Journal of Applied Sciences

ISSN 1812-5654

science alert

ANSInet
an open access publisher
http://ansinet.com

OPEN ACCESS Journal of Applied Sciences

ISSN 1812-5654
DOI: 10.3923/jas.2017.502.510

Research Article
Numerical Simulation on Thermal Performance of Flat Plate Solar Collector with Double Glass Covers

[1]Fahim Ullah, [2]Mansoor Khan Khattak, [1,3]Min Kang, [1]Ninghui Li, [1]Jun Yang and [1]Xingsheng Wang

[1]College of Engineering, Nanjing Agricultural University, 210031 Nanjing, People's Republic of China
[2]Department of Agricultural Mechanization, FCPS, The University of Agriculture Peshawar, KP, Pakistan
[3]Guanyun Research Institute for Modern Agricultural Equipment, Nanjing Agricultural University, 222200 Guanyun, China

Abstract

Background and Objectives: In this study, the numerical simulation of the steady-state thermal performance of flat plate solar collector with double glass cover, physical model, validation and its grid independence test were performed with the finite volume method. Moreover, through comparison with the conventional plate heat collector, the effects of ambient temperature, the inlet water temperature, solar radiated intensity and lower glass cover position on thermal performance of the heat collector were investigated. **Materials and Methods:** For the simulation of FPSC with double glass covers different physical model, geometric and boundary condition were used and also regression analysis was applied on the data. **Results:** From the investigated results, it was cleared that, when the ambient temperature is below 18°C, the collector with double glass covers shows advantages, while when the ambient temperature is -10°C, the instantaneous efficiency of the flat plate solar collector with double glass covers was noted 0.26 higher than that of the conventional plate heat collector. Similarly, increase in the inlet water temperature and solar radiate intensity both results in an increase in the temperature inside the collector, which enhances the insulation effect of the double glass covers. **Conclusion:** When the inlet water temperature was 50°C, the instantaneous efficiency difference between the flat-plate solar collector with the double glass covers and the conventional one increases to 0.27. Furthermore, concluded from the results of the experiment that, when the lower glass cover is located 18 mm over the absorber plate and the solar radiated intensity is to be 1000 W m^{-2}, the instantaneous efficiency of the flat-plate solar collector with the double glass covers can reach up to 0.678.

Key words: A flat-plate solar collector, double glass cover, thermal performance, the finite volume method, numerical simulation

Citation: Fahim Ullah, Mansoor Khan Khattak, Min Kang, Ninghui Li, Jun Yang and Xingsheng Wang, 2017. Numerical simulation on thermal performance of flat plate solar collector with double glass covers. J. Applied Sci., 17: 502-510.

Corresponding Author: Min Kang, College of Engineering, Nanjing Agricultural University, 210031 Nanjing, People's Republic of China

Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

The thermal use of solar energy is an effective way to alleviate the consumption of traditional fossil energy[1] and has conducted a number of relevant research work[2-5]. Present a wide range of collector include the all-glass evacuated tubular collector, heat pipe vacuum tube solar collectors, as well as flat-plate solar collector[6], with the increasing demand for the solar building integration, flat-plate solar collector because of its simple structure, pressure, durability, low maintenance, high heat efficiency, low production costs and will become the future trend of solar water heaters[5,7]. Flat solar collector is in flat shape, its working principles, exposure to sunlight through glass cover on the heat plate, the absorber plate converts solar radiation into heat transfer to the refrigerant in a tube[8]. Collector during operation because of convection, conduction radiation and dissipate heat into the environment, causing the collector heat loss[9,10].

Over the past decades, the research focuses on the thermal performance of flat-plate solar collector and in order to obtain more compact, lighter, higher efficiency of flat-plate solar collectors. Many researchers have been done a lot of experiments and theoretical studies[11]. With the development of computer technology and sophisticated CFD technology and numerical simulation has become an important means of scientific research[12,13]. For the thermal performance of flat-plate solar collector, researchers used numerical simulation method. Lu *et al.*[14] fixed temperature discharge were studied using numerical simulation method of DC system in the working conditions of the flat-plate solar collector, discussed the conditions of unsteady state heat transfer, heat pipe diameter, center distance to the collector efficiency and influence of heat production per unit area. Norm[15] done an experiment on the analysis and optimization of the thermal performance of flat-plate solar collector design, established a mathematical model of the steady-state performance of flat-plate solar collector and the thermal performance simulation program is compiled to analyze the environmental parameters and structure parameters on the instantaneous efficiency characteristics of the collector. Selmi *et al.*[16] and Brain[17] introducing the efficiency factor, building a mathematical model of flat plate collector, computer programming according to data from the core absorber plate geometry structure and core material effects on the performance of flat-plate solar collector.

Bei *et al.*[18] conducted an experiment with the new kind of snake-like tubular solar plate collector with the using of finite element method for the numerical simulation and experimental research and noted that simulation model proves the effectiveness and geometric parameters of the thermal performance of collector. Rojas *et al.*[19] studied the using of simulation analysis on the flat-plate solar collector which covered the board layer number, heat loss, performance of parameters, efficiency, export temperature of the target functional area, absorber pipe diameter, spacing of absorber pipe and optimization of the working quality of fluid flow in the collector. Saito *et al.*[20] and Sun *et al.*[21] conducted the experiment and numerical simulation study on the performance of flat-plate solar collector and they concluded from the results that the simulation results agree with the experimental results of the flat-plate solar collector and they also conclude and recommend that numerical simulation method can be used in a more complex on the thermal performance of flat-plate solar collector.

The aim of the present research was to investigate the numerical simulation on thermal performance of flat-plate solar collector with the using of double glass covers and analyzing the ambient temperature, refrigerant inlet temperature and intensity of solar radiation, transparent and determination of the instantaneous efficiency of insulation panels of the flat-plate solar collector.

MATERIALS AND METHODS

Site location: The experimental research was performed in the experimental field of the College of Engineering, Nanjing Agricultural University, China in the year, 2016 with the latitude, longitude and average elevation of 32.0611°N, 118.778°E and 12 m (39 ft), respectively.

Construction of geometric and physical model of FPSC: Flat-plate solar collector structure as shown in Fig. 1, with the parameters of the absorber plate, collector tube, heat plate bottom insulation layer, double glass cover, heat pipe, heat-absorbing panels, copper, aluminum and wood frame. The dimension and materials parameter of the model is shown in Table 1. During the operation of flat-plate solar collector the inlet water temperature is 20°C, ambient temperature is 15 , within a single tube working mass flow rate is 0.005 kg sec^{-1}, wind is assumed to 4 m sec^{-1}, considering the entire collector absorber unit periodically, numerical simulation of thermal unit and heat unit as shown in Fig. 2.

Mathematical modeling: In flat-plate solar collector for the determination of flow heat transfer, mean velocity gradient, turbulent kinetic energy, radiant transfer properties of scattering, absorption and emission of the medium can calculate with using the following equations.

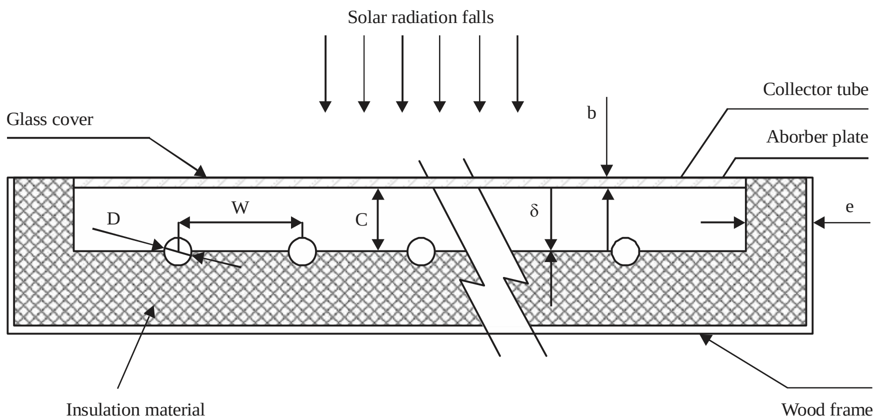

Fig. 1: Schematic diagram of flat-plate solar collector

Table 1: Dimension and physical parameters of flat-plate solar collector

Materials		Symbol		Dimension (mm)
Tube length		L		1800.0
Tube spacing		W		110.0
Tube outside diameter		D		12.0
Tube wall thickness		s		1.0
The absorber plate thickness		t		0.9
Insulation thickness		e		30.0
Thickness of the glass cover		b		4.0
Glass cover to the absorber plate distance		c		30.0
Transparent insulation panel position		H		12.0
Physical parameters	Aluminum	Copper	Wood	Glass cover
Density (kg m^{-3})	2700.0	8920.0	140.00	2200.00
Specific heat capacity (J (kg k)$^{-1}$)	900.0	385.0	1220.00	830.00
Thermal conductivity (W (m k)$^{-1}$)	120.0	398.0	0.039	0.76
Transmission rates	0.0	0.0	0	0.90
Emissivity	0.1	0.1	-	0.90
Absorption rate	0.9	0.9	-	0.10

- Flow heat transfer[22]

$$\text{Div}(\rho U) = \text{div}(T\ \text{grad}) + S \quad (1)$$

For the determination of mean velocity gradients[23] and turbulent kinetic energy (k) can be calculated using of Eq. 2:

$$\left\{\begin{array}{l} G_k = \mu_t \left\{\begin{array}{l} 2\left[\left(\frac{\partial u}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial y}\right)^2 + \left(\frac{\partial w}{\partial z}\right)^2\right] + \\ \left(\frac{\partial u}{\partial y} + \frac{\partial v}{\partial x}\right)^2 + \left(\frac{\partial u}{\partial z} + \frac{\partial w}{\partial x}\right)^2 + \left(\frac{\partial v}{\partial z} + \frac{\partial w}{\partial y}\right)^2 \end{array}\right\} \\ \mu_t = \rho c_\mu \frac{k^2}{\varepsilon} \end{array}\right\} \quad (2)$$

In flat-plate solar collector at the direction (f) at the position (r) of the radiated transfer for scattering, absorption and emission properties of the medium can be determined using the following Eq. 3 reported by literature of Patankar[24]:

$$\nabla.\left(I(r, f)f\right) + \left(\acute{\alpha} + \beta_f\right)I(r, f) = \acute{\alpha} n^2 \frac{\sigma T'^4}{\pi} + \frac{\beta_f}{4\pi}\int_0^{4\pi} I(r, f)\phi(f.f)d\Omega \quad (3)$$

Boundary conditions: Collector tubes entrance for speed and outlet for pressure outlet, that is and. The closer wall velocity with the no-slip boundary condition of the collector with the models of the both sides for the symmetric boundary conditions as shown in Fig. 2b. Control equations are discredited by the finite volume method, select second-order upwind scheme for discrete equations, using the IMPLE algorithms dealing with the pressure and speed of the coupling.

Parameter definition: Flat-plate solar collector when running under steady-state conditions, working fluid into useful energy per unit time can be calculated from Eq. 4 by Lu *et al.*[14], while the value of F_R which is the heat transfer factor Ameur *et al.*[25] could be determined using Eq. 5 and value should be determined using Eq. 6:

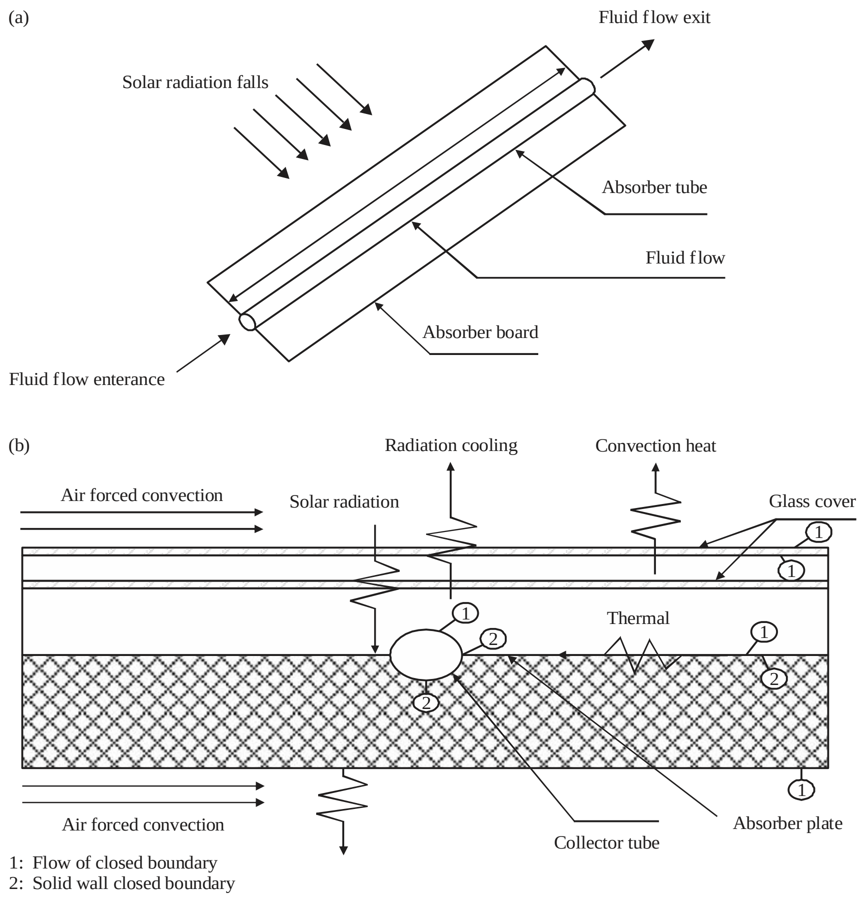

Fig. 2(a-b): Schematic diagram of the heat collecting unit of flat-plat solar collector, (a) Tube collector and hot plate and (b) Section view of collector

$$Q_u = AF_R\,[I\,(\tau\alpha)\text{-}U_L\,(T_{f,i}\text{-}T_a)] \tag{4}$$

$$F_R = \frac{mC_p}{AU_L}\left[1-\exp\left(-\frac{F'U_L A}{mC_C}\right)\right] \tag{5}$$

$$F' = \frac{\dfrac{1}{U_L}}{W\left[\dfrac{1}{U_L\left[D+\left(W-D\right)F\right]}+\dfrac{1}{C_b}+\dfrac{1}{\pi D_i h_{f,i}}\right]} \tag{6}$$

Performance output of flat-plate solar collector with the incident solar radiation falls on the collector per unit area can be determined using the Eq. 7:

$$Q = I.A \tag{7}$$

The instantaneous efficiency η is defined as a flat-plate solar collector and refrigerant per unit time absorbed into useful energy and incident per unit time on the flat plate collector area ratio of the radiant energy from the sun.

$$\eta = \frac{Q_u}{Q} = \frac{Q_u}{I.A} \tag{8}$$

In steady-state condition of the flat-plate solar collector, the instantaneous efficiency can be expressed as Benachour *et al*.[26]:

$$\eta = F_R\,(\tau\alpha) - F_R U_L \frac{(T_{f,i} - T_a)}{I} \tag{9}$$

$$U_L = \left[\frac{N}{\dfrac{344}{T_P}\times\left(\dfrac{T_P-T_a}{N+f}\right)^{0.31}}+\frac{1}{h_w}\right]^{-1} + \frac{\sigma\left(T_P+T_a\right)\times(T_P^2+T_a^2)}{\dfrac{1}{\varepsilon_P+0.0425N\left(1-\varepsilon_P\right)}+\dfrac{2N+f-1}{\varepsilon_g}-N} \tag{10}$$

$$f = (1.0\text{-}0.04h_w+5.0\times10^{-4}h_w^{2})+(1+0.058N) \tag{11}$$

$$h_w = 5.7+3.8v \tag{12}$$

Grid and physical model validation: Figure 3, shows the instantaneous efficiency trend with different grid number of the physical model with the ambient temperature T_a = 15, inlet water temperature T_{in} = 20, the intensity of solar radiation falls on the collector of about I = 700 W m^{-2}. The results in the Fig. 3 show that to increase the numbers of grids have little effect on the results of the instantaneous efficiency of the collector, while the difference of the instantaneous efficiency between the grid number of 377.3 and 305.6 was noted to 0.94%. The R^2 goodness of fit test was applied to the data to find that how much the data are closed and it was observed that the values are expected under the fitted linear model equation with the normal distribution and the R^2 value of data is 0.922.

So that, it is concluded from the results that the grid number less than 305.6 has a significant effect on the instantaneous efficiency, while when increasing the size of the grid number from 305.6 showing the non-significant effect on the instantaneous efficiency of the flat-plate solar collector. Other models are used for the model grid structure and grid nodes reported by Bei *et al*.[18] and Rojas *et al*.[19]. Figure 4, show the working fluid outlet temperature simulation and comparing experimental and calculated values. The results show the deviation is 3.40 and 1.29%, the data agree well proved that by using a physical model.

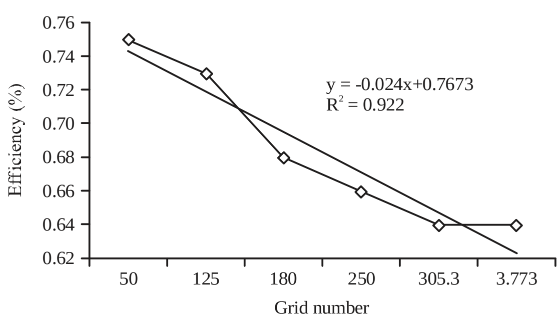

Fig. 3: Grid independent test result

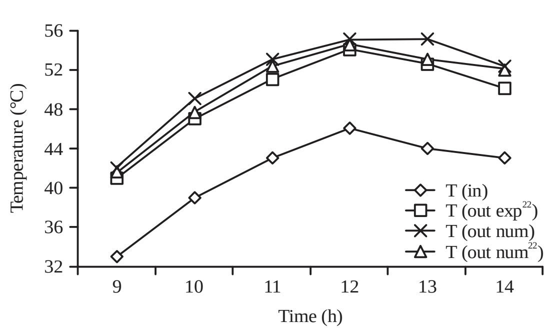

Fig. 4: Simulated and tested values of the working fluid outlet temperature

Statistical analysis: The experiment was performed in the College of Engineering with the regression method and also simulated the performance of flat plate solar collector with double glass cover.

RESULTS AND DISCUSSION

Effect of environmental temperature on the instantaneous efficiency collector: The intensity of solar radiation 700 W m^{-2}, then the double glass cover (A) and single layer glass cover (B) instantaneous efficiency of collector changes with the ambient temperature trend as shown in Fig. 5. The results show the instantaneous efficiency of two kinds of collector *i.e.* double glass cover (A) and single glass cover (B) increased with the increasing temperature from -10 to 40°C. Similarly the instantaneous efficiency of (A) and (B) glass covers were noted to increased 0.77 and 0.88, respectively. Ullah *et al*.[9] finding results was similar with these results and Sun *et al*.[21] and Patankar[24] results were in agreement with the findings of these results, reported that increasing temperature of collector increased the efficiency. Osorio and Carvalho[22] studied that efficiency of collector increased with the using of double glass cover plate.

From the Fig. 5, it was cleared that the instantaneous efficiency of the collector was found to be equal when the ambient temperature T_a = 18°C, while when the ambient temperature T_a 18°C, the instantaneous efficiency of the collector A was higher than collector B. Similarly, when the ambient temperature of the collector was T_a = -10°C, the instantaneous efficiency ratio of the collector B is highest of about 0.26. Further concluded from the result, when the ambient temperature T_a 18°C the instantaneous efficiency of collector A less than B. This is due to a double-layer glass cover effectively hinder the internal air natural convection heat collector, reduces the heat loss through the glass cover plate and instantaneous efficiency in favor of improving the

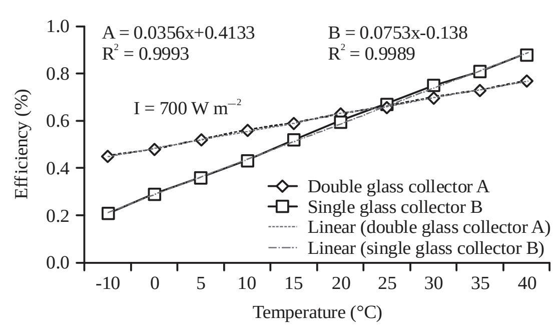

Fig. 5: Instantaneous efficiency of two types of collector with the ambient temperature

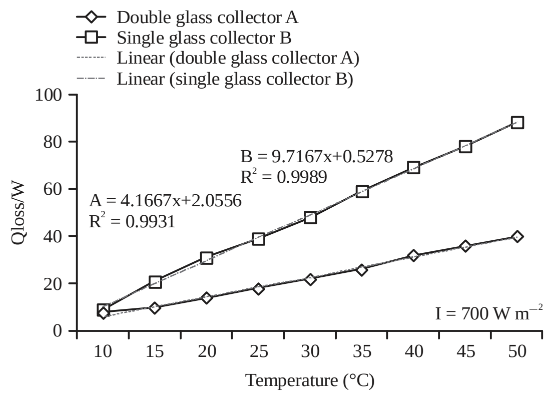

Fig. 6: Variations of heat loss and inlet water temperature of two types of collector

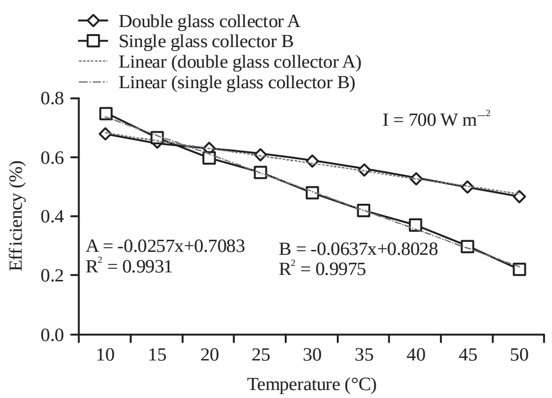

Fig. 7: Variations of instantaneous efficiency and inlet water temperature of two types of collector

collector. Low environment temperature (T_a<18°C), this effect is obvious, so the instantaneous efficiency of collector A higher than B, but at the same time, double glass cover absorb the sun's radiation under the environment of high temperature (T_a>18°C), the temperature difference between collector and the environment reduced thermal loss, double glass cover plates for collector of heat weakens, impeding the absorber plate to absorb solar radiation enhanced, resulting in the instantaneous efficiency of collector A less than B.

Influence of inlet water temperature on heat loss: Figure 6, shows the inlet water temperature and heat loss of both collector A and B and the collector heat loss vary with the changes of inlet water temperature. The results from the Fig. 6 shows that heat loss varies with the increasing of inlet water temperature from 10°C up to 50°C and the heat loss started increasing from 7.6 and 9.9 W up to 39.6 and 87.3 W for collector A and B, respectively. While the growth rate was noted 421 and 785% and B collector heat loss rate was 1.85 times of collector A with the higher inlet water temperature.

Similarly, with the increase of inlet water temperature, temperature difference between collector and the environment increase, due to the double glass panel heat when the refrigerant inlet temperature is high, the heat loss of collector A was less than collector B. Sun *et al.*[21] reported results are matched with our collector results and Osorio and Carvalho[22] Patankar[24] studied the heat loss of flat-plate collector which are in contradictory with our results. Similarly for the findings results of Villar *et al.*[27] and Tao[28] was nearly matched with present results. They studied that increasing of inlet temperature varies the heat loss of the collector.

Influence of inlet water temperature and instantaneous efficiency: Influence of inlet water temperature and instantaneous efficiency of both collectors is shown in Fig. 7. The results clearly show in the figure that the inlet water temperature of 10°C up to 50°C the instantaneous efficiency of collector A and B found 0.68 and 0.74 and started decreasing up to 0.46 and 0.21, respectively with the decrease rate was 8.8 and 54.3%. The results also show that the inlet water temperature decreases, the instantaneous efficiency of collector A much weaker than collector B. when the ambient temperature of collector T_{in} 17°C, the instantaneous efficiency of collector A less than collector B, while when the ambient temperature of collector T_{in} 17°C, instantaneous efficiency of A collector was higher than B. Similarly when the ambient temperature T_{in} = 50°C then the instantaneous efficiency of Collector B of 0.27%.

This is due to the inlet water temperature is low, the collector temperature is lower, double glass cover heat preservation effect is not obvious and impede the absorber plate heat-trapping effect, resulting in the instantaneous efficiency of collector A is less than collector B. Similarly, when the refrigerant inlet temperature is high, the collector temperature be increased accordingly, a double glass cover can reduce the heat collector heat loss. Although, double glass cover plates are still blocking the absorber plate heat, but at this point, the heat loss improves the efficiency of the collector A. The results are in agreements with the findings of Zambolin and Del Col[22], they reported that increasing of inlet water temperature increased the efficiency of the collector. Akhtar and Mullick[2] and Dhariwal and Mirdha[6] studied that efficiency is directly proportional to the inlet temperature of the collector are in agreement with the findings of these results.

Solar radiation effects on instantaneous efficiency of collector: Double glass cover and single glass cover collector instantaneous efficiency increased with the increasing intensity of solar radiation as shown in Fig. 8. The results from the Fig. 8 show that the instantaneous efficiency of collector

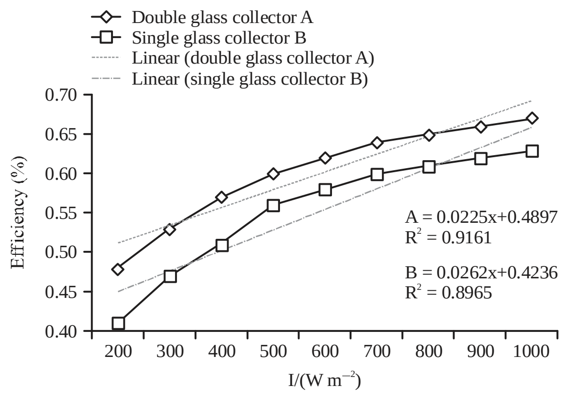

Fig. 8: Variations of instantaneous efficiency and solar radiation of two types of collector

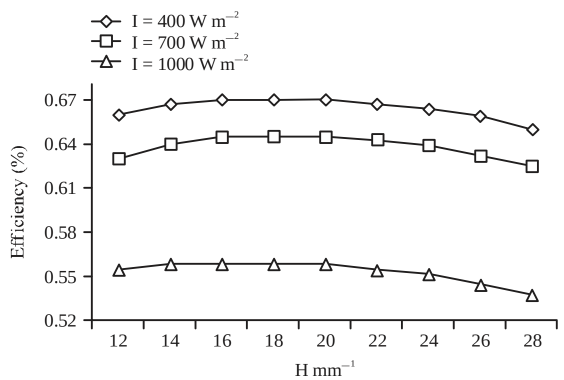

Fig. 9: Variations of instantaneous efficiency and H position of collectors A and B

A is always higher than B. Meanwhile, with the increase of solar radiation intensity the difference between the collector A and B, the instantaneous efficiency continues to expand, as the intensity of solar radiation increased from 200 W m^{-2} up to 1000 W m^{-2} the instantaneous efficiency of both collector A and B increased to 0.67 and 0.62, respectively. Further, from the figure result noted the difference value of 0.03% between collector A and B of 36.7 and 34.8%, respectively. This is because the double-layer thermal insulation of the glass cover effectively improves the efficiency of the collector A, in the condition of high solar radiation insulating effect is more obvious. Zhai *et al.*[30] reported that efficiency increased with the increasing of solar radiation is similar to the results. The results was in agreement with the findings by Osorio and Carvalho[22]. They studied that solar radiation is directly related to the efficiency of the collector. Kang *et al.*[11] and Zambolin and Del Col[29] findings results are in contradictory with our results. They conducted that increasing of solar radiation increased the efficiency of the solar collector.

Instantaneous efficiency effect on the second cover plate location in collector: The instantaneous efficiency of collector A changes with the second-tier cover position H as shown in Fig. 9 with the three different kinds of solar radiation intensity. Results from the Fig. 9 show that the instantaneous efficiency of collector A firstly increased and then decreased with the increasing value of H (transparent insulation panel position). Similarly, when the value of H was increased from 12-18 mm then the instantaneous efficiency of three different collector started increasing of 0.6, 0.9 and 0.88%, while when the value of H decreased from 18-28 mm, then the instantaneous efficiency started decreasing up to 4, 4.4 and 3.9%, respectively.

Furthermore, from the results noted the maximum instantaneous efficiency of three collectors was found to be 0.558, 0.642 and 0.678 with the 18 mm position of H, while when the single layer cover plate close to the absorber plate can effectively impede the natural convection heat transfer of air between the absorber plates. The instantaneous efficiency effectively improving the collector with the higher surface temperature increased the air between the double layer glass cover plates. When the transparent heat insulation panels from the absorber at about 18 mm, then the instantaneous efficiency of the collector reach the maximum value, while when the distance between double glass cover collector cannot be effectively weekend the natural phenomena of inlet air higher and decreasing cause the instantaneous efficiency of the collector. Norm[18] and Bei *et al.*[18] studied that efficiency of a solar collector increased with the distance between the absorber and insulation panel used in collector minimum, which is in agreement with our results. The results are in contradictory with the findings by Osorio and Carvalho[22] and Zhai *et al.*[30], they reported that efficiency of collector increased with the absorbing capacity of the absorber plate in the collector.

CONCLUSION AND FUTURE RECOMMENDATION

The results of this study concluded that when the ambient temperature is low, double glass cover heat preservation effect is more obvious and the instantaneous efficiency is highest. It was concluded from the results that the inlet water temperature increases, the instantaneous efficiency of collector decreased and the double glass cover plate can effectively reduce the heater radiator. Further, it was concluded from the results that the instantaneous efficiency of collector increased with the increasing intensity of solar radiation and recommended the double glass cover plates in the collector because the intensity of solar radiation is high. Furthermore, it was recommended from the results that the absorber plate of double glass cover plate above the second layer of glass cover with the distance of about 18 mm produce highest instantaneous efficiency.

SIGNIFICANCE STATEMENT

This study discovers the numerical simulation of flat plate solar collector double glass cover using physical model, grid independence test and also finite volume methods were applied that can be beneficial for the water heating, distillation and ventilation of storage building and agricultural, that consume less cost and provide high efficiency. This study will help the researcher to uncover the critical areas of agricultural field and also commercial areas for different purposes that many researchers were not able to explore. Thus a new theory on flat plate solar collector with double glass covers may be arrived at.

ACKNOWLEDGMENTS

Authors thank Min Kang for providing lab facilities. They extend their thanks to the China Scholarship Council and The College of Engineering, Nanjing Agricultural University, Nanjing, for supporting and providing research facilities for this study. There is no funding sources that supported this research study.

REFERENCES

1. Hestnes, A.G., 1999. Building integration of solar energy systems. Solar Energy, 67: 181-187.
2. Akhtar, N. and S.C. Mullick, 2007. Computation of glass-cover temperatures and top heat loss coefficient of flat-plate solar collectors with double glazing. Energy, 32: 1067-1074.
3. Alvarez, A., O. Cabeza, M.C. Muniz and L.M. Varela, 2010. Experimental and numerical investigation of a flat-plate solar collector. Energy, 35: 3707-3716.
4. Banos, R., F. Manzano-Agugliaro, F.G. Montoya, C. Gil, A. Alcayde and J. Gomez, 2011. Optimization methods applied to renewable and sustainable energy: A review. Renewable Sustain. Energy Rev., 15: 1753-1766.
5. Dagdougui, H., A. Ouammi, M. Robba and R. Sacile, 2011. Thermal analysis and performance optimization of a solar water heater flat plate collector: Application to Tetouan (Morocco). Renewable Sustain. Energy Rev., 15: 630-638.
6. Dhariwal, S.R. and U.S. Mirdha, 2005. Analytical expressions for the response of flat-plate collector to various transient conditions. Energy Convers. Manage., 46: 1809-1836.
7. Ullah, F., M.K. Khattak, M. Khan, L. Hassan and K. Hasrat, 2016. Impact of the dehydration process on guava by using of the parabolic trough solar concentrator. Pak. J. Food Sci., 26: 92-97.
8. Fahim, U., K.K. Mansoor, K. Min, F. Xiuqing, N. Hengtai and H.Z. Li, 2016. Experimental study on a flat plate collector assisted for solar water heating unit. Proceedings of the 5th International Conference on Sustainable Energy and Environment Engineering, January 2016, Zhuhai, China, pp: 12-13.
9. Ullah, F., M. Kang, L. Hassan, N. Li, J. Yang, X. Wang and M.K. Khattak, 2016. Impact of drying method of figs with small-scale flat-plate solar collector. World J. Eng., 13: 407-412.
10. Garg, H.P., 1985. Solar Water Heating Systems. Kluwer Academic Publishers, Norwell, MA., USA., pp: 78.
11. Kang, M.C., Y.H. Kang, S.H. Lim and W. Chun, 2006. Numerical analysis on the thermal performance of a roof-integrated flat-plate solar collector assembly. Int. Commun. Heat Mass Transfer, 33: 976-984.
12. Khoukhi, M. and S. Maruyama, 2006. Theoretical approach of a flat-plate solar collector taking into account the absorption and emission within glass cover layer. Solar Energy, 80: 787-794.
13. Xiangqiang, K., L. Lin, L. Ying and M. Dianqun, 2013. Simulation of thermal performance of flat-plate solar colletors. Acta Energiae Solaris Sin., 38: 1404-1408.
14. Lu, Y., H. Yu, H. Ding, Y. Zhang and Z. Liu, 2013. Mathematical modeling and simulation of thermal properties of flat-plate solar collector. J. Jinan Univ., 27: 293-297.
15. Norm, M., 2003. Methods of Testing to Determine Thermal Performance of Solar Collectors. ASHRAE, Washington, DC., pp: 48-121.
16. Selmi, M., M.J. Al-Khawaja and A. Marafia, 2008. Validation of CFD simulation for flat plate solar energy collector. Renewable Energy, 33: 383-387.
17. Brain, N., 1992. Solar Energy Thermal Technology. Springer, London, pp: 50-78.
18. Bei, N.I., Y. Ding and Y. Qing, 2011. Numerical simulation study on the flat-plate solar collector in the series-connected system. Energy Conservation Technol., 29: 20-23.
19. Rojas, D., J. Beermann, S.A. Klein and D.T. Reindl, 2008. Thermal performance testing of flat-plate collectors. Solar Energy, 82: 746-757.
20. Saito, A., Y. Utaka, T. Tsuchio and K. Katayama, 1984. Transient response of flat plate solar collector for periodic solar intensity variation. Solar Energy, 32: 17-23.

21. Sun, W., Y. Wang, H.J. Chen, T. Ma, J. Zha, M. Yang and Y. Zhu, 2013. Performance investigation on a sun-tracking CPC heat pipe evacuated tube solar collector. Thermal Power Generat., 42: 21-25.
22. Osorio, T. and M.J. Carvalho, 2014. Testing of solar thermal collectors under transient conditions. Solar Energy, 104: 71-81.
23. Wu, D. and W. Liu, 2017. A new fault diagnosis approach for the pitch system of wind turbines. Adv. Mech. Eng., 9: 1-9.
24. Patankar, S., 1980. Numerical Heat Transfer and Fluid Flow. CRC Press, USA., ISBN: 9780891165224, Pages: 214.
25. Ameur, H., D. Sahel and Y. Kamla, 2017. Energy efficiency of a deep hollow bladed impeller for mixing viscoplastic fluids in a cylindrical vessel. Adv. Mech. Eng., 9: 1-7.
26. Benachour, E., B. Draoui, B. Imine and K. Asnoune, 2017. Numerical simulation of conjugate convection combined with the thermal conduction using a polynomial interpolation method. Adv. Mech. Eng., 9: 1-7.
27. Villar, N.M., J.C. Lopez, F.D. Munoz, E.R. Garcia and A.C. Andres, 2009. Numerical 3-D heat flux simulations on flat plate solar collectors. Solar Energy, 83: 1086-1092.
28. Tao, W.Q., 2001. Numerical Heat Transfer. Xi'an Jiao Tong University Press, Xi'an, China.
29. Zambolin, E. and D. Del Col, 2010. Experimental analysis of thermal performance of flat plate and evacuated tube solar collectors in stationary standard and daily conditions. Solar Energy, 84: 1382-1396.
30. Zhai, X.Q., R.Z. Wang, Y.J. Dai, J.Y. Wu, Y.X. Xu and Q. Ma, 2007. Solar integrated energy system for a green building. Energy Build., 39: 985-993.