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Evaluation of solar-chimney power plants with multiple-angle collectors

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Abstract

Solar chimney power plants are plants based on solar thermal power including three parts of collector, chimney and turbine, which is able to produce electrical energy. One of the effective parameters in increasing the power production is the collector angles versus horizon. In the present study, a numerical analysis of a solar chimney power plant for different angles of the collector (divergent, convergent and horizontal type collector) is proposed. The introduced numerical model uses mathematical models of heat transfer. In this regard, effect of various angles of the three considered collectors on temperature distribution and power production of the solar chimney is evaluated. Divergent type collectors produce more power than convergent and horizontal collectors, as they produce more velocity and mass flow rates. .It will be shown that by increasing the angle of divergent-type collector (keeping the inlet height constant), the power production will be increased and the output temperature will be decreased, in a way that the angle variation of 0.8 to 1 will increase the divergent type collector output power by 11 % and will decrease the output temperature by 0.78%. In the other case, when the output height is kept constant and the collector angle changes, performance of the divergent type collector is better than the other two collectors. Power production in a constant mean height is shown to be 3 times and 1.5 times more than the convergent and horizontal collectors respectively.

Keywords:
Solar-chimney power plant, renewable energy, collector, chimney.

Nomenclature

A	Area (m^2)
c_p	Heat capacity (J/(kg.K))
d	Diameter (m)
f	friction coefficient
g	Gravitational acceleration(m/s^2)
h	Convection heat transfer coefficient (J/(m^2.K))
H	Height (m)
I	Solar radiation (w/m^2)
m	Mass flow rate (kg/s)
P	Pressure (Pa)

Greek symbols

α	absorptivity thermal diffusivity (m^2/s)
ε	emissivity
σ	Stefan – Boltzmann constant
ρ	density (kg/m^3)
τ	transmissivity

Subscripts

$a\ ,air$	air
amb	ambient
c	collector

P_e	Power output (w)
q	Heat transfer (J)
T	Temperature (K)
V	Velocity (m/s)
ch	chimney
g	ground
r	radiation
sky	sky

1. Introduction

Regarding the growing need for cheap and unlimited energy sources, renewable energies were paid more attention during the last years. One of the main sources of these renewable energies is the solar energy. The solar chimney was introduced firstly by J. Schlaich in late of 1970. Less than four years later, he outlined his ideas and theories in a conference. Then in the early of 1980, a plant with a 194.6 m height and 10.08 m diameter chimney and a 240 m diameter collector was built in Manzanres, Spain, which produced maximum power of 50 kW. Solar chimney includes three parts of a solar collector (with the energy storage layer in bottom), a chimney and a turbine. In this process, ambient cold air enters to the collector and get warm by moving through the channel and its density decreased. Appeared pressure difference caused by the density difference of the warm air inside the collector and the local cold air lead the air to move towards the chimney. The employed turbine, at the entrance of the chimney, gets the kinetic energy of the airflow and changes it to the electrical energy. Then the airflow will exit from the top of chimney by the created density difference and the chimney suction. Solar chimney has been worldly studied in many works. The main part of accomplished surveys related to solar chimney is about numerical analysis of flow field and system temperature distribution and power production of the plant. In numerical analyses, the results were compared by results of the small created model or by present results in Manzanares, Spain. Bernardes [1-4] presented a numerical and analytical model for explaining the performance of solar chimney and studied the effect of various ambient conditions and structural dimensions on the power output. Based on the results from their previous study, the factor of pressure drop at the turbine and collector diameter are important parameters for designing solar chimney. They employed results of their own made small model as well as the results of the Spain plant to verify their model. Tingzhen [5] developed a numerical analysis for the collector, turbine and chimney and compared the results to ones, which are in Spain model and studied the effects of turbine and its blades on the chimney efficiency. Petela [6], Maia [7] in a mathematics model, attempted thermodynamic analysing of the solar chimney system and its component performances based on energy and exergy balance. Gannon [8] also performed thermodynamic analyses on the solar chimney collector. Sangi [9] solved the relations governing the solar chimney geometry in Manzanares by two numerical methods and using repetitive technique and fluent software, as well as applying $k-\varepsilon$ model and to obtain velocity and temperature distributions. They studied performance of solar chimney power plant and estimated the quantity of the produced electrical energy in Iran in another paper [10]. Dai [11] and Larbi [12] studied effects of parameters such as chimney diameter, chimney height and ambient temperature on performance of solar chimney power plant. Kasaeian [13-14] studied simulation and optimization of the shape of solar chimney plant. They showed in an experiment model that the height and diameter of the chimney are the most important physical variables for solar chimney design. Also, they studied the effect of various ambient conditions on solar chimney efficiency**.** Also, Patel [15] studied effect of geometric parameters on the performance of a solar chimney power plant. Koonsrisuk [16-17] proposed a mathematical model for the solar chimney power plant in Thailand and they investigated the factor of pressure drop at the turbine and dynamic similarity in solar chimney modelling. Gou [18-19] numerically evaluated the optimal turbine pressure drop ratio. Zhou

[20-21] concentrated on performance of solar chimney power plant in Tabbat plateau using a mathematical model. Their results showed that power production was more than twice of other places with the same latitude. They also presented the optimal chimney height based on preventing the making negative buoyancy and producing more power. Pretorius [22] have studied the effect of various parameters on performance of solar chimney such as, quality of galsses used as the collector roof, turbine inlet loss coefficient and various types of soils. Choi et. al [23], investigated performance of solar chimney analytically. They established a water storage system to conserve heat energy during the night.

Coccic et al. [24] developed a one-dimensional compressible flow in a solar chimney power plant to obtain buoyancy force, velocity distribution, temperature, pressure and density variation at the collector as well as the chimney. Some of the researchers [25-27] introduced a combined system for producing water and electricity and zuo [25] concluded that the combined system can significantly increase efficiency of using solar energy.

Solar chimney has many advantages like simple design, stable and trusted energy production, few moving parts, and consequently low maintenance and repairing costs. The best of them is producing electrical energy without polluting the environment. The most important objective in this field is increasing the produced power.

The previous arts in this field were mostly devoted to study effects of the geometrical parameters like collector diameter, height and diameter of the chimney and some environmental parameters like ambient air temperature, soil type and turbine pressure loss. In the present study effects of change in collector geometry and angle variation of the collector is assessed.

To approach this objective, a good knowledge is required about the detailed performance of the solar chimney. In this regard, a numerical simulation based on mathematical model of heat transfer is proposed in this study. The model is in the same dimensions to the Manzanares power plant. Angle of the collector respect to the horizon, as one of the efficient parameter in increasing the power production, is comprehensively assessed in this study. A multiple-angel collector is simulated in various states and the effects of the angle on temperature distribution in the collector and power production of solar chimney is discussed. Variety of angles forming three different shapes of divergent, horizontal and convergent form collectors are evaluated from the aspects of power production and temperature. It is shown that the divergent type collector brings about more power compared to the convergent and horizontal ones. (See Fig. 1). In the present study, effects of collector height on the amount of power production is investigated as well. Height increment at the inlet and outlet of the collector is shown to influence the power production and temperature distribution. It will be found that divergent-form collectors perform better than convergent and horizontal types.

2. Mathematical modelling

In this section, a thermodynamic analysis on the system components, like solar chimney, collector and turbine are introduced individually.

2.1 Governing equations on the collector

Heat transfer in a collector is an important and effective issue on the performance of solar chimney. Collector determines the amount of heat transfer from roof to the ambient, from roof to the air flow in the collector and from ground to the air flow in the collector, in this way the air was warmed by going through the collector. The flow in the collector can be laminar, transient or turbulent. In the solar collector, the following assumptions are considered:

1. The flow is steady.
2. The air follows the ideal gas law.
3. Vertical gradient of temperature in the collector is neglected.
4. Energy lost to the ground is neglected.
5. Boussinesq approximation is valid.

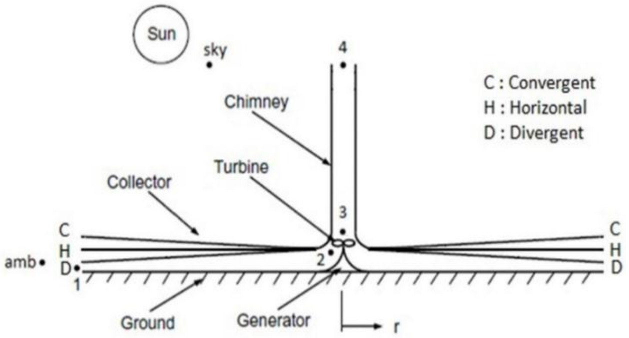

Fig. 1. Schematic of the solar chimney power plant with divergent, convergent and horizontal type collectors

Temperature, velocity and pressure distribution are obtained by solving conservation of energy, momentum and mass equations. These equations are indicated for the air flow in collector of the solar chimney and for a control volume of radius r to r+dr shown in Fig. 2. Also energy equations are defined for the considered control volume based on thermal network shown in Fig 3.

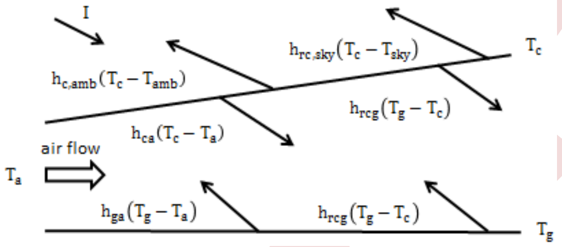

Fig. 2. Energy balance diagram in the control volume considered in the collector

Energy balance equation for the airflow indicates heat transfer between air flow in the collector, the roof of the collector and the ground: [25]

$$A_g q_{ga} + A_c q_{ca} = c_p \dot{m}_{air}(T_2 - T_1) \tag{1}$$

The following relation calculates mass flow rate: [25]

$$\dot{m}_{air} = \rho_a A V_a \tag{2}$$

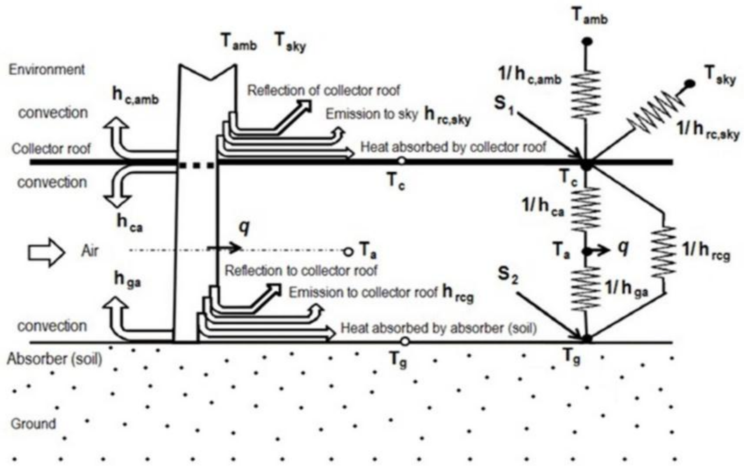

Fig. 3. Thermal network for solar chimney collector

Density variations of the air flow inside the collector is calculated based on the Boussinesq approximation: [6]

$$\rho_a = \rho_{amb}\left(1 - \beta_{amb}(T_a - T_{amb})\right) \tag{3}$$

$$\beta_{amb} = \frac{1}{T_{amb}} \tag{4}$$

Energy exchange for the collector roof that shows energy absorption from the sun and its transfer to the inside of the collector and its loss to outside of the collector can be calculated from following relations: [25]

$$S_1 = q_{rc,sky} + q_{c,amb} + q_{ca} + q_{r,cg} \tag{5}$$

The amount of the absorbed energy from the sun by the roof of the collector:

$$S_1 = \alpha_c . I \tag{6}$$

Mechanism of heat transfer between collector roof and airflow inside the collector is forced convection heat transfer that is calculated by:

$$q_{ca} = h_{ca}(T_c - T_a) \tag{7}$$

Heat transfers between the ground and the air flow inside the collector:

$$q_{ga} = h_{ga}\left(T_g - T_a\right) \tag{8}$$

Heat transfer between the collector roof and the ambient air:

$$q_{c,amb} = h_{c,amb}(T_c - T_{amb}) \tag{9}$$

Forced convection heat transfer coefficient of ambient air is calculated according to the relation used in Ref. [25]. For calculating the heat transfer coefficients of collector, the governing equations for the flat plate with constant heat flux can be used. Equations are introduced in two categories of laminar and turbulent flows by relations used in Ref. [3], [28]

The radiation heat transfer between the collector roof and ambient air can be calculated as following:

$$q_{rc,sky} = \varepsilon\sigma\left({T_c}^4 - {T_{amb}}^4\right) \tag{10}$$

The contribution of radiation heat transfer, between the collector roof and the ground can be obtained as following relation:

$$q_{r,cg} = \varepsilon\sigma\left({T_c}^4 - {T_g}^4\right) \tag{11}$$

The energy exchange of the ground is calculated by Eq. (12), which includes amounts of received transmission energy from the collector surface and the amount of transfer to the air content of the collector and its exchange with collector surface: [25]

$$S_2 = q_{ga} + q_{r,cg} \tag{12}$$

The amount of received radiation by the ground:

$$S_2 = \alpha_g \tau_c I \tag{13}$$

Bernoulli equation governing on the collector is of following form:

$$P_1 + \frac{\rho_1 V_1^2}{2} = P_2 + \frac{\rho_2 V_2^2}{2} \tag{14}$$

2.2 Governing equations in the turbine

The mounted turbine at the entrance of the chimney turns the kinetics energy of the crossing air through the chimney to the electrical power. The process in the turbine is assumed to be isentropic: [9]

The power production in the turbine is calculated from the following relation: [6]

$$P_e = c_p \dot{m}_{air}(T_2 - T_3) \tag{15}$$

Due to isentropic assumption as well as ideal gas assumption for the air the following relation can be employed (See Fig. 1):

$$\frac{P_3}{P_2} = \left(\frac{T_3}{T_2}\right)^{\gamma/\gamma-1} \tag{16}$$

2.3 Governing equations in the chimney

Chimney turns the thermal energy in the collector to the Kinetic energy. The created density difference in the system caused by increased temperature leads to pressure difference and driving force for driving the turbine and natural suction. Chimney walls assumed adiabatic.

Governing pressure equation in the chimney can be written as:

$$P_3 = P_4 + \rho_3 g H_{ch} + \Delta P_f \tag{17}$$

ΔP_f is the frictional loss within the chimney that is indicated as below:

$$\Delta P_f = f\frac{\rho H_{ch}}{d_{ch}}\frac{V^2}{2} \tag{18}$$

f denotes the friction coefficient of the chimney wall, which is calculated by the relations used in Ref. [1]

The pressure at the outlet of the chimney is obtained by the following relation:

$$P_4 = P_{amb} - \rho_{amb} g H_{ch} \tag{19}$$

3. Solution algorithm

The given equations in previous section were non-linear. Values related to temperature in different points and power production can be obtained by using the repetitive algorithm and initial estimations for temperature and mass flow rate in different parts of the system. P_3 and P_4 are achieved by using the chimney equations, velocities at points 1-4 (shown in Fig. 1) is obtained by continuity equation. Its solution flowchart is given in Fig. 4. Dimensional and physical characteristics which are used in this model are given in Table 1 and Table 2 respectively.

Table1. Used physical properties in modelling

Solar radiation (w/m^2)	1000
Ambient pressure (Pa)	101325
Ambient temperature (K)	293
Prandtl number	0.712
Gravitational acceleration(m/s^2)	9.81
Ambient air density (kg/m^3)	1.151
Ideal gas constant	287
air conductivity (W/(m.K))	0.0263
Collector roof absorptivity (α_c (m^2/s))	0.15
Ambient air velocity (m/s)	3
Air viscosity	18.65×10^{-6}
Collector roof emissivity	0.87
Stefan – Boltzman constant (σ)	5.667×10^{-8}
Ground absorptivity (α_g (m^2/s))	0.9
Collector transmissivity (τ_c)	0.85
Heat capacity (J/(kg.K))	1005

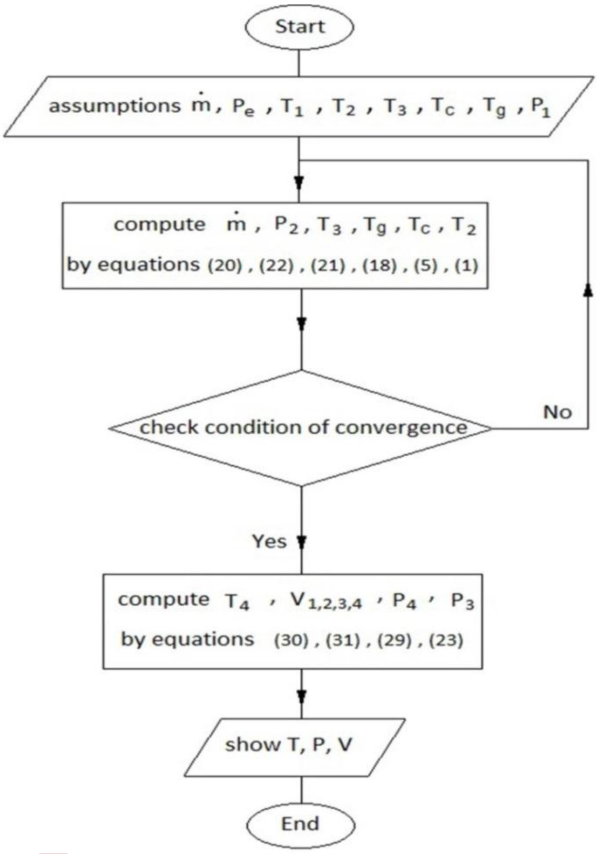

Fig. 4. Solution algorithm flowchart

Table2. Employed dimensional features in modelling the divergence, convergence and horizontal collectors.

parameter	Divergent	Horizontal	Convergent
Collector radius (m)	120	120	120
Mean Collector height (m)	1.802	1.802	1.802
Chimney radius (m)	5.08	5.08	5.08
Chimney height (m)	194.6	194.6	194.6
Teta (degree)	1.1	0	1.1
Collector outlet Height (m)	2.955	1.802	0.65

4. Model verification

The model verification is accomplished using results of Sangi [9], Dhahri [29] and Huang [30]. In this regard, the air temperature at the collector outlet, velocity at the chimney inlet and temperature distribution through the collector were compared to corresponding results of the Manzanares solar chimney power plant, Sangi [9], Dhahri [29] and Huang [30]. Comparisons between results of the present study for the divergent type collector with similar works in the literature are shown in Figs. 5-6.

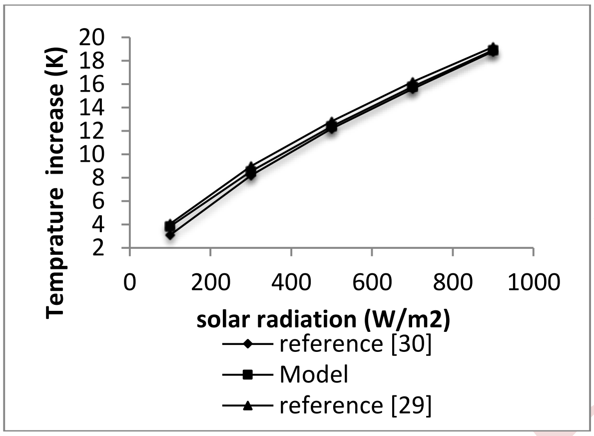

Fig. 5. Effects of solar radiation on the temperature increment in the divergent-type collector (Comparison between the present results and those of Dhahri [29] and Huang [30]

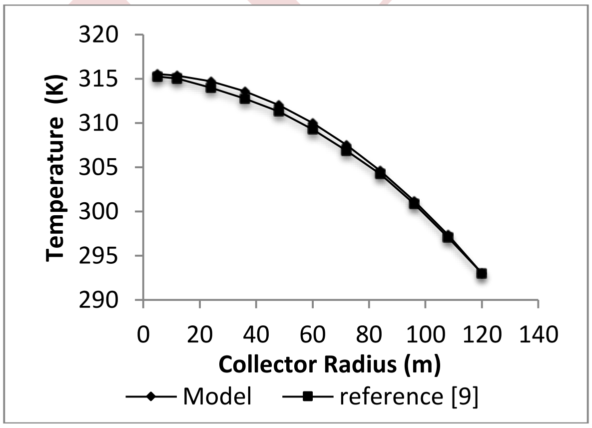

Fig. 6. Temperature distribution in the divergent type collector (comparison with results of Sangi [9])

4.1 Mesh independency

The effects of number of elements used in the collector model on the obtained results should be considered. The outlet temperature of the collector is employed as the criterion. By increasing number of elements, the outlet temperature varies, the variation continues up to element number of 400. Furthermore, elements don't influence the obtained temperature. Fig. 7 shows the effects of numbers of elements in the collector on the collector outlet temperature.

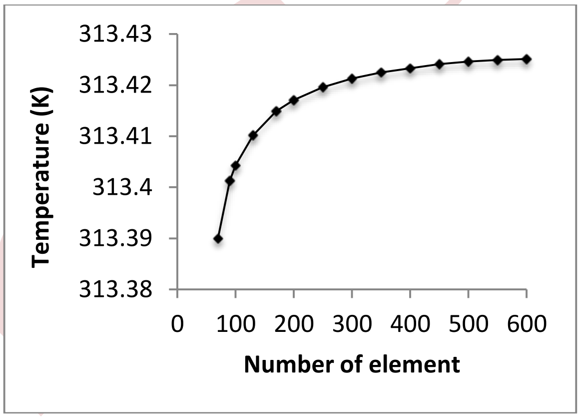

Fig. 7. Influence of Number of Independent elements in divergent type collector on the collector outlet temperature

5. Results

Fig. 8 shows influences of roof angle of a divergent type collector with constant inlet height on collector outlet temperature and power production in turbine, for radiation 1000 w/m^2. As can be seen in the figure, when the roof angle of the collector increases, the collector outlet temperature will decrease and since the collector outlet height is going to be higher by increasing the angle, the area will increase and the temperature will decrease. Increasing the roof angle of the collector, also leads to more power production in the turbine, since the mass flow rate and the velocity at chimney entrance were increased.

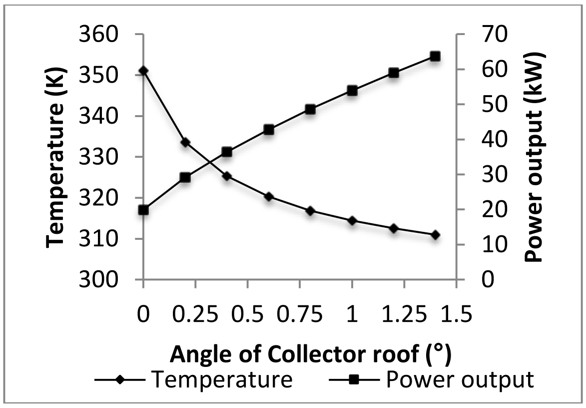

Fig. 8. Effect of roof angle of a divergent- type collector with constant inlet height on collector outlet temperature and power output in the turbine

Variations of the outlet temperature for the various solar radiations are plotted for the three types of collectors (convergent, divergent and horizontal type), with constant mean height, in Fig. 9. As can be found from the figure, increasing the solar radiation may enhance the outlet collector temperature by absorbing more thermal energies. But in convergent type collector, temperature increasing is more because of less area.

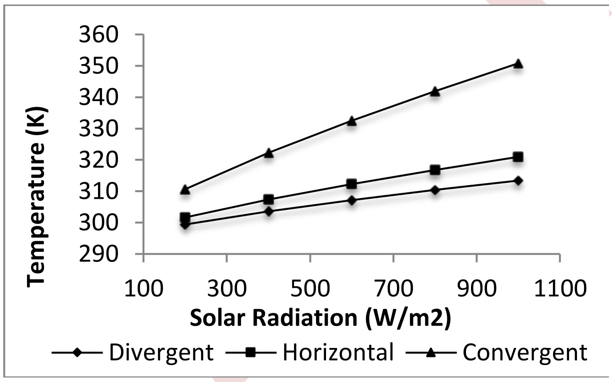

Fig. 9. Temperature at the collector outlet versus solar radiation, for mean collector height of 1.802 m

Power productions in the turbine for the variety of solar radiations are demonstrated for the three types of collectors, with constant mean height, in Fig. 10. As the figure shows, the power production increases with solar radiation, since thermal absorbing and collector outlet temperature is increased, the temperature difference between the chimney base and the chimney outlet will be more and then the buoyancy force will be more and air flow velocity in the system will be increased which led the moving of the turbine blades. It can be found from the figure that the power production in the divergent type collector is more since the mass flow rate and velocity at the chimney entrance are higher.

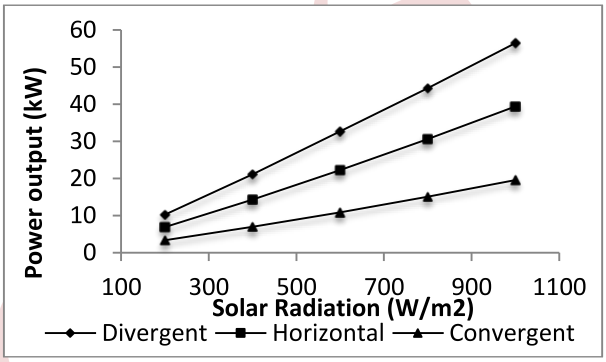

Fig. 10. Effects of solar radiation on the power output in the turbine, for mean collector height 1.802 m

Fig. 11 shows the temperature distribution of the airflow passing through the collector for roof angle of 1.1° and radiation of 1000 w/m^2. As can be observed in the figure, the temperature of the air, passing through the collector, increases with more absorbed radiation.

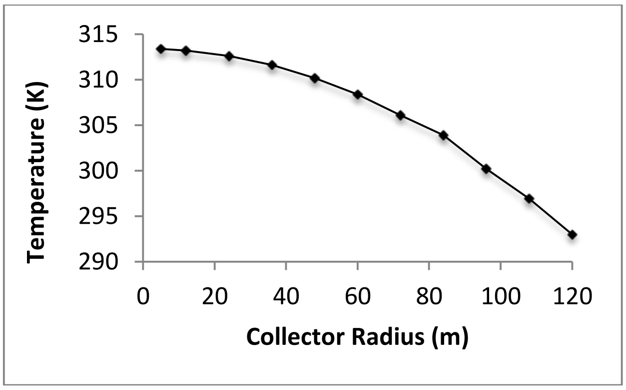

Fig. 11. Temperature distribution of the airflow passing through the collector

Fig. 12 shows the effects of roof angle (divergent, convergent, and horizontal) on the turbine power production for radiation of 1000 w/m^2 and collector outlet constant height of 2m. As explained before, temperature increasing level in the divergent type collector is more than the two other types. Therefore, the suction level and the turbine power production will be more.

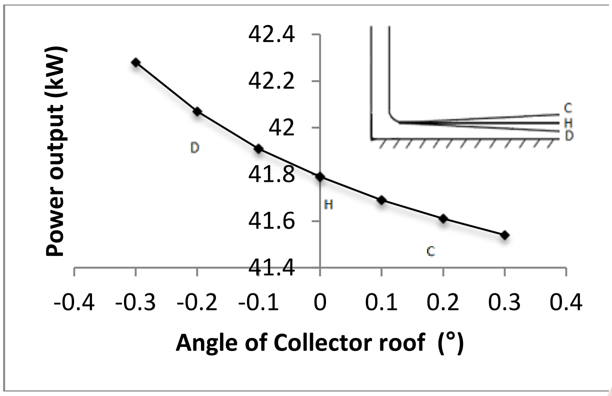

Fig. 12. Effects of the roof angle (divergent, convergent, horizontal) on the turbine power production for constant height of collector outlet.

Effects of collector roof angle (divergent, convergent and horizontal) on the air temperature at the collector outlet are shown in Fig. 13. The figure is plotted for the constant outlet height and radiation of 1000 w/m^2. As can be seen in the figure, the temperature variation is low because of constant outlet height. Although the temperature in the divergent type collector is more than two other forms, due to the lesser outlet area and consequently the more air velocity.

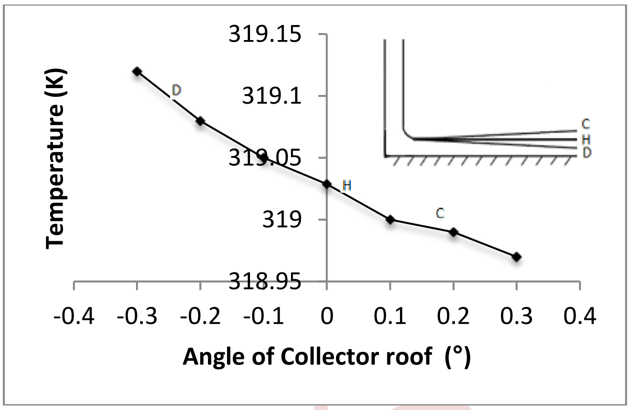

Fig. 13. Effects of collector roof angle (divergent, convergent and horizontal) on the air temperature at the collector outlet, for the constant outlet height

Fig. 14 shows the effects of collector roof angle (divergent, convergent and horizontal) on the turbine power production for constant inlet height of 2m and radiation of 1000 w/m^2. Mass flow rate as well as the velocity at the chimney entrance in the divergent type collector is more than two other states, so the power production and the suction level will be increased.

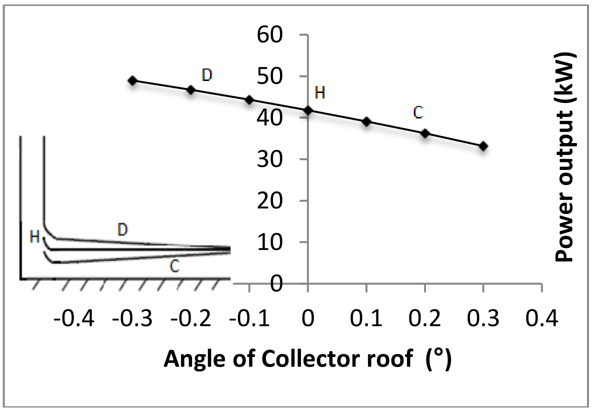

Fig. 14. The effects of collector roof angle (divergent, convergent and horizontal) on the turbine power production for the constant inlet height

Effects of collector angle (divergent, convergent and horizontal) on the outlet air temperature of collector for constant inlet height and radiation power of 1000 w/m^2. As can be seen in the Fig. 15, the temperature variation is significant due to the alteration of outlet height. The temperature of divergent type is more than the horizontal (zero degree) and the convergent type collector, as it has less outlet surface and, in consequence, more air flow velocity.

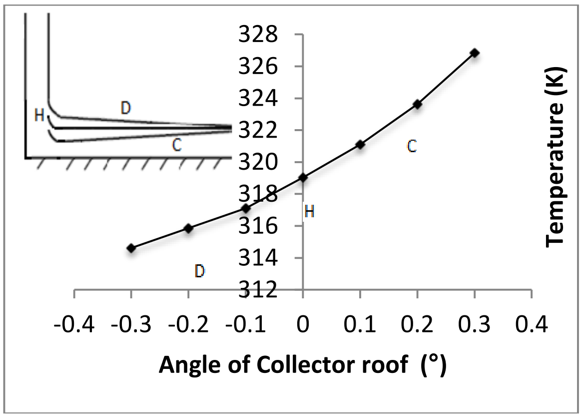

Fig. 15. The effects of collector angle (divergent, convergent and horizontal) on the outlet air temperature of collector for the constant inlet height

Some conclusions can be remarked based on the above discussions:

1. As shown by the results, performance of the divergent type collector is better than the two other forms, due to higher amounts of mass flow rate and power production. Power production in the divergent type collector is 3 and 1.5 times more than the convergent and the horizontal collectors respectively.
2. Since the divergent type collector has better performance in respect to convergent and the horizontal collectors, the effects of angle increment in the divergent type collector for constant inlet height was investigated. In this case, the more the angle, the more power production may be achieved in a way that within the angle variation from 0.8° to 1°, the power production increased by 11%.
3. The results were obtained based on three states for the collector: constant inlet height, constant mean height and constant outlet height :

- In the divergent type collector with constant inlet height, when the angle increases, the temperature will decrease and the power production will increase as mass flow rate increases in a way that within angle variation from 0.8° to 1° the outlet temperature is decreased by 0.78% and the power outlet is increased by 11%.
- For the constant mean height of the collector, if the receiving radiation increases, outlet temperature in the convergent type collector will be more than the two others and the power production in the divergent type collector will be more than the two other forms, so that increasing the radiation from 800 W/m^2 to 1000 W/m^2 enhances the temperature in the convergent type collector by 2.63% and the power production in the divergent type collector by 21.59%.
- For the constant inlet height of the collector, because of more outlet height than the two other types, if the divergent type collector angle increases, the produced power will be more and the collector outlet temperature will be lesser than the two other cases, while by increasing the angle of the convergent type collector, because of lesser outlet height in respect to the other two cases, the produced power decreases and the collector outlet temperature increases. For angle variation of 0.1° to 0.2° in the divergent type collector, the outlet temperature decreases by 0.46% and the power output increases by 5.37% while in the convergent type collector the first increases by 0.79% and the latter decreases by 7.34%.

6. Concluding Remarks

The performance of the solar chimney power plant for three types of divergent, convergent and horizontal collectors is comprehensively assessed in this study. In this regard, an inclusive mathematic model is proposed for thermal simulation of the turbine, the collector and the chimney. The governing equations are solved numerically.

1. The results reveal that the performance of the divergent collector is higher than the two other types, since it has more mass flow rate.
2. The outlet air temperature of the divergent collector and turbine production power are obtained 313.4K and 56.5kw, respectively, for the radiation power of 1000 W/m^2.
3. Due to the better performance of the divergent type collector, effects of angle increasing in the divergent collector for constant inlet height are studied. In this case, the production power is found to be intensified as the angle increases.
4. The results are obtained based on three cases namely constant inlet height, constant mean height and constant outlet height of the collector. In the divergence collector with constant inlet height, when the angle increases, the temperature will decrease and the produced power will increase due to higher mass flow rates. For the case of constant mean height of the collector, when the receiving solar radiation increases, the outlet temperature in the convergent collector will be higher than the other forms, in contrast the produced power of the divergent collector will be higher than two other forms. For the case of constant outlet collector height, the temperature and produced power in the divergent collector is higher than the other forms, but the difference is not significant in comparison with previous cases.

Reference

[1] M.A. Bernardes, A. Vob, G. Weinrebe, "Thermal and technical analyses of solar chimneys", *Solar Energy* Vol. 75, pp. 511-524, (2003).

[2] M.A. Bernardes, "Convective heat transfer coefficients for solar chimney power plant collectors", *Heat transfer-Mathematical modelling, Numerical Methods and Information Technology*, Prof. Belmiloudi A, (2011).

[3] M.A. Bernardes, T. W. von Backstrom, D. G. Kroger, "Analysis of some available heat transfer coefficients applicable to solar chimney power plant collectors", *Solar Energy* Vol. 83, pp. 264-275, (2009).

[4] M.A. Bernardes, T. W. von Backstrom, "Evaluation of operational control strategies applicable to solar chimney power plants", *Solar Energy* Vol. 84, pp. 277-288, (2010).

[5] M. Tigzhen, L. Wei, X. Guoling, X. Yanbin, G. Xuhu, P. Yuan, "Numerical simulation of the solar chimney power plant systems coupled with turbine", *Renewable Energy* Vol. 33, pp. 897-905, (2008).

[6] R. Petela, "Thermodynamic study of a simplified model of the solar chimney power plant", *Solar Energy* Vol. 83, pp. 94-107, (2009).

[7] C.B. Maia, J.O. Castro Silva, L. Cabezas-Gomez, S.M. Hanriot, A.G. Ferreira, "Energy and exergy analysis of the airflow inside a solar chimney", *Renewable and Sustainable energy reviews* Vol. 27 pp. 350-361, (2013).

[8] A. J. Gannon, T. W. von Backstrom, "Solar chimney cycle analysis with system loss and solar collector performance", *Solar energy engineering*, pp. 122-133, (2000).

[9] R. Sangi, M. Amidpour, B. Hosseinizadeh, "Modelling and numerical simulation of solar chimney power plants", *Solar Energy*, (2011).

[10] R. Sangi, "Performance evaluation of solar chimney power plant in Iran", *Renewable and Sustainable energy reviews* Vol. 16, pp. 704-710, (2012).

[11] Y.J. Dai, H.B. Huang, R.Z. Wang, "Case study of solar chimney power plants in Northwestern regions of China", *Renew Energy* Vol. 28, pp. 1295-1304, (2003).

[12] S. Larbi, A. Bouhadjar, T. Chergui, "Performance analysis of a solar chimney power plant in the southwestern region of Algeria", *Renewable and Sustainable energy reviews* Vol. 14, pp. 470-477, (2010).

[13] A. Kasaeian, M. Ghalamchi, M. Ghalamchi, "Simulation and optimization of geometric parameters of a solar chimney in Tehran", *Energy Conversion and Management* Vol. 83, pp. 28-34, (2014).

[14] A. Kasaeian, E. Heidari, Sh. Nasiri Vatan, "Experimental investigation of climatic effects on the efficiency of a solar

chimney pilot power plant", *Renewable and Sustainable energy reviews*, (2011).

[15] S. K. Patel, D. Prasad, M. R. Ahmed, "Computational studies on the effect of geometric parameters on the performance of a solar chimney power plant", *Energy conversion and Management*, Vol. 77, pp. 424-431, (2014).

[16] A. Koonsrisuk, T. Chitsomboon, "Mathematical modeling of solar chimney power plants", *Energy* Vol. 51, pp. 314-322, (2013).

[17] A. Koonsrisuk, T. Chitsomboon, "Dynamic similarity in solar chimney modelling", *Solar Energy* Vol. 81, pp. 1439-1446, (2007).

[18] P. Gou, J. Li, Y. Wang, Y. Liu, "Numerical analysis of the optimal turbine pressure drop ratio in a solar chimney power plant", *Solar Energy* Vol. 98, pp. 42-48, (2013).

[19] P. Guo, J. Li, Y. Wang, Y. Wang, "Evaluation of the optimal turbine pressure drop ratio for a solar chimney power plant", *Energy Conversion and Management*, Vol. 108, pp. 14-22, (2016).

[20] X. Zhou, F. Wang, J. Fan, RM. Ochieng, "Performance of solar chimney power plant in Qinghai-Tibet Plateau", *Renewable and Sustainable energy reviews* Vol. 14, pp. 2249-2255, (2010).

[21] X. Zhou, J. Yang, B. Xiao, G. Hou, F. Xing, "Analysis of chimney height for solar chimney power plant", *Thermal Engineering*, (2008).

[22] J.P. Pretorius, D.G. Kroger, "Critical evaluation of solar chimney power plant performance", *Solar Energy* Vol. 80, pp. 535-544, (2006).

[23] Y.J. Choi, D. H. Kam, Y.W. Park, Y. H. Jeong, "Development of analytical model for solar chimney power plant with and without water storage system", *Energy*, Vol. 112, pp. 200-207, (2016).

[24] A. S. Cocic, V. D. Djordjevic, "One dimensional analysis of compressible flow in solar chimney power plants", *Solar Energy*, Vol. 135, pp. 810-820, (2016).

[25] L. Zuo, Y. Zheng, Z. Li, Y. Sha, "Solar chimneys integrated with sea water desalination", *Desalination* Vol. 276, pp. 207-213, (2011).

[26] X. Zhou, B. Xiao, W. Liu, X. Guo, J. Yang, J. Fan, "Comparison of classical solar chimney power system and combined solar chimney system for generation and seawater desalination", *Desalination* Vol. 250, pp. 249-256, (2010).

[27] N. Niroomand, M. Amidpour, "New combination of solar chimney for power generation and seawater desalination", *Desalination and Water Treatment* Vol. 51, pp. 7401-7411, (2013).

[28] J. P. Holman, *Heat transfer*, 10th ed, McGraw-Hill, New York, pp. 247-248 , 236.

[29] A. Dhahri, A. Omri, J. Orfi, "CFD modelling of a solar chimney power plant", *International Congress on Renewable Energies and the Environment*, (2012).

[30] H. Huang, H. Zhang, Y. Huang, F. Lu, "Simulation calculation on solar chimney power plant system", *International conference on power engineering*, pp. 1158-1161, (2007).