EXPERIMENTAL ANALYSIS OF PHOTOVOLTAIC THERMAL HEAT EXCHANGER- Review

Akash Barote[1], Dr. M S Kadam[2]

[1] *Student, Mechanical Engineering Department, JNEC, Maharashtra, India*
[2] *Prof, Mechanical Engineering Department, JNEC, Maharashtra, India*

ABSTRACT

Solar energy is clean and is abundantly available. Solar technologies use the sun to provide heat, light, electricity, etc for domestic and industrial applications. With the alarming rate of depletion of the major conventional energy resources such as Coal, Petroleum and Natural gas, coupled with the environmental degradation caused by the process of harnessing these energy sources, it has become an urgent necessity to invest in renewable energy resources that would power the future sufficiently without degrading the environment through green house gas emission. The energy potential of the sun is immense, but despite this unlimited solar energy resource, harvesting it is a challenge mainly because of the limited efficiency of the array cells. The best conversion efficiency of most commercially available solar cells is in the range 10- 20s% [1], [8]. Although recent breakthrough in the technology of solar cells shows significant improvement but the fact that the maximum solar cell efficiency still falls in the less than 20s% range shows there are enormous room for improvement. The goal of this thesis is to identify these rooms and ways to improving them. One of such room is array mounting and tracking mechanism that moves or positions solar array to absorbing extended solar irradiance for maximum power output.

Keyword : - *Solar energy,Conventional energy, Natural gas, Solar cell, Photovoltaiccell, etc.*

1.REVIEW OF SEMICONDUCTOR DEVICE PHYSICS OF SOLAR CELLS

Solar cell like the crystalline silicon based solar cell shown in Figure 1 above is a solid state semiconductor p-n junction device that converts sunlight into direct-current electricity through the principle of photo-voltaic effect. The first conventional photovoltaic cells were produced in the late 1950s, and were principally deployed to provide electrical power for orbital satellites. During this initial deployment, excessive cost of manufacturing and poor efficiency of solar modules were some of the major challenges that limit their competitiveness as a major source for meeting the increasing energy demand that has continued till now. However, recent improvements in design, manufacturing, performance, reduced cost and quality of solar cells and modules have not only opened up the doors for their deployments in applications like powering remote terrestrial applications, rural electrification projects, battery charging for navigational aids, water pumping, telecommunications equipment and critical military installations, but has also propelled solar power system as a competitive means to meeting the ever increasing power need for the world economy. While the focus of this thesis is improving the efficiency of a solar power system, it’s important to take some cursory, but refreshing look at the semiconductor physics of a solar cell.

2. Flat plate PV/T collector

The main four types of fl at plate collector (Figure 1) differ from each other in function of the fl uid used to remove heat (liquid or air) and of the use of a glass cover to lower the frontal panel heat losses (glazed or unglazed). The purpose of the technology is to collect the heat released by the PV laminate surface (which is not able to completely convert all the global solar radiation to electrical energy) as much as it can, putting in close contact the laminate rear part and the thermal absorber, typically made in copper or aluminium, using special glues or similar compounds. Therefore, heat is exchanged to a fl uid (water, mixture of water and anti-freezing liquid or air) fl owing into channels or pipes as parts of the absorber. Thermal losses are kept low by using a suitable insulation on the edges and the bottom part of the collector. There are two main critical points: – the contact between the rear part of the cells and the thermal absorber has to be enhanced to reduce the thermal resistances both of conduction and interface among the different layers: PV laminate, glue, metal absorber. That is much more relevant when considering an unglazed collector which has large frontal heat

3. PV/T collector model and simulations

A simulation model of the COGEN PV/T collector (see next section 4) has been developed in order to predict the performance in steady state conditions by varying numerous parameters (such as fl uid fl ow rate, fl uid temperature inlet, etc). The collector has been divided into elementary volumes individually solved, considering heat transmission in the z direction only (Figure 2). Each elementary volume contains: – 4 mm thick tempered glazing to obtain a 20 mm gap interspace; – Photovoltaic laminate composed by Tedlar, EVA, silicon cells, EVA;

4. PV/T collectors and test rig arrangement

The PV/T test rig is set in Vicenza in the north-east of Italy on the fl at roof of a building which is part of the Department of Industrial Management and Engineering (University of Padova). The aim is to test the performance of different collectors under the same test methods and boundary conditions. The collectors tested are: • COGEN – It is a fl at plate, glazed, liquid cooled collector, developed by the Department together with a private company. The cells are a single-crystalline type with a gross area of 1.2 m2 (overall dimensions: 1.70 m × 1.20 m × 0.07 m) and nominal power of 135 Wp (open circuit voltage of 22.7 V, short circuit current of 8.45 A and electrical effi ciency of 11.2% (without cover glass) at STC). The absorber is a roll-bond type made of aluminium and suitably glued to the Tedlar fi lm of the PV laminate (thermal resistances are minimized by the roll-bond technology and by the planarity of one side of the heat exchange surface); 25 mm of polystyrene is used as rear absorber insulation. All of the system is included in an aluminium frame with an overall weight of 40–45 kg (Figure 4). • PVTWIN – model 422 – manufactured by the PVTWINS (The Netherlands). It is a fl at plate, glazed, liquid cooled collector, bought by the Department. The cells are a multi-crystalline type with a gross area of 2.54 m2 (overall dimensions: 1.895 m × 1.895 m × 0.16 m) and nominal power of 295 Wp (open circuit voltage of 43 V, short circuit current of 9.3 A and electrical effi ciency of 11.6 % at STC). The absorber is a plate-and-tube type made of copper: the absorber is properly glued to the rear part of the PV laminate and insulated with 40 mm of polyurethane. All the system is included in an aluminium frame with an overall weight of about 100 kg as described in Figure 6 together with air channels. Two headers are set in the shorter sides of the collector to direct the air from the inlet air duct to the collector air channels and from the collector air channels to the outlet air duct. All of the system is included in a stainless steel and back plastic frame with an overall weight of 80–100 kg (Figure 6). The three collectors are set southward with a tilt angle of 30º (as to get the maximum annual energy for a latitude of 45º). A picture of the test rig is shown in Figure 7, whereas, the test rig scheme is depicted in Figure 8. The test rig piping lines can be split into two circuits: • The water storage tank circuit: the water storage is kept between 12ºC and 14ºC thanks to a 5 kW chiller. The chilled water before reaching the storage tank is sent to a plate heat exchanger via an automatic 3-way valve driven by a temperature controller, set to have a well defi ned collector circuit water temperature at the outlet of the heat exchanger (T8). • The collectors circuit: the water at the outlet of the plate heat exchanger gets to the header: here it is possible to send the water to the PVTWIN collector (Line 1) or/and to the COGEN/MSS collector (Line 2) and to partially by-pass the collectors through the by-pass line. As can be seen, only one collector between

5. PV/T measurements

The measurements took place on a series of sunny days with clear skies and different conditions with regard to the global solar radiation on the collector surface (two levels, 250 to 400 W m−2 and 690 to 800 W m−2) and water mass fl ow rate (40, 80 and 120 kg h−1 m−2). In order to get measurements not too much affected by thermal transient regime, each test had a duration of 15 to 20 minutes. The fi rst step was to defi ne the electrical behaviour of the PV cells undertaking a fl ash test by manually varying the electrical load (equivalent dissipative resistances, R4 in Figure 9) of the collector. Figure 10 and Figure 11 depict the voltage-power characteristics of the PVTWIN and the MSS collectors. Tests have been carried out at a specifi c mass fl ow rate of 80 kg h−1 m−2 (see [5] for hints about optimum mass fl ow rate) and at two levels of solar radiation (300 and 800 W m−2) and water inlet temperature (20 and 30ºC). The fi gures point out the voltage-current state for maximum DC electrical power in the vicinity of the curve knee; furthermore, increasing inlet water temperature has a negative effect on the electrical power produced by the collectors, in terms of 8%

Compared to the two other collectors, the MSS one is unglazed and can work with both water and air: that is, it has water inlet/outlet pipes and air inlet/outlet ducts. By the way, during our tests the air ducts were kept closed and only water was used to remove heat from the PV. The expected thermal effi ciency is signifi cantly less than that for a glazed type, mainly due to the frontal side thermal losses as described in the introduction part: at zero the reduced temperature thermal effi ciency is 27%, decreasing more slowly with 40 instead of 120 kg h−1 m−2 water fl ow rate. Glazed type collectors show a better thermal effi ciency, substantially equivalent for COGEN and PVTWIN; anyway, the latter is more penalized at a higher mass fl ow rate (slope increases more at higher mass fl ow rate). The water temperature increase in the collectors is in the range of 2 to 8ºC as a function of the mass fl ow rate. With regard to electrical effi ciency, the last two collectors have the best behaviour: at zero reduced temperature both have an electrical effi ciency of 10.3% even if increasing abscissa (i.e. because surface collector temperature increases) PVTWIN effi ciency is less sensitive (more constant). The latter remark is also true for the MSS collector (the slope is even lower than PVTWIN) and for all the collector types electrical effi ciency decreases more quickly with a higher mass fl ow rate.

As already stated in former studies [9], it is interesting to evaluate the exergetic effi ciency of the three PV/T collectors in the same conditions of Figure 12 to Figure 15. It is well known that exergy is a state function representing the quota directly convertible in mechanical work of a quantity of energy. While electrical energy is basically pure exergy, thermal energy that cannot be converted in mechanical work without a temperature difference between source and sink, has an exergetic quota depending on such a temperature difference. So it is possible to defi ne an exergetic effi ciency of the PV/T panels, that is the ratio between useful exergy (in output) and used exergy (in input where hex,t is the exergetic quota of the useful thermal power produced by the collectors (varying in the range of 1 to 8%) and xex,e, xex,t, xex,tot respectively the electrical, thermal and total exergetic effi ciency (reference for exergy is the measured ambient (external) temperature, 28ºC). Exergetic effi ciency of hybrid collectors is higher than PV only collectors (by the quantity ht · hex,t) and, above all, than thermal only collectors (by the quantity he). Figure 16 and Figure 17 depict the total exergetic effi - ciency of the three collectors for the two mass fl ow rates (40 and 120 kg h−1 m−2), assuming the same values of Figure 12 to Figure 15 as regard solar radiation, inlet temperature and ambient temperature. The COGEN collector is the best for Tred > 0.02 and m . = 40 kg h−1 m−2 but, while both MSS and PVTWIN show a better behaviour with higher mass fl ow rate, the COGEN collector decreases its performance at m . = 120 kg h−1 m−2 . From all the measured data (not only the ones reported here) it is possible to make the following statements, that are quite in agreement with previous results [10]: – with glazed collectors, when global solar radiation is high (700 to 800 W m−2) it is advisable to use higher values of water mass fl ow rate, in order to guarantee an appropriate cooling of the PV laminate thus limiting the negative infl uence of temperature increase on PV performance; – with unglazed collectors, conversely, lower mass fl ow rates are better in order not to penalize too much thermal effi ciency; – for the same reason, when global solar radiation is lower (350 to 400 W m−2), for both glazed and unglazed technologies it is advisable to use lower mass fl ow rates.

Conclusions

The main purpose of the test rig set-up at the Department of the University of Padova in Vicenza was to measure the thermal and electrical performances of a self-built PV/T glazed liquid cooled collector and to compare it with other state-of-the-art commercially available PV/T collectors. The experimental results are quite in agreement with calculated values by a simulation program based on a detailed analytical model. The results show that the thermal effi ciencies at a zero reduced temperature for the glazed type collectors (PVTWIN, COGEN) are comparable and around 60% with 10 to 12% of electrical effi ciency; the thermal effi ciency is expected to increase to around 70% for thermal energy only production. Water temperature increase in the collectors is in the range of 2 to 8ºC as a function of the mass fl ow rate

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