Effect of Mass Flow Rate on Energy and Exergy of N-PVT-CPC Active Double Slope Solar Distiller

Anil Kumar[1], Dharamveer Singh[2]

[1]Dr. APJ Abdul Kalam Technical University, Lucknow, U.P., India

[2]Professor, Dr. APJ Abdul Kalam Technical University, Lucknow, U.P., India

Abstract: ***This research paper deals with the effect of mass flow rate ($\dot{m}_f$) and number of collectors (N) on energy metrics of basin type double slope solar energy based water purifier (DSSEBWF) by incorporating N alike PVT compound parabolic concentrator collectors (NPVTCPCs) connected in series keeping water depth as 0.14 m. All four kinds of weather conditions of the composite climatic condition of New Delhi have been taken for the computation of different parameters. The equations obtained for different parameters after solving energy balance equation for all components of the proposed system have been fed to mathematical programming done in MATLAB for computing different parameters. The computation of different relevant parameters has been carried out for different values of $\dot{m}_f$ while keeping N as constant and vice-versa to know the effect of $\dot{m}_f$ and N on the energy metrics for NPVTCPC-DSSEBWF. It has been concluded that the value of energy payback time (ENPBT) increases, but life cycle conversion efficiency (LCCE) decreases with the increases in the value of $\dot{m}_f$; whereas ENPBT decreases, but LCCE increases with the increase in N at given value of water depth of 0.14 m.***

Keywords: Mass, Energy, Exergy, Solar Distiller

1. Introduction

The energy and fresh water are two basic needs for the survival of life on the planet earth. However, energy and fresh water are not available in abundance to meet the need of human beings as the globe is facing the scarcity of both these basic items. The conventional source of energy is detrimental to the environment due to the emission of green house gases and hence to the human beings and the source of conventional energy is limited, too. The solar energy technology based systems which are simple and environment friendly has the potential to meet both energy as well as fresh water needs. The solar energy based active water purifier involving solar panel can generate DC electric power as well as fresh water. This type of solar energy based system is self-sustainable and hence can be installed and operated successfully at the remote locations where sunlight is present in abundance. Energy metrics analysis of the solar energy based system is essential because it tells whether the system is technically feasible from energy and exergy viewpoints.

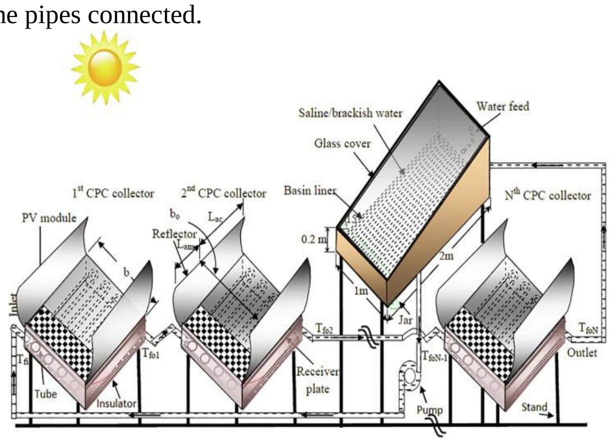
The solar energy based active water purifier came into existence in 1983 [1] and from that time, many new designs have been reported by various researchers around the globe. The solar energy based active water purifier means the provision of external source of heat to the basin of solar energy based passive water purifier. The external source of heat can be made available as solar collectors/industry waste heat using heat exchanger or similar other kinds of provision can be made. Rai and Tiwari reported the enhancement in yield of solar energy based water purifier by incorporating one conventional flat plate collector (FPC) over solar energy based passive water purifier of the same basin area due to the addition of heat to the basin in active mode of operation. This water purifier was not self sustainable as the pump needed some electric power for working which was supplied through grid.

2. System Description

Fig. 3.1 illustrates the active dual inclined solar distiller with compound parabolic concentrator collector. The 2 m × 1 m basin size is connected to a dual inclined active solar distiller is made of reinforced plastic and inclined at 15° the condensing cover, with the help of putty to close the upper system properly. To absorbed maximum heat the basin box wall is coated with black paint. The radiation energy is flows through reflection, absorption transmit with help of glass cover on top surface. A certain percentage after absorbing of solar energy in water, the rest is transmitted and reflected in to basin liner, the temperature of basin liner rises. However, the thermal energy carried away by water and temperature rises. The risen water temperature is amid glass and water surface. The evaporated water on the glass cover (shelter) condenses through film-type condensation. The frozen water on the inner portion of glass cover is stored in jar with the help of pipe arrangements. The wall is on the down side the opening is provided from the basin with the help of pipes and water through this collected to Jar. To receive maximum solar radiation box is faced in south direction.

Partly covered PVT-CPC is 0.25 m × 1 m kept below the collector because the minimum temperature of water there is shallow (Chow et al. 2006). The collector is mounted in series that means second inlet is joint first the outlet, the 3rd inlet is connected to the 2nd outlet, and this arrangement continues until the plate. Our focus is on raising basin's water temperature and the chain connection arrangement for it being the best; we can get more distilled by raising the temperature of the basin. This arrangement in which collectors are connected in such a way is called as series connection and outlet of compound parabolic concentrator is connected to basin. Now we need some supply source to operate this system, 19

For which a pump is applicable, which acts as medium to feed basin and collectors. Solar basin is connected to inlet of pump and the first PVT-CPC water collector inlet to exit the pump, but the pump needs to be powered and powered by a DC motor. It is connected with help of pipes. In a box system made of aluminum to capture absorption, for heat reduction, the top box 0.1m thickness insulation is made of wool-insulation thickness 0.004 m parabolic-shaped CPC collector aluminum coating. There are basically two fields used in this system. The area of aperture and receiver is half of aperture area. With the help of a parabolic surface, the radiation beam is reflected towards the receiver surface. The collectors PVT-CPC with 30° inclined to horizontal to get maximum radiation. The pump is connected to motor which consumes power generated by PVT. The surrounding water PVT is get heat through the convection mode through the pipes connected.



3. Methodology

The methodology to investigate the effect of $\dot{m}f$ and N on the energy metrics of NPVTCPC-SEBDSWF are as follows:

Step I

The radiation on the horizontal surface has been taken from Indian Meteorological Department situated at Pune in India. The values of solar flux at the inclined plane have been evaluated using Liu and Jordan formula with the help of computation program in MATLAB.

Step II

Values of hourly fresh water yield for different values of $\dot{m}f$ at a given values of N have been evaluated using equation (15) followed by the evaluation of fresh water yield on the basis of year. Similarly, Values of hourly fresh water yield for different values of N at a given values of $\dot{m}f$ have been evaluated using equation (15) followed by the evaluation of fresh water yield on the basis of year. Values of hourly exergy for different values of mass flow rate at given value of N have been evaluated using equations (17) and (18) followed by the evaluation of exergy on the basis of year.

Step III

The gross energy output values for different values of $\dot{m}f$ at given value of N have been evaluated using equation (16) followed by the evaluation of gross energy output on the basis of year. Similarly, gross energy output values for different values of N at given value of mass flow rate have been evaluated using equation (16) followed by the evaluation of gross energy output on the basis of year 31

Step IV

The gross exergy output values for different values of $\dot{m}f$ at given value of N have been evaluated using equation (23) followed by the evaluation of gross exergy output on the basis of year. Similarly, gross exergy output values for different values of N at given value of $\dot{m}f$ have been evaluated using equation (23) followed by the evaluation of gross exergy output on the basis of year.

Step V

The energy payback time values for different values of $\dot{m}f$ at given value of N have been evaluated using equations (24) and (25) on the basis of energy and exergy respectively. Similarly, energy payback time values for different values of N at given value of $\dot{m}f$ have been evaluated using equations (24) and (25) on the basis of energy and exergy respectively.

Step VI

The energy production factor values for different values of $\dot{m}f$ at given value of N have been evaluated using equations (26) and (27) on the basis of energy and exergy respectively. Similarly, energy production factor values for different values of N at given value of $\dot{m}f$ have been evaluated using equations (26) and (27) on the basis of energy and exergy respectively.

Step VII

The life cycle conversion efficiency values for different values of $\dot{m}f$ at given value of N have been evaluated using equations (28) and (29) on the basis of energy and exergy respectively. Similarly, life cycle conversion efficiency values for different values of N at 32 given value of $\dot{m}f$ have been evaluated using equations (28) and (29) on the basis of energy and exergy respectively.

4. Conclusion

The analysis for NPVTCPC-SEBDSWF has been done considering all four kinds of atmospheric situations to know the effect of mass flow rate and N on energy metrics of the system. Based on the current research study, the following conclusions have been made:

1) The value of energy payback time increases with the increases in mass flow rate and it becomes almost constant after $\dot{m}f = 0.12\ kg/s$.
2) The value of energy production factor increases with the increases in mass flow rate and it becomes almost constant after $\dot{m}f = 0.12\ kg/s$.
3) The value of life cycle conversion efficiency based on energy decreases with the increases in mass flow rate and it becomes almost constant after $\dot{m}f = 0.10\ kg/s$. Similarly, the value of life cycle conversion efficiency based on exergy decreases with the increases in mass flow rate and it becomes almost constant after $\dot{m}f = 0.11\ kg/s$.

References

[1] Rai SN, Tiwari GN, Single basin solar still coupled with flat plate collector, Energy Convers Manage 1983;23(3):145–9.

[2] Kumar S, Tiwari A., An experimental study of hybrid photovoltaic thermal (PV/T) active solar still, Int. J Energy Res 2008; 32:847–58.

[3] Kern EC, Russell MC. Combined photovoltaic and thermal hybrid collector systems. In: Proceedings of the 13th IEEE photovoltaic specialists, June 5–8, Washington, DC, USA. p. 1153–7.

[4] Singh G, Kumar S, Tiwari GN. Design, fabrication and performance of a hybrid photovoltaic/thermal (PVT) double slope active solar still. Desalination 2011; 277:399–406.

[5] Singh DB, Yadav JK, Dwivedi VK, Kumar S, Tiwari GN, Al-Helal IM., Experimental studies of active solar still integrated with two hybrid PVT collectors. Sol Energy 2016; 130:207–23.

[6] Tiwari GN, Yadav JK, Singh DB, Al-Helal IM, Abdel-Ghany AM., Exergoeconomic and enviroeconomic analyses of partially covered photovoltaic flat plate collector active solar distillation system, Desalination 2015; 367: 186–96.

[7] Singh DB and Tiwari GN, Enhancement in energy metrics of double slope solar still by incorporating N identical PVT collectors, Solar Energy 143 (2017) 142–161

[8] Singh DB, Exergoeconomic and enviroeconomic analyses of N identical photovoltaic thermal integrated double slope solar still, Int. J. Exergy, Vol. 23, No. 4, 2017

[9] Singh DB, Kumar N, Harender, Kumar S, Sharma SK, Mallick A, Effect of depth of water on various efficiencies and productivity of N identical partially covered PVT collectors incorporated single slope solar distiller unit, Desalination and Water Treatment, 138 (2019) 99–112

[10] Singh DB, Improving the performance of single slope solar still by including N identical PVT collectors, Applied Thermal Engineering 131 (2018) 167–179

[11] Singh DB, Kumar N, Kumar S, Dwivedi VK, Yadav JK, Tiwari GN, Enhancement in exergoeconomic and enviroeconomic parameters for single slope solar still by Incorporating N Identical partially covered photovoltaic collectors, Journal of Solar Energy Engineering, 2018, Vol. 140 / 051002-1

[12] Sahota L, Tiwari GN, Exergoeconomic and enviroeconomic analyses of hybrid double slope solar still loaded with nanofluids, Energy Conversion and Management, Volume 148, 15 September 2017, Pages 413-430

[13] Atheaya D, Tiwari A, Tiwari GN, Al-Helal IM., Analytical characteristic equation for partially covered photovoltaic thermal (PVT) – compound parabolic concentrator (CPC), Sol Energy 2015;111:176–85. 42

[14] Tripathi R, Tiwari GN, Al-Helal IM. Thermal modelling of N partially covered photovoltaic thermal (PVT)–Compound parabolic concentrator (CPC) collectors connected in series. Sol Energy 2016;123:174–84.

[15] Singh DB and Tiwari GN, Performance analysis of basin type solar stills integrated with N identical photovoltaic thermal (PVT) compound parabolic concentrator (CPC) collectors: A comparative study, Solar Energy 142 (2017) 144–158

[16] Singh DB and Tiwari GN, Exergoeconomic, enviroeconomic and productivity analyses of basin type solar stills by incorporating N identical PVT compound parabolic concentrator collectors: A comparative study, Energy Conversion and Management 135 (2017) 129–147

[17] Prasad H., Kumar P, Yadav RK, Mallick A, Kumar N, Singh DB, Sensitivity analysis of N identical partially covered (50%) PVT compound parabolic concentrator collectors integrated double slope solar distiller unit, Desalination and Water Treatment, 153 (2019) 54–64

[18] Gupta VS, Singh DB, Sharma SK, Kumar N, Bhatti TS, Tiwari G.N. Tiwari, Modeling self-sustainable fully-covered photovoltaic thermal-compound parabolic concentrators connected to double slope solar distiller, Desalination and Water Treatment, 190 (2020) 12–27

[19] Singh DB and Tiwari GN, Effect of energy matrices on life cycle cost analysis of partially covered photovoltaic compound parabolic concentrator collector active solar distillation system, Desalination 397 (2016) 75–91

[20] Gupta VS, Singh DB, Mishra RK, Sharma SK, Tiwari GN, Development of characteristic equations for PVT-CPC active solar distillation system, Desalination 445 (2018) 266–279

[21] Singh V. Singh DB, Kumar N, Kumar R., Effect of number of collectors (N) on life cycle conversion efficiency of single slope solar desalination unit coupled with N identical partly covered compound parabolic concentrator collectors, https://doi.org/10.1016/j.matpr.2020.04.232

[22] Singh DB, Singh G., Kumar N, Singh PK, Kumar R., Effect of mass flow rate on energy payback time of single slope solar desalination unit coupled with N identical compound parabolic concentrator collectors, https://doi.org/10.1016/j.matpr.2020.05.137

[23] Sharma GK, Kumar N., Singh DB, Mallick A, Exergoeconoic analysis of single slope solar desalination unit coupled with PVT-CPCs by incorporating the effect of dissimilarity of the rate of flowing fluid mass, https://doi.org/10.1016/j.matpr.2020.04.642

[24] Sampath kumar K., Arjunan T.V, Senthilkumar P., The experimental investigation of a solar still coupled with an evacuated tube collector, Energy Sources Part A: Recov. Util. Environ. Effects 35 (3) (2013) 261–270. 43

[25] Singh R.V., Kumar S., Hasan M.M., Khan M.E., Tiwari G.N., Performance of a solar still integrated with evacuated tube collector in natural mode, Desalination 318 (2013) 25–33.

[26] Kumar S., Dubey A., Tiwari GN, A solar still augmented with an evacuated tube collector in f6orced mode, Desalination 347 (2014) 15–24.

[27] Mishra R.K., Garg V., Tiwari G.N., Thermal modeling and development of characteristic equations

of evacuated tubular collector (ETC), Sol. Energy (2015) 165–176.

[28] Singh D.B., Dwivedi V.K., Tiwari G.N., Kumar N., Analytical characteristic equation of N identical evacuated tubular collectors integrated single slope solar still, Desalination Water Treatm., Taylor and Francis 88 (2017) 41–51.

[29] Singh D.B., Tiwari G.N., Analytical characteristic equation of N identical evacuated tubular collectors integrated double slope solar still, J. Solar Energy Eng.: Include. Wind Energy Build. Energy Conserv, ASME 135 (5) (2017), pp. 051003(1–11).

[30] Singh D.B., Tiwari G.N., Energy, exergy and cost analyses of N identical evacuated tubular collectors integrated basin type solar stills: a comparative study, Solar Energy 155 (2017) 829–846.

[31] Issa R.J., Chang B., Performance study on evacuated tubular collector coupled 295 solar Still in west Texas climate, Int. J. Green Energy (2017), https://doi.org/10.1080/15435075.2017.1328422.

[32] Singh D.B., Al-Helal I.M., Energy metrics analysis of N identical evacuated tubular collectors integrated double slope solar still, Desalination, Elsevier 432 (2018) 10–22.

[33] Singh D.B., Al-Helal I.M., Energy metrics analysis of N identical evacuated tubular collectors integrated single slope solar still, Energy 148 (2018) 546– 302.

[34] Singh, H.N., Tiwari, G.N., Evaluation of cloudiness/haziness factor for composite climate. Energy 30 (2005) 1589–1601.

[35] Huang, B.J., Lin, T.H., Hung, W.C. and Sun, F.S., (2001), Performance evaluation of solar photovoltaic/thermal systems, Solar Energy, 70(5), pp. 443–448.