal efficiency first decreased and then increased as the depth decreased *(Zhang L., Fang J. et al., 2017)*.

Huairui Li et al. suggested an experimental approach for predicting the performance of a solar concentrator with a cavity receiver. They found that a non-window cavity receiver is favoured if the optical error is less than 4 mrad and the ideal geometric concentration ratio is more than 3000 and if the optical error is larger than 4 mrad, a windowed cavity receiver with an optimal geometric concentration below 1200 is preferred *(Li H, Huang W. et al. 2013)*.

Steinfeld and Schubnell described a semi-empirical method for determining the optimum aperture size and the optimum operating temperature of a solar cavity receiver with maximum energy conversion efficiency *(Steinfeld A. and Schubnell M., 1993)*. Wu et al. performed a three-dimensional numerical analysis to determine the cumulative heat loss from the cavity receiver under various inclinations of the receiver. Results showed that natural convection heat loss Nusselt number is sensitive to the tilt angle and aperture size, except at 90° tilt angle, no matter how other parameters change at this point, the natural convection heat loss Nusselt number always fluctuates in a small value *(Wu S., Guo et al., 2014)*.

Qiu et al., studied numerically and experimentally a cavity receiver dish collector. They found that the cavity receiver's performance is better with up-flows than down-flows *(Qiu K., Yan L. et al. 2015)*. The rectangular and cylindrical cavity receivers were investigated as the heat source of the organic cycle of the Rankine by *Loni et al*. The various parameters of the cavity receivers are designed to achieve higher collector performance and higher overall thermal efficiency *(Loni R., Kasaeian A. et al. 2016, Loni R, Kasaeian A. et al. 2016)*. The thermal performance of the Fuzzy Focal Solar Parabolic Dish Concentrator with modified cavity receiver was experimentally and theoretically analyzed by Reddy et al., for different operating conditions. It has been found that the collector's performance has been improved by increasing volume flow rates *(Reddy K., Natarajan S.K. et al. 2015)*.

MATERIALS AND METHODS

MODEL DESIGN AND METHODOLOGY

The factors that contribute to the receiver wall's temperature profile and net heat transfer rate can be divided into two components: geometry-dependent factors and temperature-dependent factors. The geometry-dependent factors include: tracking error, reflectance, spillage and shadowing *(Loni R., Kasaeian A. et al., 2016)*.

TracePro *software* can measure the effects of geometry-dependent factors. Temperature-dependent factors include external radiation heat loss, inner cavity wall irradiation, convection heat loss, and heat loss from conduction. These factors depend on the different parts of the receiver's surface temperatures *(Le Roux W.G., Bello-Ochende T. et al., 2014).*

The present parabolic collector was entirely designed in SolidWorks 2016 SP5 Premium and to optimize the solar energy output from the reflective surfaces to the heat collecting component, the mirrors on a parabolic concentrator need to be precisely aligned. To achieve maximum efficiency, multiple parameters of system can be varied, including the mirror and receiver positions. A major parameter of the dish solar collector system is the solar flux distribution on the absorber. In order to know above mentioned parameters, the flux peaks and the local slope errors must be introduced in the ray tracing code, not the total concentration error. Then the behaviour of each of these light rays is determined, taking into consideration multiple factors that reduce the total energy entering the receiver. Atmospheric attenuation causes a ray's power to decrease as it passes through air and is modeled by a mathematical function in this simulation. In this paper, two important factors have been added to the existing model, which affect the efficiency of a solar parabolic collector. The first was the shape of the sun, referring to the fact that the sun is not a point source and does not emit parallel light rays. In this method, the shape of the sun was determined by a Gaussian function describing the possibility of a ray coming from a certain position on the sun and thus having a certain angle usual with the curved surface. Optical error was the second factor considered in this paper. This can be broken down into two parts: slope and specular error. Slope error is associated with the parabolic mirror's macroscopic shape and occurs when the reflective mirror is not perfectly parabolic, but slightly rough with small parabolic mirror surface imperfections. Specular error is related to the heliostat surfaces microscopic roughness, surface parabolic reflectors, parabolic troughs, etc.

The following equation was used to integrate the two sources of error:

$$\sigma_{tot} = \sqrt{\sigma_{slope}^2 + \sigma_{specular}^2 + \sigma_{sun}^2} \tag{1}$$

Where the σ_{total} was then used to describe a single Gaussian distribution representing the probability of a reflected ray leaving a surface mirror with a certain angle of deviation from the predicted light *(Pavlovic S., Stefanovic V. et al., 2014)*.

FOCAL RECEIVER

The modeling of the open-cavity receivers is shown in Fig.1.

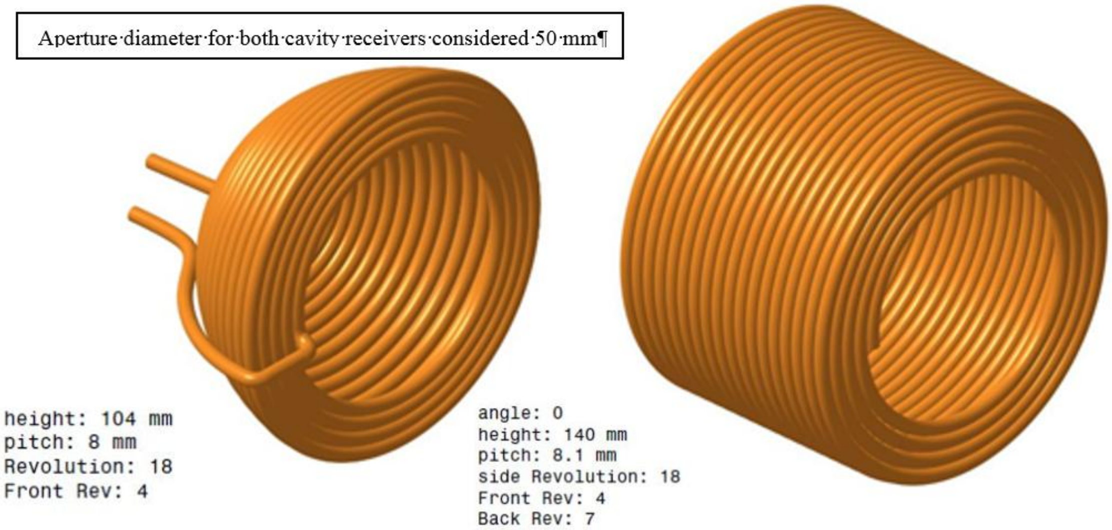

Fig. 1 - A rectangular open-cavity solar receiver and optimized semi-spherical cavity receiver

In a subsequent step, the focal absorber absorbs the concentrated solar radiation and converts it into thermal energy *(Kaushika N. and Reddy K., 2000)*. A receiver's basic feature is to absorb the maximum amount of solar energy reflected and transfer it to the working fluid as heat, with minimal losses. To achieve this purpose, a cavity receiver is used. The position of the cavity receiver should be varying to achieve the preferred performance of collector in different setups. The receiver is covered with insulation (Fig. 2).

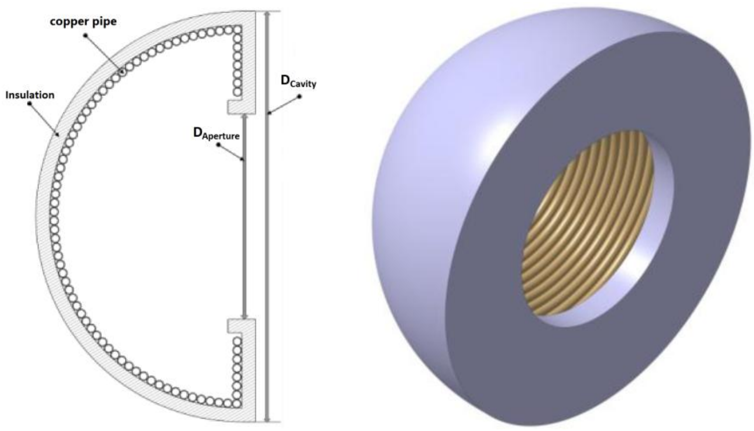

Fig. 2 - Insulated cavity receiver

BASIC FEATURES OF THE CONCENTRATING SOL AR COLLECTOR

In this part, the design of the solar collector is viewed with an emphasis on the design of the reflector. This design dramatically reduces the cost of the system, while allowing high concentration ratios for medium and high temperature applications. Table 1 shows the design parameters of the Solar Parabolic Dish Concentrator (SPDC). The table gives the values of different parameters because the built model has many geometric features.

Table 1

Changeable characteristics of the SDC and achieved results

Concentrator diameter (m)	1.5
Focal distance (mm)	1004.46
Paraboloid rim angle	25.25
Collector aperture area (m^2)	1.767146
Cavity tube outer diameter (mm)	8
Cavity tube inner diameter (mm)	6
Number of tube coils	18
Cylindrical Cavity inner diameter, Din (m)	0.13
Cylindrical Cavity outer diameter, Dout (m)	0.14
Semi-spherical cavity receiver inner diameter, Din (m)	0.13
Semi-spherical cavity receiver outer diameter, Dout (m)	0.14
Height of the cavity receiver, h (m)	0.18
Solar beam irradiations, Isun(W/m^2)	700
Average wind speed (m/s)	5
Ambient temperature (°C)	22
Volumetric flow rate, V (ml/s	100
Working fluid (Water/Oil)	water
Reflectivity of segments	95%.
CRg	114.8542
Number of mirrors	200
Fs/Diam	00.67

A common SPDC consists mainly of a parabola with an absorber placed at the focal position by some arms.

A reflector in a nacelle can be rotated around two axes: the horizontal axis (angle of elevation) of the mast support and the vertical axis (angle of azimuth) of the mast support.

The SPDC is placed on the ground and is made from small elementary square mirrors. Its novelty is the changeable characteristics of the SPDC (dish opening diameter, dish depth, and Focal distance).

Such ranges are adequate for comprehensive applications such as research on heat and electricity generation, etc.

In Fig.3, a pilot model of the assembled SPDC illustrates the arrangement of 200 mirrors on main frame with 1500 mm dish aperture diameter, 1004.46 mm focal distance and 150 mm dish depth.

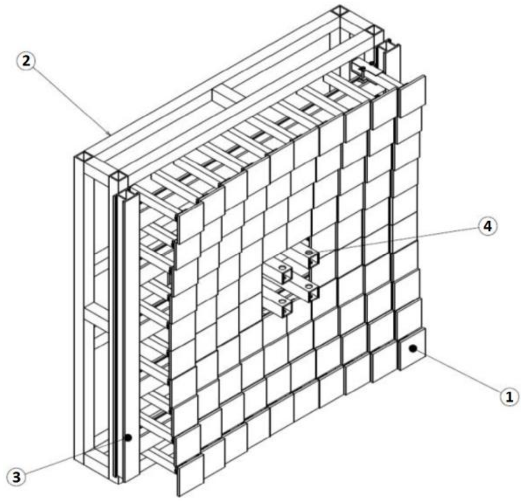

Fig. 3 - Pilot model of changeable collector

(Feizolahzadeh M., Motlagh A.M. et al. 2017)

1-optical unit; 2-main frame; 3-aluminium profile; 4-receiver joints

The dimensions of the reflective surfaces in the solar dish concentrator are determined by the desired power at the maximum insolation and collector conversion efficiency levels.

The parabolic concentrator's mathematical representation is a paraboloid that can be represented as a surface obtained by rotating parabola around the axis shown in Fig.4.

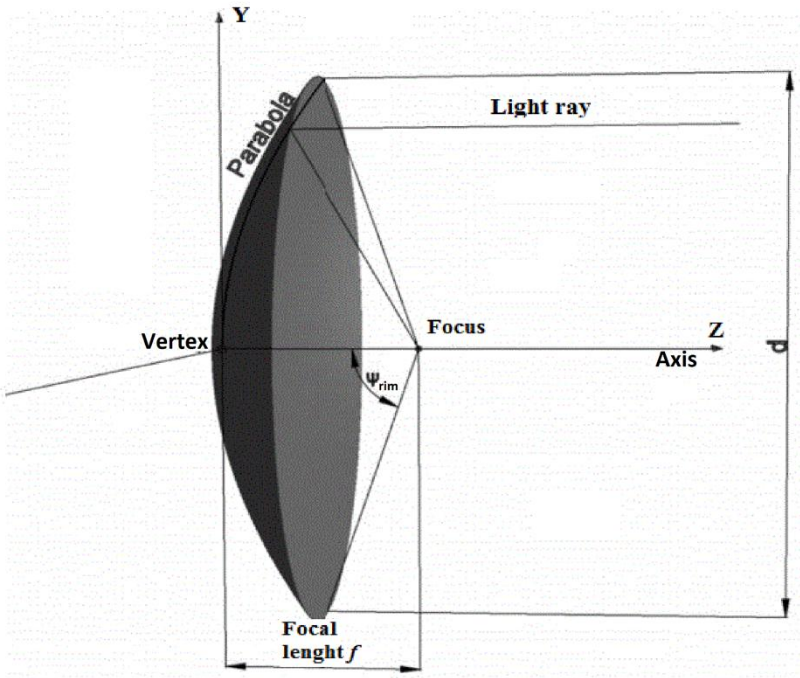

Fig. 4 - Ideal shape of parabolic solar concentrator

(Pavlovic S., Stefanovic V. et al. 2014)

Parabolic dish solar mathematical equations: the ratio of geometric concentration can be defined as the area of the collector aperture A_{app} divided by the receiver surface area A_{rec} and it can be calculated by Eq.(2):

$$CR_g = (sin^2\theta_a)^{-1} = A_c A_r^{-1} = \frac{A_{app}}{A_{rec}} \tag{2}$$

The geometric concentration ratio of the designed solar parabolic concentrator is CR = 114.8542.

The solar parabolic concentrator's mechanical model is designed in SolidWorks 2016 SP5 Premium.

For selected points, the parabolic shape of the solar concentrator is obtained by entering X and Y coordinates. Parabola Calculator 2.0 is used to calculate the necessary points that define parabola. Table.2 shows the calculated coordinates (X and Y) for the designed parabola.

Table 2

Coordinates of designed parabola

X(mm)	Y(mm)	X(mm)	Y(mm)	X(mm)	Y(mm)	X(mm)	Y(mm)	X(mm)	Y(mm)	X(mm)	Y(mm)
-750	140	-525	68.6	-300	22.4	-75	1.4	150	5.6	375	35
-742.5	137.214	-517.5	66.654	-292.5	21.294	-67.5	1.134	157.5	6.174	382.5	36.414
-735	134.456	-510	64.736	-285	20.216	-60	0.896	165	6.776	390	37.856
-727.5	131.726	-502.5	62.846	-277.5	19.166	-52.5	0.686	172.5	7.406	397.5	39.326
-720	129.024	-495	60.984	-270	18.144	-45	0.504	180	8.064	405	40.824
-712.5	126.35	-487.5	59.15	-262.5	17.15	-37.5	0.35	187.5	8.75	412.5	42.35
-705	123.704	-480	57.344	-255	16.184	-30	0.224	195	9.464	420	43.904
-697.5	121.086	-472.5	55.566	-247.5	15.246	-22.5	0.126	202.5	10.206	427.5	45.486
-690	118.496	-465	53.816	-240	14.336	-15	0.056	210	10.976	435	47.096
-682.5	115.934	-457.5	52.094	-232.5	13.454	-7.5	0.014	217.5	11.774	442.5	48.734
-675	113.4	-450	50.4	-225	12.6	0	0	225	12.6	450	50.4
-667.5	110.894	-442.5	48.734	-217.5	11.774	7.5	0.014	232.5	13.454	457.5	52.094
-660	108.416	-435	47.096	-210	10.976	15	0.056	240	14.336	465	53.816
-652.5	105.966	-427.5	45.486	-202.5	10.206	22.5	0.126	247.5	15.246	472.5	55.566
-645	103.544	-420	43.904	-195	9.464	30	0.224	255	16.184	480	57.344
-637.5	101.15	-412.5	42.35	-187.5	8.75	37.5	0.35	262.5	17.15	487.5	59.15
-630	98.784	-405	40.824	-180	8.064	45	0.504	270	18.144	495	60.984
-622.5	96.446	-397.5	39.326	-172.5	7.406	52.5	0.686	277.5	19.166	502.5	62.846
-615	94.136	-390	37.856	-165	6.776	60	0.896	285	20.216	510	64.736
-607.5	91.854	-382.5	36.414	-157.5	6.174	67.5	1.134	292.5	21.294	517.5	66.654
-600	89.6	-375	35	-150	5.6	75	1.4	300	22.4	525	68.6
-592.5	87.374	-367.5	33.614	-142.5	5.054	82.5	1.694	307.5	23.534	532.5	70.574
-585	85.176	-360	32.256	-135	4.536	90	2.016	315	24.696	540	72.576
-577.5	83.006	-352.5	30.926	-127.5	4.046	97.5	2.366	322.5	25.886	547.5	74.606
-570	80.864	-345	29.624	-120	3.584	105	2.744	330	27.104	555	76.664
-562.5	78.75	-337.5	28.35	-112.5	3.15	112.5	3.15	337.5	28.35	562.5	78.75
-555	76.664	-330	27.104	-105	2.744	120	3.584	345	29.624	570	80.864
-547.5	74.606	-322.5	25.886	-97.5	2.366	127.5	4.046	352.5	30.926	577.5	83.006
-540	72.576	-315	24.696	-90	2.016	135	4.536	360	32.256	585	85.176
-532.5	70.574	-307.5	23.534	-82.5	1.694	142.5	5.054	367.5	33.614	592.5	87.374
600	89.6	630	98.784	660	108.416	690	118.496	720	129.024	750	140
607.5	91.854	637.5	101.15	667.5	110.894	697.5	121.086	727.5	131.726		
615	94.136	645	103.544	675	113.4	705	123.704	735	134.456		
622.5	96.446	652.5	105.966	682.5	115.934	712.5	126.35	742.5	137.214		

EXPERIMENTAL SETUP

The parabolic dish collector system's changeable parameters are as follows: focal length of the dish *(f)*, aperture diameter of dish (D), dish rim angle (φ), area of the receiver (A) and concentration ratio (C). The Experimental SPDC's main components are: the solar concentrator, the cavity receiver, the solar heat exchanger, the drying chamber, as shown in Fig.5.

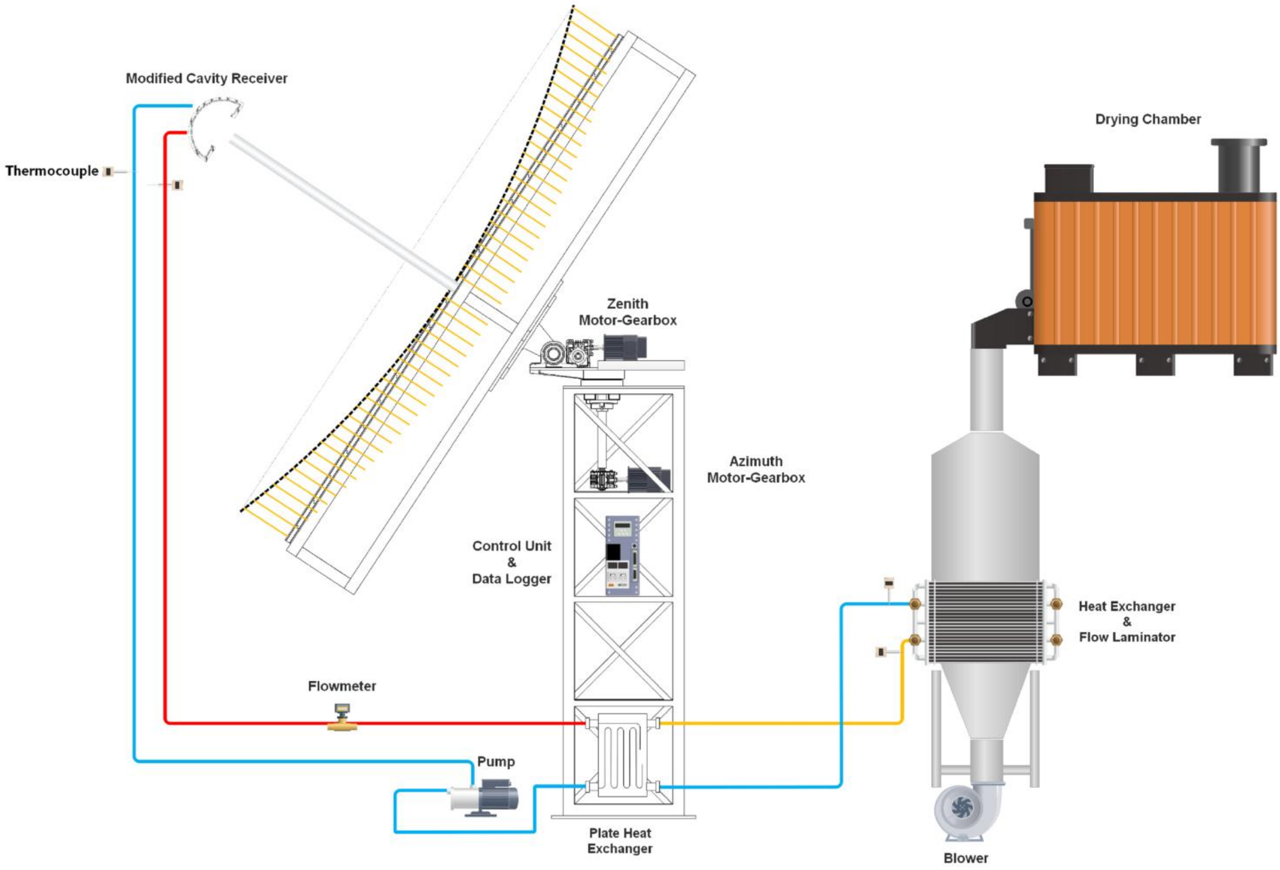

Fig. 5 - Schematic of experimental setup of a solar drying apparatus with changeable solar dish collector

SIMULATION OF THE MODEL

TracePro software, Lamda Research Corporation, USA, is used for optical analysis of the solar parabolic thermal concentrator. All material properties are assigned in TracePro. Concentrator segments are defined as standard reflective-coated mirrors with the reflection coefficient of 95%.

Cavity receivers have been placed in different distances from vertex of dish concentrator (At the concentrator's focal point and below the focal length). The internal surface of the cavity receiver was considered to be a perfect absorber.

The source of radiation was considered to be circular with a diameter equal to the parabolic dish diameter (1,500 mm).

The radiation source was placed 4,000 mm from the vertex of the parabolic dish and had a circular grid pattern for Monte Carlo ray tracing to generate 120,000 rays.

The spatial profile of the rays produced was random and solar radiation was the angular profile.

According to experiential value, the solar irradiation for the city of Urmia in Iran is between 450 W/m^2 and 950 W/m^2.

Then for optical analysis, the solar irradiance was considered 750 W/m^2.

Fig.6 shows the optical system for the traced-ray solar parabolic concentrator.

The process of optical concentration consists of three objects: solar parabolic dish reflector, radiation source and cavity receiver (at the concentrator's focal point and below the focal length).

Optical analyses are performed by generating and calculating Monte Carlo ray trace for 120,000 rays.

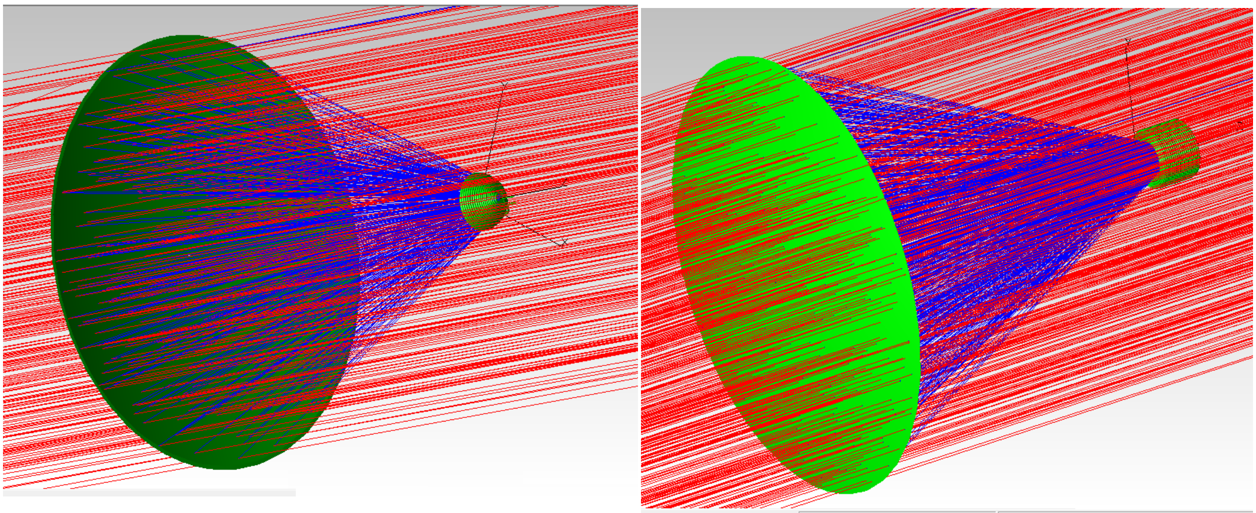

Fig. 6 - Optical system of solar parabolic concentrator with cylindrical and semi-spherical receivers

Based on simulation results for cylindrical cavity receiver from all emitted rays 113,251 rays reached the absorber surface, which is 94.37% of the rays emitted. Total map of irradiance for absorbed flux on receiver is shown in Fig.7.

The total cavity receiver flux was 990.23 W. It can be seen from Fig.7 that calculated values for total irradiance are in compliance with the theoretical values. The irradiance in the receiver ranges from 5.177× 10^{-8} W/m^2 to 2.917× 10^5W/m^2 and at the receiver periphery the irradiance varies from 6.012 to 3.88 × 10^4 W/m^2. The maximum irradiance occurs in a circle with diameter of 40 mm (from -20 mm to 20 mm).

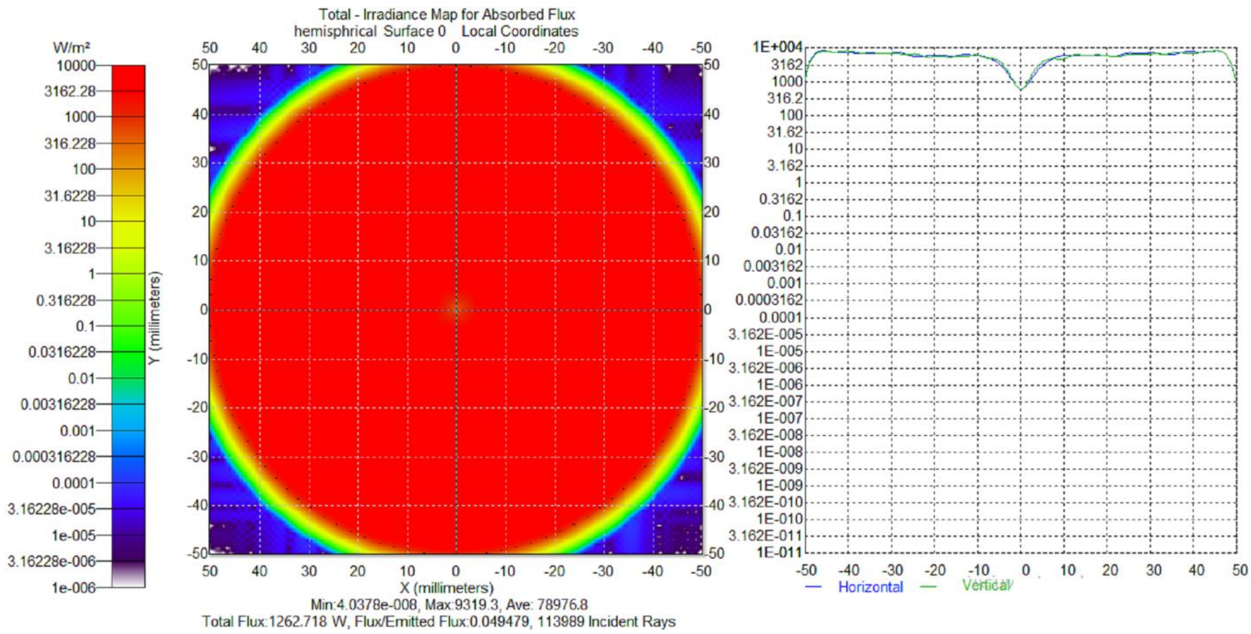

Fig. 7 - Irradiance Map for absorbed flux on cylindrical receiver

For semi-spherical cavity receiver from all emitted rays 113,989 rays reached the absorber surface, which is 94.9% of the rays emitted. Total map of irradiance for absorbed flux on receiver is shown in Fig. 8. The total cavity receiver flux was 1262.718 W. It can be seen from Fig.8 that the calculated values for total irradiance match to the theoretical values. The irradiance in the receiver ranges from 4.037× 10-8 W/m^2 to 3.162×105 W/m^2 and at the receiver periphery the irradiance varies from 264.6 to 2.025 × 104 W/m^2. The maximum irradiance occurs in a circle with diameter of 50 mm (from -25 mm to 25 mm).

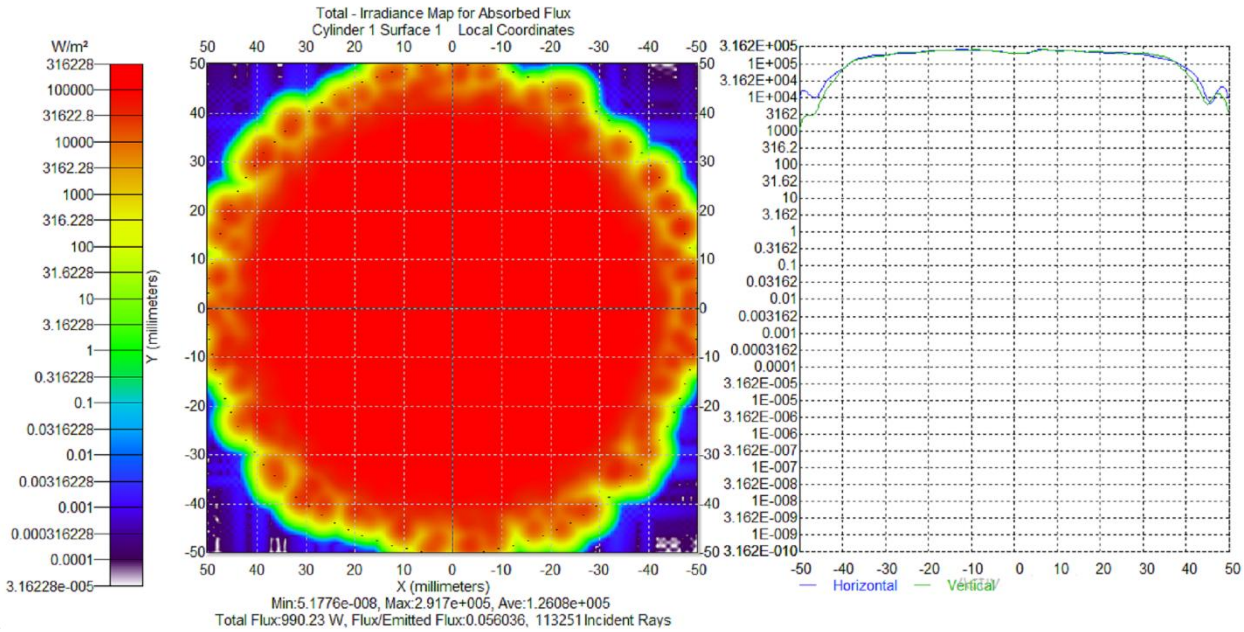

Fig. 8 - Irradiance Map for absorbed flux on semi-spherical receiver

Considering the total area of the receivers, this assessment can be made: the uniformity of irradiance in semi-spherical receiver is better and it has got better optical performance.

APPLICATION OF SOLAR ENERGY TO DRY CROPS AND GRAINS

During the conventional open-air drying process, a large percentage of agricultural produce is spoiled. Using the solar drying process, crops will dry faster than open sun drying in the field with the added advantage of protecting against birds, insects and worms. Sun drying is still the most common method used to preserve agricultural products in most of Iran. Temperature required for drying is 60°- 70°C. Solar concentrating parabolic dish collector is used to get this temperature.

The temperature at receiver is up to 125°C; the receiver has water as working fluid and a circulating pump passes it through the heat exchanger. Heat from hot fluid is extracted by supplying cold air through heat exchanger. Then the hot air is blown by a pump inside the cabin where crops are placed as shown in Fig.9.

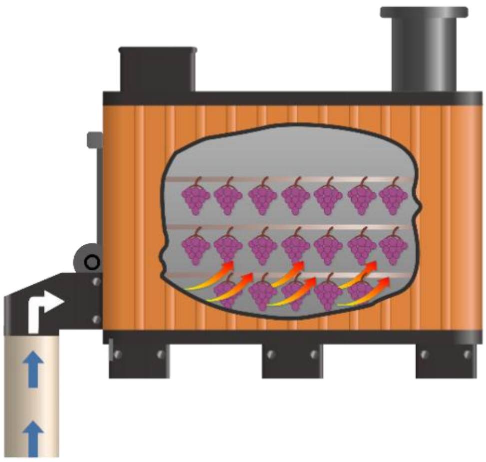

Fig. 9 - Schematic diagram of drying chamber

The objective of this work is to simulate and optimize Solar Parabolic Collector and cavity receivers which can be used in a solar drying apparatus and increase the performance of the solar drying apparatus. The result shows that semi-spherical receiver is better and it has got better optical performance. Thereby, it is highly recommended for different types of solar dryers, such as direct drying (solar box dryer), or indirect drying (solar cabinet dryer).

As shown in Fig.9, the drying cabinet temperature with a width of 0.55 m and a length of 0.65 m, equipped with 3 drying trays mounted inside the drying cabinet, can be controlled using the designed collector. Fresh air flows into the heat exchanger via the air inlet and the heated air exits the heat exchanger. Then the heat exchanger's heated air is passed over the drying material that is horizontally stacked on the 3 thin layers. As simulation results show, the temperature obtained through the semi-spherical receiver is higher than through the cylindrical receiver. So, the designed Solar Parabolic Collector and cavity receivers need less time for drying compared to other collectors.

CONCLUSIONS

This paper presents optical simulations of an innovative solar dish reflector and cavity receivers using the ray-tracing software. In the ray-tracing simulations, a receiver model is introduced to test the effect of physical parameters of the cavity. This type of cavity enables a homogeneous distribution of solar flux on the absorber and increases the efficiency of the cavity receiver. The advantage of TracePro software is that when sufficient rays are used, the Monte Carlo method gives reliable results. In many applications, this solar collector can be used, from domestic hot water applications to industrial processes. The model is designed in SolidWorks 2016 SP5 Premium and then analyzed optically. This method of optimization will enable optimum geometric and optical parameters to be found for the different types of solar parabolic dish concentrators as well as for the geometric, optical and thermal parameters of the cavity receivers. The result shows that semi-spherical receiver is better and it has got better optical performance. Therefore, it can be recommended for different types of solar dryers, such as direct drying (solar box dryer), or indirect drying (solar cabinet dryer).

REFERENCES

[1] Bal L.M., Satya S. and Naik S., (2010), Solar dryer with thermal energy storage systems for drying agricultural food products: A review. *Renewable and Sustainable Energy Reviews,* 14(8): 2298-2314;

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

[3] Feizolahzadeh M., Motlagh A.M. and Banakar A., (2017), Experimental setup of solar dish collector with changeable structure. *INMATEH-Agricultural Engineering*, 53(3): 103-112;

[4] Huang W., Huang F., Hu P. and Chen Z., (2013), Prediction and optimization of the performance of parabolic solar dish concentrator with sphere receiver using analytical function. *Renewable energy,* 53: 18-26.

[5] Jamil B. and Akhtar N., (2017), Comparative analysis of diffuse solar radiation models based on sky-clearness index and sunshine period for humid-subtropical climatic region of India: A case study. *Renewable and Sustainable Energy Reviews*, 78: 329-355.

[6] Karthikeyan A. and Murugavelh S., (2018), Thin layer drying kinetics and exergy analysis of turmeric (Curcuma longa) in a mixed mode forced convection solar tunnel dryer. *Renewable energy*, 128: 305-312;

[7] Kasaeian A., Daneshazarian R., Rezaei R., Pourfayaz F. and Kasaeian G., (2017), Experimental investigation on the thermal behaviour of nanofluid direct absorption in a trough collector. *Journal of Cleaner Production,* 158: 276-284;

[8] Kaushika N. and Reddy K., (2000), Performance of a low cost solar paraboloidal dish steam generating system. *Energy conversion and management*, 41(7): 713-726;

[9] Kumar R., Gupta V. and Varshney R., (2017), Numerical simulation of solar greenhouse dryer using computational fluid dynamics. *International Journal of Research and Scientific Innovation* IV (Issue VIS): 111-115;

[10] Le Roux W.G., Bello-Ochende T. and Meyer J.P., (2014), The efficiency of an open-cavity tubular solar receiver for a small-scale solar thermal Brayton cycle. *Energy Conversion and Management*, 84: 457-470;

[11] Li H., Huang W., Huang F., Hu P. and Chen Z., (2013), Optical analysis and optimization of parabolic dish solar concentrator with a cavity receiver. *Solar energy*, 92: 288-297;

[12] Li Z., Tang D., Du J. and Li T., (2011), Study on the radiation flux and temperature distributions of the concentrator–receiver system in a solar dish/Stirling power facility. *Applied Thermal Engineering* 31(10): 1780-1789;

[13] Loni R., Kasaeian A., Asli-Ardeh E.A. and Ghobadian B., (2016), Optimizing the efficiency of a solar receiver with tubular cylindrical cavity for a solar-powered organic Rankine cycle. *Energy*, 112: 1259-1272;

[14] Loni R., Kasaeian A., Asli-Ardeh E.A., Ghobadian B. and Le Roux W., (2016), Performance study of a solar-assisted organic Rankine cycle using a dish-mounted rectangular-cavity tubular solar receiver. *Applied Thermal Engineering*, 108: 1298-1309;

[15] Lovegrove K., Burgess G. and Pye J., (2011), A new 500 m^2 paraboloidal dish solar concentrator. *Solar Energy,* 85(4): 620-626;

[16] Pavlovic S., Stefanovic V. and Bojic M., (2014), Optical simulation of a solar parabolic collector using ray-tracing software Trace Pro. Hong Kong, China: 211-218;

[17] Qiu K., Yan L., Ni M., Wang C., Xiao G., Luo Z. and Cen K., (2015), Simulation and experimental study of an air tube-cavity solar receiver. *Energy conversion and management*, 103: 847-858;

[18] Reddy K. and Kumar N.S., (2009), An improved model for natural convection heat loss from modified cavity receiver of solar dish concentrator. *Solar Energy*, 83(10): 1884-1892;

[19] Reddy K., Natarajan S.K. and Veershetty G., (2015), Experimental performance investigation of modified cavity receiver with fuzzy focal solar dish concentrator. *Renewable Energy,* 74: 148-157;

[20] Si-Quan Z., Xin-Feng L., Liu D., Qing-Song M., (2019), A numerical study on optical and thermodynamic characteristics of a spherical cavity receiver. *Applied Thermal Engineering*, 149: 11-21;

[21] Soltani S., Bonyadi M. and Avargani V. M., (2019), A novel optical-thermal modeling of a parabolic dish collector with a helically baffled cylindrical cavity receiver. *Energy*, 168: 88-98;

[22] Steinfeld A., Schubnell M., (1993), Optimum aperture size and operating temperature of a solar cavity-receiver. *Solar Energy,* 50(1): 19-25;

[23] Stijepovic M.Z., Papadopoulos A.I., Linke P., Stijepovic V., Grujic A.S., Kijevčanin M. and. Seferlis P., (2017), Organic Rankine Cycle system performance targeting and design for multiple heat sources with simultaneous working fluid selection. *Journal of cleaner production*, 142: 1950-1970;

[24] Vásquez J., Reyes A. and Pailahueque N., (2019), Modeling, simulation and experimental validation of a solar dryer for agro-products with thermal energy storage system. *Renewable energy*, 139: 1375-1390;

[25] Venkatachalam T., Cheralathan M., (2019), Effect of aspect ratio on thermal performance of cavity receiver for solar parabolic dish concentrator: An experimental study. *Renewable energy,* 139: 573-581;

[26] Wang M., Siddiqui K., (2010), The impact of geometrical parameters on the thermal performance of a solar receiver of dish-type concentrated solar energy system. *Renewable Energy,* 35(11): 2501-2513;

[27] Wu S.Y., Guo F.H. and Xiao L., (2014), Numerical investigation on combined natural convection and radiation heat losses in one side open cylindrical cavity with constant heat flux. *International Journal of Heat and Mass Transfer*, 71: 573-584;

[28] Wu S.Y., Xiao L., Cao Y. and Li Y.R., (2010), Convection heat loss from cavity receiver in parabolic dish solar thermal power system: A review. *Solar energy*, 84(8): 1342-1355;

[29] Wu S.Y., Xiao L., Cao Y., Li Y.R., (2010), A parabolic dish/AMTEC solar thermal power system and its performance evaluation. *Applied Energy*, 87(2): 452-462;

[30] Wu Z., Caliot C., Bai F., Flamant G., Wang Z., Zhang J. and Tian C., (2010), Experimental and numerical studies of the pressure drop in ceramic foams for volumetric solar receiver applications. *Applied Energy*, 87(2): 504-513;

[31] Yang S., Wang J., Lund P.D., Jiang C., Huang B., (2018), Design and performance evaluation of a high-temperature cavity receiver for a 2-stage dish concentrator. *Solar Energy* 174: 1126-1132;

[32] Zhang L., Fang J., Wei J., Yang G., (2017), Numerical investigation on the thermal performance of molten salt cavity receivers with different structures. *Applied energy,* 204: 966-978.