International Journal of Mechanical and Industrial Engineering

Volume 3 | Issue 1 Article 14

July 2013

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BHASKAR B. GARDAS
Veermata Jijabai Technological Institute (VJTI), Mumbai University, gardas.bhaskar@gmail.com

M.V TENDOLKAR
Sardar Vallabh Bhai Patel Polytechnic, Borivali (W), Mumbai 400103, Maharashtra, India., mvtendolkar@vjti.org.in

Recommended Citation
GARDAS, BHASKAR B. and TENDOLKAR, M.V (2013) "DESIGN OF COOLING SYSTEM FOR PHOTOVOLTAIC PANEL FOR INCREASING ITS ELECTRICAL EFFICIENCY," *International Journal of Mechanical and Industrial Engineering*: Vol. 3 : Iss. 1 , Article 14.
DOI: 10.47893/IJMIE.2013.1129
Available at: https://www.interscience.in/ijmie/vol3/iss1/14

DESIGN OF COOLING SYSTEM FOR PHOTOVOLTAIC PANEL FOR INCREASING ITS ELECTRICAL EFFICIENCY

BHASKAR B. GARDAS[1] & M.V TENDOLKAR[2]

[1]Department of Mechanical Engineering,
Veermata Jijabai Technological Institute (VJTI), Mumbai University, 400019.
[2] Sardar Vallabh Bhai Patel Polytechnic, Borivali (W), Mumbai 400103, Maharashtra, India.
E-mail: gardas.bhaskar@gmail.com, mvtendolkar@vjti.org.in

Abstract: Photovoltaic solar cell generates electricity by receiving solar irradiance. The temperature of photovoltaic modules increases when it absorbs solar radiation, causing a decrease in efficiency. This undesirable effect can be partially avoided by applying a heat recovery unit with fluid circulation with the photovoltaic module. Such unit is called photovoltaic/thermal collector (PV/T) or hybrid (PV/T). The objective of the present work is to design a system for cooling the solar cell in order to increase its electrical efficiency and also to extract the heat energy. A hybrid solar system which generates both electricity and heat energy simultaneously is studied. This hybrid system consists of PV cells attached to an absorber plate with fins attached at the other side of the absorber surface. Simulation model for single pass, single duct solar collector with fins is prepared and performance curves are obtained. Performance with seven different gases analysed for maximum heat transfer, minimum mass flow rate & minimum number of fins. Hydrogen is found to be the most suitable option with the present. For hydrogen, the system requires a mass flow rate of 0.00275 kg/s, which is the least amongst all. Theoretical number of fins required in this case is found out to be 3.46.

Keywords*: Flat Plate PV/T Collector, Solar Irradiance, Electrical Efficiency, Electrical Power*

I. INTRODUCTION

Meticulous efforts of research work can be observed to be focused across the world towards the analysis and practical implementation of solar energy, due to the concern of global crisis on oil and gas prices. The year 1973 brought an end to the era of secure & cheap oil. In October of the same year, oil prices shot up fourfold causing a severe energy crisis all over the world. Thus, the year 1973 is considered as the year of first oil shock. In the same decade, one more oil shock jolted the world in 1979. By the end of 1980, the price of crude oil stood at 19 times what it had been just 10 years earlier [1]. The energy consumption in the world, particularly in the industrialized countries, has been growing at an alarming rate [2]. Moreover, the pollution hazard arising out of fossil fuel burning has become quite significant in recent years. About 86 % of the world's energy supply comes from the fossil fuels [2]. According to Deffeyes [3], oil has already started to its peak. This process will push energy prices higher, until sustainable sources replace dependency on fossil fuels as major source of energy [4]. The sustainable energy such as solar energy in the form of solar radiation has been identified as one of the promising source of energy to replace the dependency on other energy resources. The global need for energy savings requires the usage of renewable sources in many applications. One of the renewable sources of energy is the photovoltaic solar energy (PV) [5]. As revealed by Hoffmann [6], the photovoltaic (PV) solar market has shown an impressive 33 % growth per year since 1997 till date. PV Cell is a semiconductor device that generates electricity when light falls on it [7]. A PV cell converts only a small fraction (approximately less than 20 %) of the irradiance into electrical energy [7]. The balance is converted into heating of the cell. As a result, cell can be expected to operate above ambient temperature. If the temperature is increased, there is marked reduction in the cell voltage. Cell voltage decreases by approximately 2.2 mV per ^{0}C rise in operating temperature [7].

Ebrahim Ali [8], in an experiment, investigated single pass solar air heater with photovoltaic cell with compound parabolic collector (CPC) and fins as shown in the "Fig. 1". He discovered that the electrical power of the collector increases with the radiation intensity. Goh li Jin [9, 10] concluded that the solar collector can be changed to double pass collector to improve its performance. Sopian [11] designed and tested double pass photovoltaic thermal solar collector.

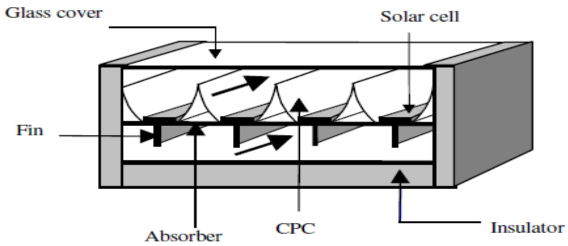

Figure 1. The Schematic Model of Single Pass, Double Duct (PV/T) Solar Collector with CPC and Fins [8]

He found that because of the turbulence, the heat transfer coefficient increases, which improves performance of the system. Othman [12] designed a double-pass photovoltaic-thermal solar air heater. In this system the fins are introduced in the second channel flow passage, parallel to the length of the collector, as shown in "Fig. 2". The fins on the back of the photovoltaic panel increase the heat transfer with the air and enhance the efficiency of the system. The double pass PV/T solar air collector with fins and compound parabolic concentrator (CPC) gives very good electrical and thermal energy output [13]. But, the low thermal conductivity of air results in poor heat transfer between the panel and the flowing air. Hence, the air heater efficiency is low. So, in this study, the comparative study is done to improve the electrical output of the PV system, by passing different gases over a finned, single duct & single pass solar collector, the design of which is simple as compared to double pass system.

II. PROBLEM DEVELOPMENT

In the present work, fins are attached to the rear face of the panel as shown in the "Fig. 3".The rear surface of the panel is a substrate such as aluminum. The fins are modeled as being an extension of this substrate. The substrate material is soldered or attached with adhesive to the rear surface of the cells. In addition, a rectangular duct is attached to the rear surface of the panel, for which the heat transfer parameters are based on the assumption of forced convection.

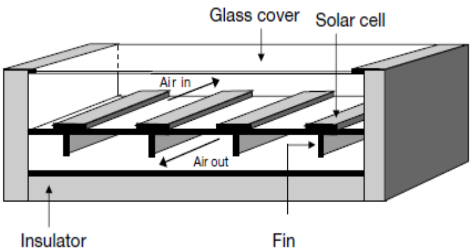

Figure 2. Finned Double-Pass Photovoltaic-Thermal Solar Air Heater [12]

The duct allows the gas to be blown across the rear surface of the panel. Parameters of the system which are required to be fed in the MAT LAB software are solar irradiation, fin thickness, fin height, fin width, flow velocity, and thermal conductivity of the fin material. Outputs of the model are cell temperature, electrical efficiency, electrical power output, number of fins required for cooling, fin efficiency & mass flow rate of the gas used. Constants of the system are emissivities, thermal conductivities, convective thermal resistances, Stefan-Boltzmann constant and the ambient temperature.

III. BOUNDARY CONDITIONS

The input to the system is the solar irradiance. The boundary conditions are the heat losses due to the radiation and convection on the front and back (Q_{rad}, Q_{conv}) of the panel, as well as the electrical power output. The thermodynamic properties of the panel, thermodynamic properties of the fin, and physical dimensions of the panel layers are held constant throughout the study.

IV. ASSUMPTIONS

To simplify the analysis, the following assumptions are made:

1. Steady state of energy transfer is achieved.
2. No heat generation within the fin.
3. Uniform heat transfer coefficient (h) over the entire surface of the fin.
4. Homogeneous and isotropic fin material.
5. Negligible contact thermal resistance.
6. Heat conduction is one dimensional.
7. Capacity effects of the glass cover, solar cells and back plate is neglected.
8. The temperatures of the glass cover, solar cells and plates vary only in the direction of working fluid flow.
9. The side losses from the system are negligible.

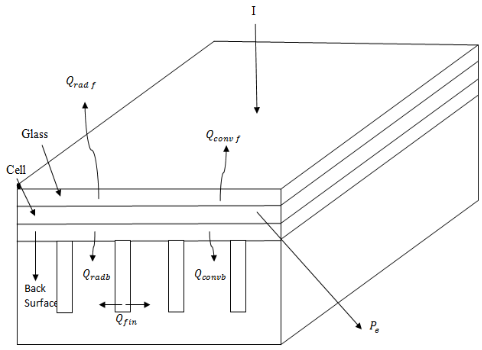

Figure 3. Schematic Representation of the Model

V. CONSTANTS FROM THE LITERATURE

1. $T_a = 25\ ^0C = 298$ K.
2. a = -3.47 (For open rack) [14]
3. b = -0.0594 (For open rack) [14]
4. $I_o = 1000\ W/m^2$ [14]
5. $\epsilon_g = 0.94$ [15]
6. $\epsilon_b = 0.893$ [15]
7. $\sigma = 5.67\ X\ 10^{-8}\ \frac{W}{m^2K^4}$ [16]
8. $R_{Conv} = 0.2\ K.\frac{m^2}{W}$ [17]
9. $K = 120\,\frac{W}{m\,.K}\ (Al)$ [17]

VI. EQUATIONS USED

1. $T_b = \left[e^{(a+b.U)}\right] + T_a$ [14]

2. $T_C = T_b + \frac{I\,X\,\Delta t}{I_o}$ [14]
3. $\Delta t = 3^0$ [14]
4. $Q_{radf} = \epsilon_g . \sigma \left(T_g{}^4 - T_a{}^4\right)$ [18]
5. $Q_{conv\,f} = \frac{T_g - T_a}{R_{Conv}}$ [17]
6. $Q_{conv\,b} = \frac{T_b - T_a}{R_{Conv}}$ [17]
7. $Q_{radb} = \epsilon_b . \sigma \left(T_b{}^4 - T_a{}^4\right)$ [18]
8. $\eta_{pv} = 0.15[1 - 0.0045\,(T_{pv} - 25)]$ [19]
9. $P_e = \eta_{pv}$ x I [17]
10. $I = Q_{rad} + Q_{conv} + P_e + Q_{fin}$ [17]
11. $A_{CS} = b$ x t
12. $Q_{fin} = n[k . A_{CS} . m . (T_b - T_a) . \tanh(ml)]$ [16]
13. Perimeter of the fin (P) = 2 (b+ t)
14. Reynolds number (R_e) = $\frac{U.L}{v}$ [16]
15. $For\ R_e = 1.115 \times 10^5 < R_e < 5 \times 10^5$
    $N_{U.L} = \frac{h.L}{K_f} = 0.664\ x\ R_e{}^{1/2} . P_r{}^{1/3}$ [18]
16. $N_{U.L} = \frac{h.L}{K_f} = P_r^{\frac{1}{3}} . (0.037\ R_{el}{}^{0.8} - 850)$
    $For\ R_e = 5 \times 10^5 < R_e < 10^7$ [18]
17. $m = \sqrt{\frac{h.P}{K.A_{cs}}}$ [18]
18. $\eta_{fin} = \frac{\tan h\,(ml)}{ml}$ [18]
19. $T_1 = \left(\frac{T_b + T_a}{2}\right)$
20. $Q = \dot{m} . C_p . \Delta T$

VI. VALIDATION OF RESULTS

The validation of the present model is carried out with two references. “Fig. 4” shows the relationship between electrical efficiency and cell temperature.

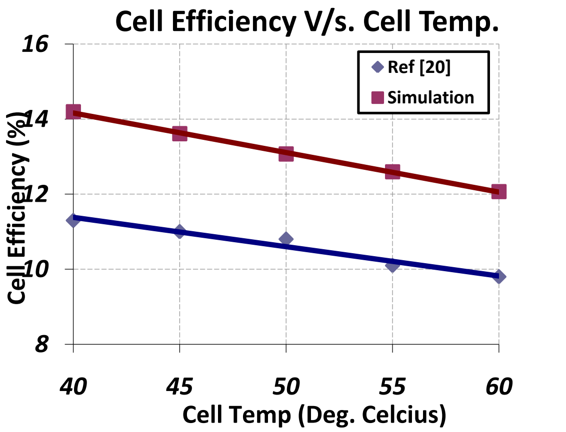

Figure 4. Relationship between the Electrical Efficiency and Cell Temperature at reference temperature of 25⁰ C

It can be observed from the graph that the increase in temperature of the panel results in decreasing its electrical efficiency. The results from the theoretical model developed are found to be in better agreement with those mentioned in the reference. The discrepancy between the two values is attributed to the unaccounted losses occurring in practice. Also, the relative efficiency and cell efficiency temperature coefficient values (Eq. 8 in Section VI) of both the papers are different. The reference efficiency of 12.7 % and cell efficiency temperature coefficient of 0.0063 is used in the reference [20] , whereas in the present work the relative efficiency of 15 % and cell efficiency temperature coefficient 0.0045 are used. The validation of electrical power is shown in “Fig. 5”. It can be observed from the graph that there is much better agreement between the predicted values from the theoretical model developed and those mentioned in the reference. The electrical power output increases with the increase in solar irradiance, being a direct function of solar irradiance.

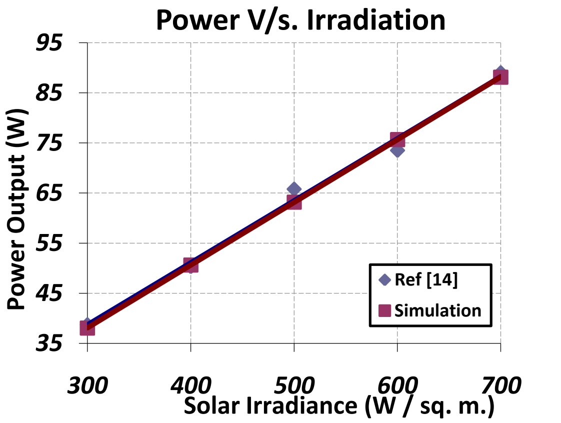

Figure 5. Relationship between the Electrical Power and Solar Irradiation at 25^0 C.

VII.RESULTS & DISCUSSIONS

Comparison of fin efficiency for seven gases is shown in “Fig. 6”. The aluminium fin at an irradiation of 1000 W/m^2 is showing maximum efficiency of 97.58 %, when water vapor is made to flow through the duct.

“Fig. 7” shows the comparative graph for the required mass flow rate, which should flow through the duct to absorb ‘Q’ and cool the panel’s rear surface. The graph indicates that, to absorb ‘Q’, the mass flow rate required for hydrogen is the least of all i.e. 0.00275 kg/s, whereas the maximum mass flow rate is for carbon dioxide and of the magnitude of 0.04559 kg/sec through the duct.

“Fig. 8” represents the requirement of number of fins, which are to be attached at the back side of the PV Panel. The figure yields that least number of fins are required for hydrogen , i.e. n = 3.46.

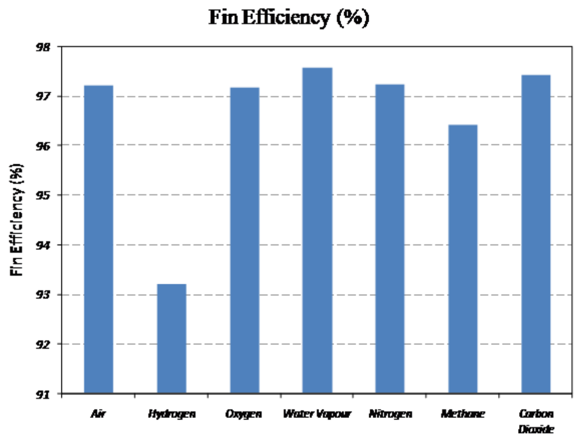

Figure 6. Comparison of Fin Efficiency for Various Gases.

[For b = 0.6 m, l = 0.15 m, t = 0.025 m, k = 120 W/m.K, I = 1000 W/m^2]

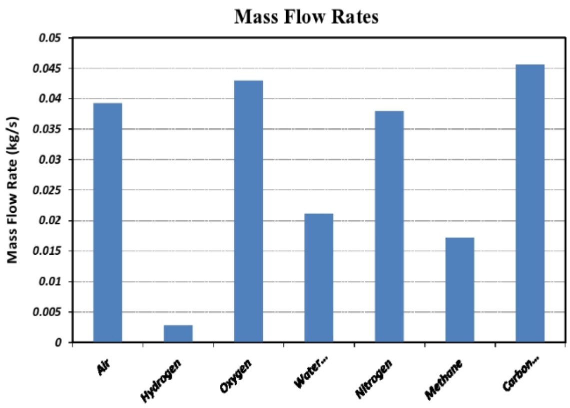

Figure 7. Comparison of Mass Flow Requirement for Various Gases.

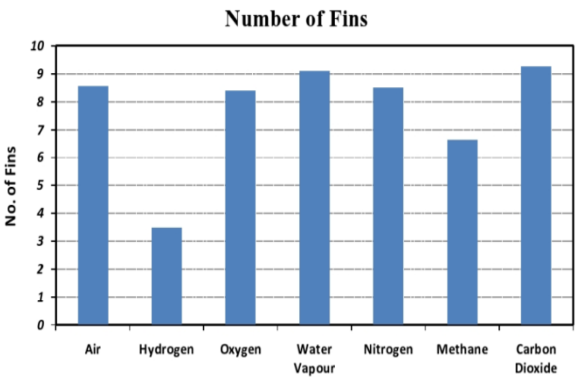

Figure 8. Comparison of Number of fins required for Various Gases.

[For b = 0.6 m, l = 0.15 m, t = 0.025 m, K = 120W/m.K, I = 1000 W/m^2]

Maximum theoretical number of fins of 9.23 is required when carbon dioxide is made to flow though the duct.

VI. CONCLUSIONS

Solar cells generate more electricity when receive more solar radiation but the efficiency drops when temperature of solar cells increases. Hybrid photovoltaic and thermal collector is the solution to this problem. Simulation model for single pass, single duct solar collector with fins is developed and performance curves are analysed. The simultaneous use of hybrid PV/T and fins have a potential to significantly increase in power production and reduce the cost of photovoltaic electricity. Seven gases are passed though the duct to identify the gas which would give the maximum heat transfer, with minimum mass flow rate & minimum number of fins. The gas identified is hydrogen. For hydrogen, the system requires a mass flow rate of 0.00275 kg/s, which is the least of all other gas mass flow rate values & Number of fins required are 3.46.

[For b = 0.6 m, l = 0.15 m, t = 0.025 m, k = 120 W/ m.K, I = 1000 W/m^2]

NOMENCLATURE

T_b = Back surface module temperature (^{0}C).
T_a = Ambient temperature (^{0}C).
I = Solar Irradiance (W/m^2).
V = Wind speed (m/s).
a = empirically determined coefficients establishing the upper limit for the module temperature at low wind speeds and high solar irradiance.
b = empirically determined coefficient establishing the rate at which module temperature as Wind speed increases.
T_C = Cell temperature of the module (^{0}C).
I_o = Reference Solar Irradiance on module.
Δt = Temperature difference between the cell and the module back surface at an irradiance level of 1000 W/m^2.
Q_{radf} = Radiative heat flux through the front panel.
Q_{convf} = Convective heat flux through the front panel (W/m^2).
Q_{convb} = Convective heat flux through the rear panel (W/m$^{2)}$. Q_{radb} = Convective heat there through rear surface of the panel (W/m^2).Q_{fin} = Convective heat transfer through the fin (W/m^2).ϵ_g = Surface emissivity of glass.
σ = Stefan Boltzmann constant.
t = Thickness of the fin (m).
P = Perimeter of the fin.
υ = Kinematic Viscosity (m^2/s).
U = Velocity of the flowing fluid (m/s)

R_e = Reynolds number.
$N_{U.L}$ = Nusselt Number.
P_r = Prandtl Number.
η_{fin} = Efficiency of the fin.
ΔT = Difference between mean temperature of the flowing stream and the atmospheric temperature (K).

U = velocity of the gas flowing through the duct (m/s).
T_1 = Mean temperature of the flowing stream (K).
η_{pv} = Electrical Efficiency of the PV Panel.
P_e = Electrical Power.
n = No. of Fins.
A_{CS} = Cross sectional area of the fin (m^2).
T_g = Glass surface temperature (K).
R_{Conv} = Convective thermal resistance ($K . \frac{m^2}{W}$).
ϵ_b = Tedlar Emissivity.
k = Thermal conductivity of fin material ($\frac{W}{m.K}$).
h = Convective heat transferor coefficient ($\frac{W}{m^2K}$).
l = length of the fin (m).
b = Width of the fin (m).
C_p = Specific heat of the gas at constant pressure (kJ/kg.K)
k_f = Thermal conductivity of the gas flowing through the back surface of the panel

L = Length of flow (m)

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