Experimental Investigation of Thermal Performance of Photovoltaic Thermal (PVT) Systems

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Abstract— *The phenomenon of photovoltaic systems is based on the principals of semiconductor physics and they operate with a semiconductor element, such as silicon. Photovoltaic cells can generate electricity only when they receive a certain amount of photon energy and thus they convert only a fraction of the solar irradiance, which is received from the sun in the form of electromagnetic radiation in the electromagnetic spectrum, into electrical energy. The remaining radiation is stored as heat in photovoltaic systems, causing some irreversibilities in the system.*

In general, the experimental setup, the accumulated heat, which reduces the efficiency of the photovoltaic systems, is aimed to be removed from the system and turned it into useful energy. By employing some heat transfer enhancement systems, the photovoltaic cell temperature decreased to the range of 40-60 °C, the temperature range at which a photovoltaic system runs optimal, whereby an approximate improvement of 20% in electrical efficiency of the PV system achieved. Aluminum and copper cylindrical fins or some refrigerant fluids used as heat transfer enhancement elements in the systems.

In this operating conditions, the electrical efficiency of the system decreases to around 6.5% down from the nominal electrical efficiency of 12% under optimal operating temperature. The fin surface temperature and ambient temperature of the control volume decreased in direct proportion to the air velocity. At about 5 m/s air velocity, the fins bodies and ambient air were cooled down by about 50%, accordingly, the electrical efficiency decreased from 12% to only 9.5%.

Keywords— Thermal efficiency of PV cells; electrical efficiency; copper fins; aluminum fins; pv/t systems.

I. INTRODUCTION

In parallel with the developing and increasingly diversified industry, as well as the seek for comfort, the need for energy is increasing rapidly. This need can no longer be met by relying on fossil fuels even if conventional energy producing systems are used effectively and environmental pollution is disregarded. Due to increased energy load and the adverse effects of fossil fuels on environment, a quest for new and renewable clean energy sources are sought [1,2]. Renewable energy sources have been seen as a solution to the disadvantages caused by fossil fuels and solar energy has made its first place with its high potential and large geographical availability.

Surveying the literature, one can easily see that there is an abundance of experimental study on the thermal analysis of the photovoltaic system. Most of these studies focus on removing the radiation-induced heat accumulation, which decreases the yield from the photovoltaic system, with appropriate cooling systems in order to maintain the electrical output at fair levels as well as obtaining a utilizable thermal energy source.

In the literature, there are many complex and detailed mathematical models for thermal performance analysis. However, in order for the performance analysis of such systems should easily be calculated and be compared to similar systems; generally, a performance analysis based on the first law of Thermodynamics is sufficient. In thermodynamic analysis of the Photovoltaic thermal (PVT) systems, the system is regarded to be a continuous flow control volume (open system). Mass and energy transfers from the boundaries of the control volume are calculated using conservation equations. Atypical control volume set for the experimental systems studied in the literature is given in Fig. 1.

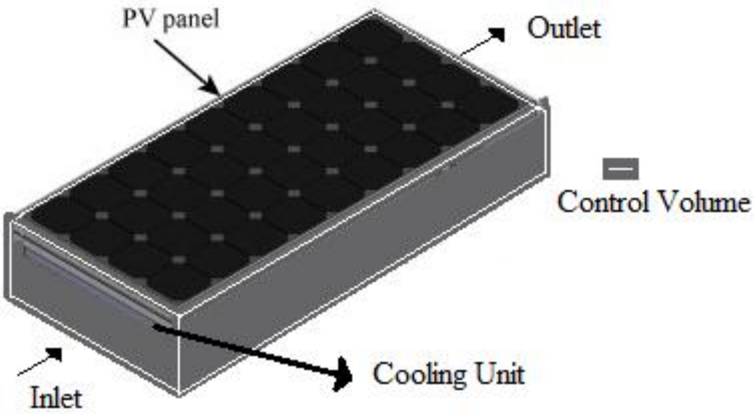

FIGURE 1. A TYPICAL CONTROL VOLUME FOR EXPERIMENTAL STUDIES IN THE LITERATURE

The mass transfer from system to control volume or from control volume to system at any given time interval of Δt is equal to the change in mass in the control volume in the same time interval.

$$\dot{m}_i - \dot{m}_o = \Delta \dot{m}_{kh} \quad [kg/s] \tag{1}$$

The changes in the control volume has to be equal to zero for it is a continuous flow system, and therefore;

$$\sum \dot{m}_i = \sum \dot{m}_o [kg/s] \tag{2}$$

The energy equation for continuous flow systems with necessary simplifications made is;

$$\dot{Q}_{thermal} = \dot{m}(h_o - h_i) \quad [kW] \tag{3}$$

$$\dot{Q}_{thermal} = \dot{m}.c_p(T_o - T_i) \quad [kW] \tag{4}$$

And the total solar power gained from the sun can be expressed as follows, as the sum of the thermal power gain and the generated electrical power ($\dot{Q}_e$ = V.I).

$$\dot{Q}_g = \dot{m}\left[(h_o - h_i) + \left(\frac{{V_o}^2 - {V_i}^2}{2}\right)\right] + \dot{Q}_e \quad [kW] \tag{5}$$

$$\dot{Q}_g = \dot{m}\left[c_p(T_o - T_i) + \left(\frac{{V_o}^2 - {V_i}^2}{2}\right)\right] + I.V \quad [kW] \tag{6}$$

The First Law efficiency is expressed as;

$$\eta_I = \frac{\dot{Q}_g}{\dot{Q}_{solar}} \tag{7}$$

which is a commonly used expression for efficiency calculations in the literature.

II. LITERATURE REVIEW

The use of energy is increasingly diversifying and the difference between the amount of energy produced and the energy load that has to be met is increasing each day. Fossil fuels were preferred to be the primary energy source to meet energy needs. Fossil fuels, which do not require use of high technology in neither accessing nor making use of, have brought in a number of problems. These problems, which showed off as simply environmental pollution in early times, have brought about the major global warming and the greenhouse effect issue, which is truly a catastrophe forerunner. Greenhouse gases which are emitted as a result of inefficient and excessive use of fossil fuels have caused serious damages to the atmosphere. Therefore, different types of environmental friendly sources are sought.

Energy sources referred to as renewable energy sources in the literature have almost no environmental impacts. The best renewable source of energy that can be used as an alternative to fossil fuels is solar energy [3]. Also the highest capacity renewable energy source among all renewable is solar [4]. Different applications are available in utilization of solar energy. The first application is solar collector systems while the latest and most technologically developed one is the photovoltaic systems which generate electricity from solar irradiation.

The greatest problem in photovoltaic systems is the increased cell temperature under in solution [5].A number of methods have been developed to prevent cell temperature from rising [6].This excess heat accumulated in photovoltaic systems can be converted into useful thermal energy [7].Such Photovoltaic systems can be combined with thermal systems (which is then called a PVT) and both reduction in the system efficiency can be avoided by drawing heat and the drawn heat can be transferred to a fluid which can serve as a thermal agent and hence increase the total yield from the system. PV/T systems were first implemented in 1970s by Martin Wolf [8]. Michel et al. used nano-fluids in PV/T system as heat transfer agent [9]. Numerical simulation studies are also being made on PV/T systems such as those referred to in a detailed review by Tchen et al. [10]. Ion the other hand, many numerical simulation studies focused on thermal and electrical efficiencies of PVT systems are available in the literature, too [11-15].

PV/T systems can be designed in different ways to optimize efficiency for different climate zones. Conventional PV systems are more efficient in cold climate regions because of the low ambient temperature [16].Among examples for integration of PV/T systems to cold climate regions are those of Chow et al. and Athientis et al. [17,18].

III. MATERIAL AND METHOD

The photovoltaic system reaches a steady state temperature of about 120 °C at under800 W/m2 solar irradiation. This temperature is far too higher than the optimum operating temperature of 40 °C for the photovoltaic system. At this operating conditions, the electrical efficiency of the system decreases to around 6.5% down from the nominal electrical efficiency of 12% under optimal operating temperature. The conversion of the photovoltaic system to the photovoltaic thermal (PV/T) system helped avoid this yield reduction.

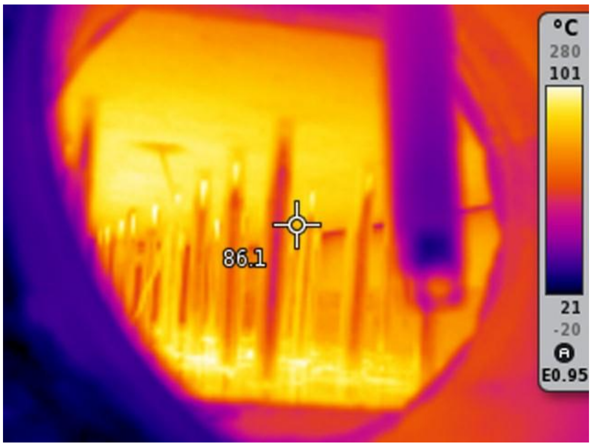

FIGURE 2.ALUMINUM FINS WITHIN THE CONTROL VOLUME WITH NATURAL CONVECTION

The PV / T is designed to create a control volume within the experimental rig. As can be seen from Fig. 2, in the absence of air flow in the control volume, the surface temperature of about 120 °C could be reduced to 86 °C by adding aluminum fins under natural convection conditions thanks to the increase in the total heat transfer surface area.

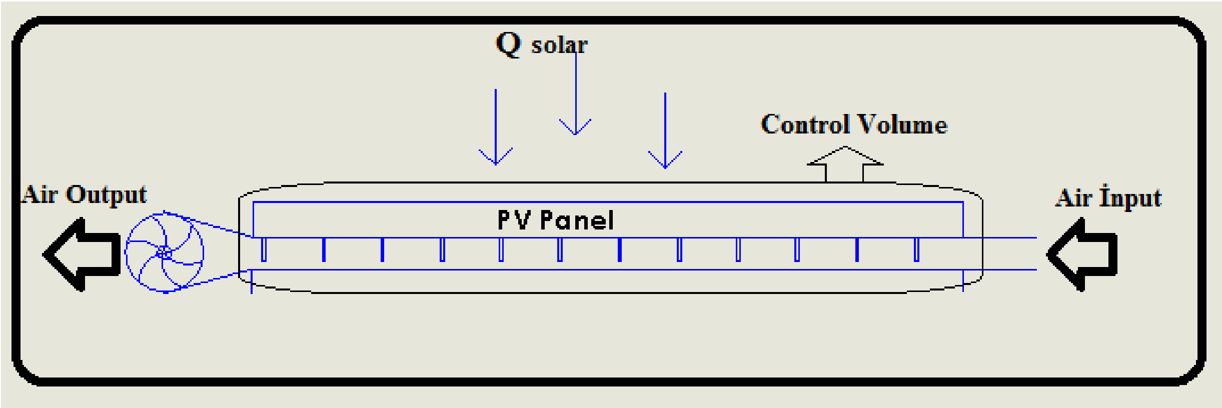

FIGURE 3.DESIGNED CONTROL VOLUME.

Additionally, in the next step, the PV/T experimental rig has been equipped with a fan at the outlet port of the control volume in order to draw air through the control volume. Why the fan has been installed on the outlet end is that this prevents the heat transfer to the feed air from the fan body, which is heated during the working regime.

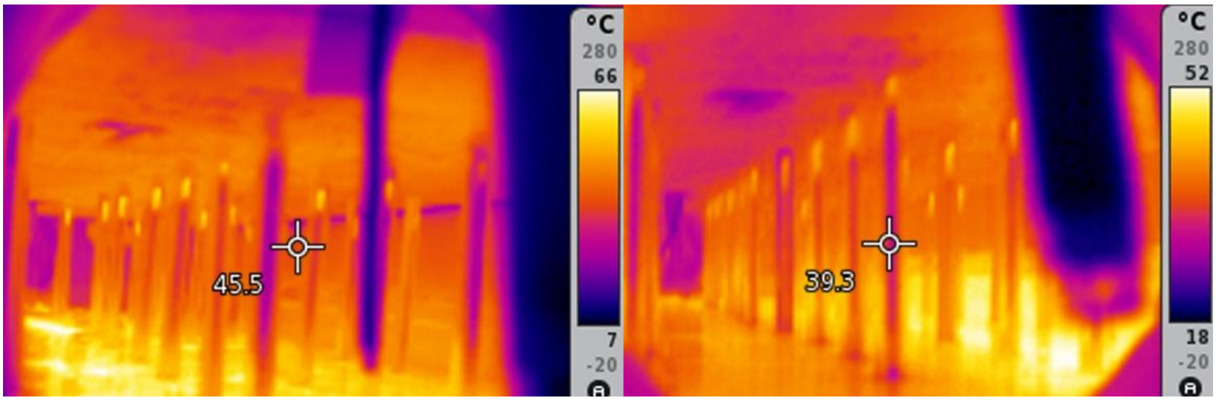

FIGURE 4.FIN BODY TEMPERATURE AND AMBIENT TEMPERATURE WITH SUCTION PUMP AT 5 m/s AIR VELOCITY

In the photovoltaic thermal experimental rig, air suction with forced convection is provided at different air velocities, the fin surface temperature and ambient temperature of the control volume decreased in direct proportion to the air velocity. At about 5 m/s air velocity, the fins bodies and ambient air were cooled down by about 50%, as shown in Fig. 4. Accordingly, the electrical efficiency decreased from 12% to only 9.5%. The efficiency calculation is made by considering the net yield, and the net electrical power drawn by the fan is subtracted.

IV. RESULTS AND DISCUSSION

Researchers conducted on thermal examination of photovoltaic systems (cooling) can be collected under several headings as follows;

- Using microchannel technology and nano-fluids.
- Liquid spray cooling.
- Thermoelectric modules.
- Forced convection cooling using the fins with air or water.
- Removing heat from the photovoltaic surface by employing phase change materials.

TABLE 1
COMPARISON OF DIFFERENT TECHNOLOGIES

Technology Used	Benefits	Drawbacks
Studies using microchannel technology nano-fluids	• Thermal efficiency • High heat transfer coefficient	• High cost and difficulty of applicability.
Cooling operation with water sprays.	• Increased energy efficiency. • It is more efficient than air cooling.	• The entire surface area of the PV panel is only partially cooled. • Removed heat is wasted.
Studies with thermoelectric modules.	• Electrical efficiency is increased. • It reduces hot spotting.	• Heat loss due to conduction between the hot and cold parts through semi-conductors • Heat cannot be transferred well enough.
Forced convection cooling using fins with air or water	• Overall efficiency is increased. • Economically feasible. • Heated air or water used to heat buildings.	• Air-cooling efficiency is lower than cooling with water. • More effective than cooling with air cooling with water in hot climates.
Removing heat from the photovoltaic surface by employing phase change materials.	• It can store large amount of heat with a small temperature changes. • The phase change takes place at a constant temperature. • The captured heat used to heat buildings.	• Paraffin solid which has a low thermal conductivity. • You need more capacity for heat storage. • In colder areas it is less efficient.

In this study, different types of PV / T systems were compared by examining the analysis of thermal performance. Efficiency of thermal systems integrated with photovoltaic system is high, and it also increases the overall system efficiency. The total yield from the system is about 55% greater than the yield of the photovoltaic electrical system alone.

The combination of thermal collectors and photovoltaic systems is very important in terms of energy efficiency. Using Photovoltaic systems in combination with thermal systems (which is simply called a PV/T system) will become general in the industry. Developing material technologies and increased energy demand will force increase researches on renewable energy sources which in turn will increase yields from renewable energy systems.

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