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Electrical and thermal efficiency of air-based photovoltaic thermal (PVT) systems: an overview

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ABSTRACT

The development of photovoltaic thermal (PVT) system is a very promising area of research. PVT systems using in various applications, such as solar drying, solar cooling, water heating, desalination, and pool heating. With the recognition of the potentials and contributions of PV system, considerable research has been conducted to attain the most advancement which may produce reliable and sustainable PVT system. The cooling system's design refers to the absorber design which mostly focuses on water and air-based PVT systems. An air-based system has been developed through different absorber configurations, air flow modes and single- or double-pass design. Hence, a summarization on various research and development of air-based PVT system will be presented.

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1. INTRODUCTION

Solar energy is one of the sustainable energy which promises clean energy production. Regarding to limited conventional fuels, the implementation of solar technology is going into great advancement as one used to produce electrical energy using photovoltaic (PV) solar system. Furthermore, thermal energy can be generated which by utilizing working fluids in an integrated cooling system of PV; known as photovoltaic thermal (PVT) system. Regarding to the principle on how it works, electrical energy will be generated from a direct conversion of solar energy. The concept of PVT system in producing both electrical and thermal energy simultaneously had been studied in details. As heat from the sunlight or solar energy had been absorbed, the heat will be extracted by the air that flow in the cooling system. Focusing on air deployment as the coolant or working fluid, air-based PVT has been widely used for domestic application such as drying of agricultural products. Though, the study of PVT still experiencing great improvements in achieving great efficiency of energy production [1-13].

Energy and exergy analysis for PVT systems were studied base on theoretical and experimental study. Sarhaddi et al. [14], [15] performed a detailed energy and exergy analysis of an air-based PVT system to calculate the thermal and electrical parameters, exergy components and exergy efficiency of a typical air-based PVT system. The analysis showed that increasing inlet air velocity or solar radiation intensity, increased the exergy efficiency initially and then decreased after attaining a certain maximum inlet air velocity or solar radiation intensity. It was also reported that increasing wind speed increases the exergy efficiency. They also reported that the working fluid to have a significant effect on the exergy efficiency and that the exergy efficiency can be increased if an incompressible fluid (water) is used in PVT system. In this review, describe types of air-based PVT systems is presented. Also, electrical and thermal efficiency of air-based PVT systems base on energy and exergy analysis is presented.

2. TYPES OF AIR-BASED PVT SYSTEMS

PVT system which utilized air as the coolants in extracting heat from the PV panel had been employed to produced hot air aside the generation of electricity. An air-based PVT system consists of a PV panel, insulation and a frame as well as one or more glass cover or a transparent material placed over the absorbing plate (Figure 1) with air flowing around it. Based on air flow pattern, air-based PVT systems can be categorised into five types are: (i) conventional air-based PVT systems or as known back-pass air-based PVT system (Figure 2a), (ii) Double-pass with inlet air from channel above a PV panel (Figure 2b), (iii) single-pass parallel PVT system (Figure 2c), (iv) Single-pass with a channel above a PV panel (Figure 2d), and (v) double-pass with inlet air from channel above a PV panel (Figure 2e).

Figure 1. Configuration of air-based PVT system

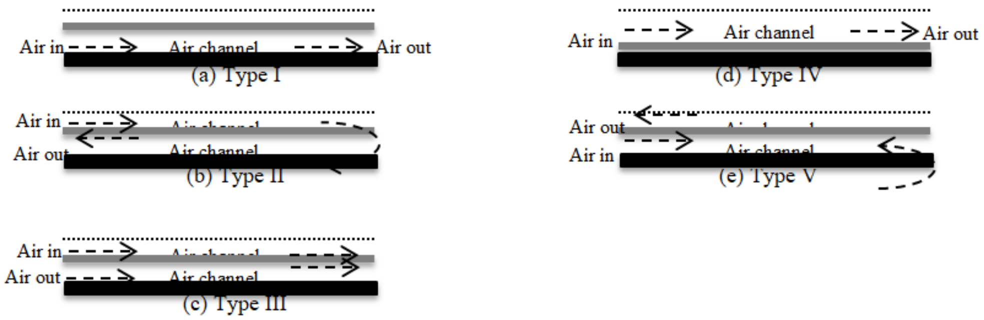

Figure 2. Sectional of air-based PVT systems [16] [17]

3. STUDIES CONDUCTED ON AIR-BASED PVT SYSTEMS

In PVT air-based, the air acts to cool down the panel. Several studies have been conducted during these recent years on the air hybrid collectors [18]. Early in 1996, a performance comparison on single and double pass PVT air collector had been conducted by Sopian et al. [19] which by then they concluded that the double pass-type PVT air collector portrayed better performance regarding the cooling of a solar cell.

One study focused by Hegazy [16] on such collectors and they had been evaluated through numerical modelling. Involved various designs of PVT air collectors such as: (i) air channel above PV collector, (ii) air channel below PV collector, (iii) single pass PV collector and (iv) double pass PV collector.

In 2006, Naveed et al. [20] experimentally investigated PVT grooved transpired plate performance. A range of 6K of decreasing of module temperature had been observed. It resulted simple payback period of eight years, economically.

By using parameter or restriction of experiment carried out under no wind conditions and laminar flow, Arulanandam et al. [21] had conducted mathematical study of PVT. He numerically simulated a quarter of hole pitch and correlated numerical results in order to estimate Nusselt number as a function of suction velocity, hole diameter, plate thickness, and porosity.

Other numerical study also had been pursued by Li and Karava [22]. Heat transfer and air flow between PV panel and trapezoidal grooved transpired plate had been focused in this research. Nusselt number had been correlated by including length and height of groove, slope of trapezoidal corrugation, wind velocity, and width of PV module.

A PVT air system included a PVT air collector connected to a short length duct with fan for the air transfer had been designed by Bambrook [23]. In minimizing the energy output, the collector depth and the air mass flow rate had been optimized.

Yang and Athienitis [24] presented a prototype of open loop air-based building integrated PVT system with a single inlet. The study had involved through a wide-ranging series of experiments in a full scale solar simulator. A numerical control volume model was presented and confirmed based on the experimental results.

A study on basis of annual overall thermal energy and exergy for New Delhi has been carried out past five years by using energy metrics of PVT air collector. They have investigated that, by including the cost of energy in the manufacturing of components of the PVT module air collector, the payback and efficiency resulted vice versa pattern as the payback increased, the efficiency decreased respectively [25].

Then, the single and double-pass design of PVT had been improved for energy and exergy analysis which had been done by Kamthania et al. [26]. Yet, by all means, the superiority of double-pass PVT as the best design had been ratified as well from the outcome of this study.

Tonui and Tripanagnostopoulos [27] have developed an economical modification technique which in the meantime the heat transfer of PVT air collector can be improved. From the attained data of experiments, they had been validated for both glazed and unglazed PVT model as had been designated in the experimental procedure.

The performance of PVT was influenced by the thickness of the glass as well as the module’s temperature and the inlet flow [28]. Substituting mono facial PV cells with bifacial PV cells has led to the development of bifacial PVT panels. The integration of an aluminum reflector contributes to 40% increment in both energy generation [29].

A study of four air-based bifacial PVT panels were designed, resulting maximum efficiencies of 45% to 63% were observed for the double-path-parallel bifacial PVT panel. It contributed as second preferred design due to its performance in generating up to 20% additional total energy compared to the single-path panel. However, for the analysis on daily average exergy efficiency, the double-path-parallel panel is 0.35% lower than that of a single-path panel [30].

A study which was configuring single and double glass were developed and analyzed. It had been observed that greater duct depth affect single glass more than double glass configuration. It had been preferred for the PVT system to be designated with effective economical calculations in order to ensure low life rate for affordable system [31].

4. ENERGY AND EXERGY EFFICIENCY OF AIR-BASED PVT SYSTEMS

An assessment of proposed design by Solanki et al. [32] on the performance of air- based PVT had been conducted. The experiment was carried out under variable insolation and air flow rate by constituting three mono crystalline silicon glass to tedlar type PV modules. They attained 42%, 8.4% and 50% respectively for the efficiencies of thermal, electrical and system.

An exergy analysis of flat plate air based PVT system had been conducted by Srimanickam et al. [33]. It had been attained that the system had generated 9.78%, 24.22%, 44.84% and 11.23% respectively of electrical, thermal, overall energy efficiency and exergy efficiency. Various energy and exergy efficiencies of air-based PVT systems as shown in Table 1.

Table 1. Performance of air-based PVT Systems

Year	Author(s)	Study	Performance Analyses	Energy Efficiencies (%)			PVT Exergy Efficiency (%)
				Thermal	PV	Overall	
1996	Sopian et al. [19]	Experimental and theoretical	Energy analysis	35	7.5	50	NA
1997	Garg and Adhikari [31]	Experimental	Energy analysis	42	8.4	50.4	NA
2000	Hegazy [16]	Experimental	Energy analysis	58	8.1	55	NA
2000	Sopian et al. [34]	Experimental	Energy analysis	60	NA	NA	NA
2003	Saitoh et al. [35]	Experimental and theoretical	Energy analysis	40–50	10-13	NA	NA
2005	Othman et al. [36]	Experimental and theoretical	Energy analysis	NA	NA	39–70	NA

2006	Othman et al. [37]	Experimental	Energy analysis	NA	9	38–70	NA
2007	Tonui and Tripanagnostopoulos [38]	Experimental	Energy analysis	52	9–10	61–62	NA
2007	Tiwari and Sodha [39]	Experimental and theoretical	Energy analysis	NA	10	40	NA
2007	Alfegi et al. [40]	Experimental	Energy analysis	15.2–26.4	11.4–12.7	26.6–39.13	NA
2008	Alfegi et al. [41]	Experimental	Energy analysis	17–26.43	10.5–12.09	27.5–40.4	NA
2008	Nayak and Tiwari [42]	Experimental and theretical	Energy–exergy analysis	NA	NA	NA	4
2009	Joshi et al. [43]	Experimental	Energy analysis	26.4–30.5	9.5–11	41.6–47.4	NA
2009	Alfegi et al. [44]	Experimental	Energy analysis	NA	NA	49.1–62.8	NA
2009	Dubey et al. [45]	Experimental and theoretical	Energy analysis	NA	NA	9.75–10.41	NA
2009	Ibrahim et al. [46]	Theoretical	Energy analysis	32.4–50.1	11.9	NA	NA
2010	Agrawal and Tiwari [47]	Experimental and theoretical	Energy–exergy analysis	NA	NA	53.7	NA
2010	Agrawal and Tiwari [48]	Experimental and theoretical	Energy–economic analysis	33.54	7.13	NA	NA
2010	Sarhaddi et al. [14]	Experimental and theoretical	Energy analysis	17.18	10	45	NA
2010	Sarhaddi et al. [15]	Experimental and theoretical	Energy–exergy analysis	17.18	10	45	10.75
2010	Shahsavar and Ameri [49]	Experimental and theoretical	Energy analysis	60	9.5	72	NA
2011	Agrawal and Tiwari [50]	Theoretical	Energy–exergy analysis	70.62	NA	NA	NA
2012	Amori and Al-Najjar [51]	Theoretical	Energy analysis	19.4–22.8	9–12.3	47.8–53.6	NA
2012	Agrawal et al. [52]	Experimental and theoretical	Energy–exergy analysis	35.7	12.4	NA	NA
2013	Agrawal and Tiwari [53]	Experimental	Energy–exergy–environmental analysis	32	NA	NA	NA
2014	Yang and Athienitis [24]	Experimental and theoretical	Energy analysis	27.1	10	NA	NA
2014	Kim et al. [54]	Experimental	Energy analysis	22	15	NA	NA
2014	Amori and Al Raheem [55]	Experimental	Energy analysis	46–62	8.3–10.4	NA	NA
2015	Li et al. [56]	Experimental and theoretical	Energy analysis	50	11.9–12.4	77.7	NA
2015	Good et al. [57]	Experimental	Energy analysis	71.5	17.4	NA	NA
2015	Ahn et al. [58]	Experimental	Energy analysis	23	15	38	NA
2015	Jahromi et al. [59]	Theoretical	Energy–exergy–economic analysis	51.6–52	7.5–8.7	NA	9.6–9.7
2015	Kamel and Fung [60]	Theoretical	Energy analysis	32.8–41	16–17	NA	NA
2015	Rajoria et al. [61]	Theoretical	Energy–exergy–enviro-economic analysis	12.1–28.1	3.1–9.1	NA	NA
2016	Gholampour and Ameri [62]	Experimental	Energy–exergy analysis	55	NA	69.91	8.66
2016	Rounis et al. [63]	Theoretical	Energy analysis	48	16.5	NA	NA

2016	Mojumder et al. [64]	Experimental and theoretical	Energy analysis	56.19	13.75	NA	NA
2016	Hazami et al. [65]	Experimental and theoretical	Energy–exergy analysis	50	15	NA	14.8
2016	Tiwari and Tiwari [66]	Experimental	Energy–exergo-economic analysis	NA	NA	68.5	NA
2016	Slimani et al. [67]	Experimental and theoretical	Energy analysis	70	10.5	90	NA
2017	Salem et al. [67]	Experimental	Energy–exergy analysis	31.6–57.9	17.7–38.4	59.3–92	11.1–13.5
2018	Fudholi et al. [10]	Experimental and theoretical	Energy–exergy analysis	21.3–82.9	9.87–11.34	31.21–94.24	12.66–12.91

5. CONCLUSIONS

Air-based PVT systems had achieved great efficiencies in producing both thermal and electrical energy. Maximum efficiency value of thermal gain attained up to 82.9% while different study had achieved 38.4% of electrical energy. Latest exergy study presented exergy efficiency obtained more than 12%. Further research and analysis would like to be recommended in order to obtain best system in generating useful energy, portrayed by the exergy value, can be achieve by the system.

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