Effect of Packing Factor on the Performance of PV/T Water Heater

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Abstract: Effect of packing factor (the fraction of absorber plate area covered by the solar cells) on the -Long-term performance of a photovoltaic/thermal hot water system under the meteorological conditions of Malaysia has been simulated. In this study, the typical weather year file containing the weather parameters for Kuala Lumpur has been considered. The results indicate that for both glazed and unglazed conditions, the increment of the packing factor resulted in the decreasing solar fraction, whereas this effect for the coverless PV/T collectors was found sharper than the glazed ones. For polycrystalline and mono crystalline silicon cells, the maximum solar fraction was found in the polycrystallin cells, while the minimum one was obtained from the mono crystalline solar cells. Apparently, the curves followed the same pattern for the unglazed PV/T collectors.

Key-Words: - Photovoltaic Thermal (PV/T), Packing Factor, TRNSYS, Electrical Power Output, Auxiliary Heating Rate, Water Temperature.

1 Introduction

The application of solar energy can be broadly classified into two categories; thermal energy systems which converts solar energy into thermal energy and photovoltaic energy system which converts solar energy into electrical energy. The vital component in solar energy system is the solar collections systems. Two solar energy collection systems commonly used are the flat plate collectors and photovoltaic cells. Normally, these two collection systems are used separately. These two systems can be combined together in a hybrid photovoltaic thermal (PVT) energy system [1].

The term PVT refers to solar thermal collectors that use PV cells as an integral part of the absorber plate. The system generates both thermal and electrical energy simultaneously [1].Photovoltaic (PV) modules convert a part of solar radiation energy directly into electricity, while, the unconverted part of the solar radiation into electricity is absorbed in a PV module resulting in very high temperatures[2].The photovoltaic (PV) cells suffer efficiency drop as their operating temperature increases especially under high insulation levels and that in order to maintain a high electrical output from the PV device, the operation temperature of the PV/T system needs to be kept low [3-5].

Solar radiation in Malaysia, which is entirely equatorial, is high by the world's standards with an average daily solar radiation of 4.5 kWh/m^2 and an average daily sunshine duration of about 4-5 hours. In the case of solar, the energy available is about four times of the world's fossil fuel resources. Therefore, in Malaysia, the climatic conditions are favourable for the development of solar energy [6, 7]

Many researchers have acknowledged the performance of solar water heating systems using the PV/T collectors, which has resulted in the rapid growth of both theoretical and applied research studies on the thermosyphon and active water heater systems.

The first research of water based PV/T systems were reported in the middle of 1970s to early 1980s where the performance of integration of photovoltaic and thermal system for hot water production based on Hottel-Whillier model [8] had been analyzed and it was observed that the system is economic and feasible [9]. The main concept of photovoltaic thermal collector using water or air as the working fluid was proposed by Kern and Russell in 1978 [10]. Florschuetz performed the theoretical analysis of a PV/T collector through an improved Hottel–Whillier model [11]. A comparative experimental study in (PV/T) collectors with liquid and air as the heat removal fluid (working fluid) was made by Hendrie and Raghuraman (1980) [12]. The heat transfer at the air gap behind the photovoltaic panels was studied by Moshfegh and Sandberg [13]. Later, a commercial polycrystalline PV module was used for making a PV/T collector as compared to a conventional solar water heater and to demonstrate the idea of an integrated photovoltaic and thermal solar system

(IPVTS). The study introduced the concept of primary-energy saving efficiency for the evaluation of a PV/T system. The primary-energy saving efficiency of this IPVTS exceeded 0.60. This was higher than for a pure solar hot water heater or a pure PV system. The characteristic daily efficiency reached 0.38 which was about 76% of the value for a conventional solar hot water heater using glazed collectors [14].

Research of hybrid PV/T solar systems for domestic hot water and electricity production continued and in recent years, one combined system was designed [15]. In this work, both passive (thermosyphonic) and active systems were considered.

In passive system the water in the collector expanded as the sun heated it and raised through the collector into the top of the storage tank, then it was replaced by the cooler water and it flowed down the collector, circulation continues as long as there was sunshine. The collector was linked with a storage tank. Active system needed pump to circulate the water from the collector to storage. The heat removal fluid was water with antifreeze liquid. The results of this study showed that a substantial amount of thermal and electrical energy was produced especially when both hot water and electricity was required, particularly in applications where low temperature water like hot water production for domestic use, was required.

A PV/T water heating system with natural circulation was proposed [16,17], the whole PV/T assembly was placed in a flat-box Al-alloy frame and the water heating system comprises of one collector, one water tank, the valves and pipes. The water tank was installed horizontally to an Al-alloy bracket. The electrical system was composed of 144 black single crystalline silicon cells in series, converter, accumulator batteries and the associated switches and wiring. This system was tested with variations of the system water mass, PV module covering factor and front glazing transmissivity. The results of experimental works revealed that by incrementing the hot-water load per unit heat-collecting area to 80 kg/m2, the daily electrical efficiency, the characteristic daily thermal efficiency, the characteristic daily total efficiency and the characteristic daily primary-energy saving was about 10.15%, more than 45%, above 52%and up to 65%, for this system with a PV cell covering factor of 0.63 and front-glazing transmissivity of 0.83, respectively. The simulation results showed that the overall performance system increased with the higher the covering factor and the glazing transmissivity. This system had been tested some years ago [18] and the results showed that a high hot water temperature in the collector system can be achieved.

PV/T dual systems were designed [19] and in their collectors both water and air heat exchangers (WHE and AHE) were together in the same device and there were three main modes of arrangements. In mode A, water heat extraction was in contact with PV rear surface. In mode B, air heat extraction acted as the additional element of WHE and played the role of the thin metallic sheet (TMS) in the air channel. Mode C as the WHE was simply placed on the opposite air channel wall, this system was easier in construction than the other two arrangements. The results of experimental works indicated that, mode A was the most effective combination for the heat extraction operation among the three tested system design modes. With modification of systems, satisfactory thermal efficiency for both water and air heat extraction systems were obtained. Modifications were consisted of: in the middle of the air channel was placed a thin metallic sheet, the mounting of fins on the opposite side wall to PV rear surface of the air channel and the placement of the sheet combined with small ribs on the opposite air channel wall. Aiming to achieve higher thermal and electrical output the modified systems combined with diffuse reflector. These systems provide hot water or air depending on the thermal needs of the building.

A solar water heater system using a glass to glass PV/T module developed [20]. In this system solar radiation was absorbed by PV module and transferred to absorber.

The outlet of water became inlet to glass-absorber combination and was further connected to the inlet of conventional flat plate collector for higher operation temperature; both collectors were connected to an insulated storage tank. One water pump circulated the water between collectors and tank. It was concluded that this system was a self sustainable system and could be installed at remote areas for fulfillment of hot water requirements and electrical energy production. It was added that absorber collector which covered partially with PV module gave better thermal and average cell efficiency compare to studies have been done by earlier researchers.

The design of a novel building integrated photovoltaic/thermal (BIPVT) solar collector was theoretically analyzed through the use of a modified Hottel–Whillier model and was validated with experimental data from testing on a prototype BIPVT collector [21].The results showed that key design parameters such as the fin efficiency, the thermal conductivity between the PV cells and their supporting structure, and the lamination method had a significant influence on both the electrical and thermal efficiency of the BIPVT. Furthermore, it was shown that the BIPVT could be made of lower cost materials, such as pre-coated colour steel, without significant decreases in efficiency. Finally, it was shown that by integrating the BIPVT into the building rather than onto the building could result in a lower cost system. This was illustrated by the finding that insulating the rear of the BIPVT may be unnecessary when it is integrated into a roof above an enclosed air filled attic, as this air space acts as a passive insulating barrier.

One of the most attractive applications of solar energy is for hot water usage in the public and commercial sector. In Malaysia, the available building surface for the residential, commercial and industrial sector is approximately 110,000,000 m2. Hence, the potential for solar water heaters for Malaysia is 75 GW (thermal). There are over 100 hospitals and hotels throughout the nation that the existing hot water system can be converted to solar assisted system and hence increase the market of the solar energy systems. Hospitals and hotels utilized over 30 % of the total energy consumption for water heating .In the year 2002, there were 10,000 domestic solar water heaters installed in Malaysia, with an annual growth rate of 10–15%. Heaters installed were both locally manufactured and imported, with the majority of imports coming from Australia (ASEAN, 2000).Solar thermal opportunities do exist for certain industries that require processing of hot water or pre-heating of water ahead of other forms of thermal input [22].

Satisfactory performance and reliability of a solar water heating system requires adequate sizing of its components as well as accurate prediction of the delivered useful energy and outlet water temperature [23].

Among the computer simulation programs and tools (i.e. from simple domestic hot water systems to the design and simulation of building their equipment, as well as control strategies, occupant behaviour, alternative energy systems, etc.) is TRNSYS, which has been developed for the transient simulation of systems [24].

This research work aimed to model, simulate and predict the long-term impact of packing factor on the performance of a photovoltaic/thermal hot water system under the meteorological conditions of Malaysia.

2 System Model

The system is modelled with the well known TRNSYS program. The program consists of many subroutines that model subsystem components. Once all the components of the system have been identified and a mathematical description of each component is available, it is necessary to construct an information flow diagram for the system. The purpose of the information flow diagram is to facilitate identification of the components and the flow of information between them. From the flow diagram, a deck file has to be constructed containing information on all system components, weather data file, and the output format [25].

3 Results and Observations

The variations of PV/T water heater performance with the packing factor (the fraction of absorber plate area covered by the solar cells) for both glazed and unglazed PV/T cells are shown in Figs. 1 and 2. The figures show the average yearly solar fraction for various packing factors. For both glazed and unglazed conditions, the increment of packing factor resulted in the decreasing solar fraction. It appeared that this effect for the coverless PV/T collectors was sharper than the glazed ones. It can be seen that the solar fraction went down very little even as the packing factor increased from 0.1 to 1. In addition, a slow decrease of the fraction from 0.715 to 0.67 and 0.714 to 0.66 can be reached for the uncovered polycrystalline and mono crystalline solar cells, respectively.

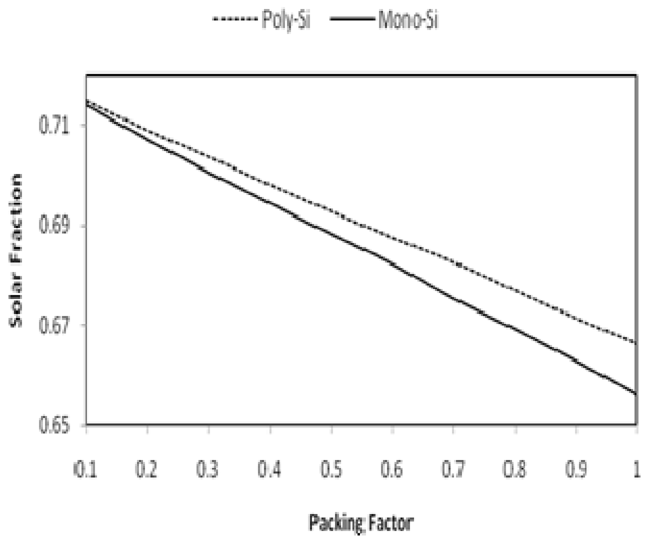

Fig.1 Variations of solar fraction versus the packing factor (No. of glass covers = 0)

On the contrary, for the glazed PV/T collectors, the declining trend was the same for different solar cells, but it dropped slightly from 0.997 to 0.993 and 0.996 to 0.991, subsequently. This can be attributed mainly to the fact that, regardless of the values of the packing factor, the solar fraction of the covered PV/T collectors was higher than the collectors without the glass covers.

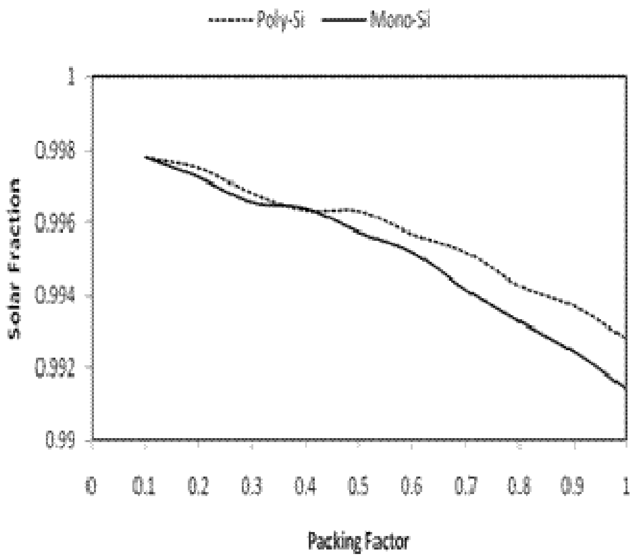

Fig.2 Variations of solar fraction versus the packing factor (No. of glass covers = 1)

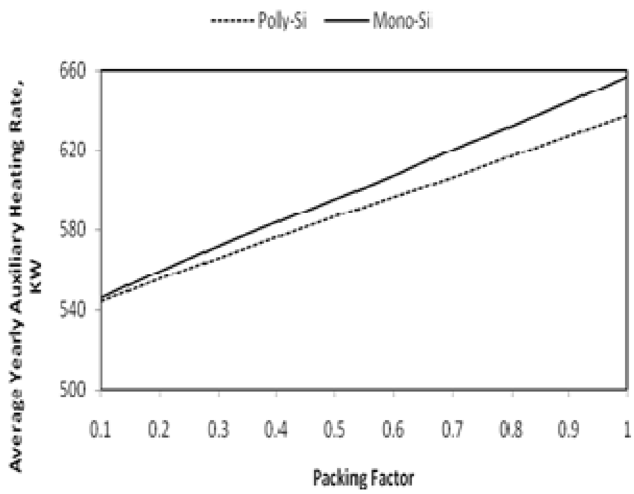

Fig.3 Variations of average yearly auxiliary heating rate versus the packing factor (No. of glass covers = 0)

The auxiliary heating rate is plotted as the function of packing factor (Figs. 3 and 4).

A rise in the packing factor means more collector area is covered by the PV cells. Hence, the auxiliary heating rate increases along with the increase in the packing factor. As can be seen from the figures, the a-Si cells needed less auxiliary heating rate than the comparable poly crystalline and mono crystalline cells. The auxiliary heating rate increased from 539 to 582 kW, 545-637kW and 546 to 657.3 kW for the unglazed a-Si, Pc-Si and Mc-Si, respectively.

The increase of auxiliary heating rate for the glazed collectors had a slight change with respect to the coverless PV/T collectors. Nevertheless, the tendency of enhancement of it was rather small and it was from 4.2 - 13.7 kW and 4.2 - 16.3 kW for Pc-Si and Mono crystalline -Si, respectively.

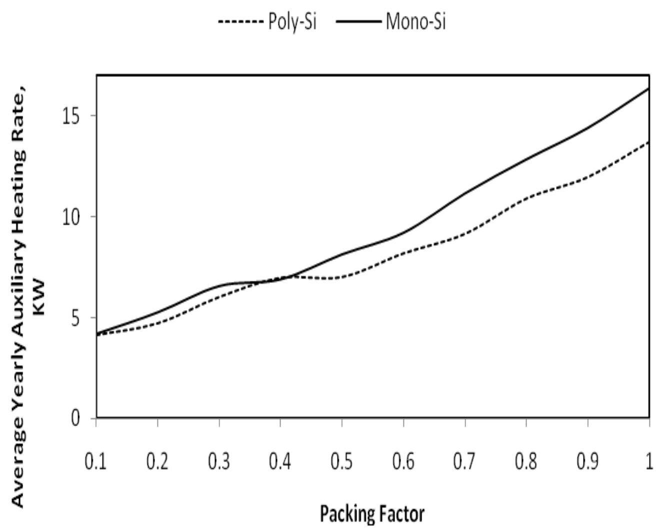

Fig.4 Variations of average yearly auxiliary heating rate versus the packing factor (No. of glass covers = 1)

The electricity produced by the photovoltaic thermal collector for Pc-Si and Mc-Si cells based on the variations of packing factors in both glazed and unglazed configurations is presented in Figs 5 and 6. It can be seen from the figures that, the electrical energy produced by the mono crystalline for the glazed and unglazed collectors was more than that of the polycrystalline cells in different packing factors. Electricity production increased by the increment in the packing factor for both coverless and covered configurations.

It was noteworthy that the average percentage of the electrical power outputs for the coverless mono c-Si and Poly c-Si cells were 12.7%, 13.0% more than that of the covered ones, as the packing factor increased from 0.1 to 1, respectively.

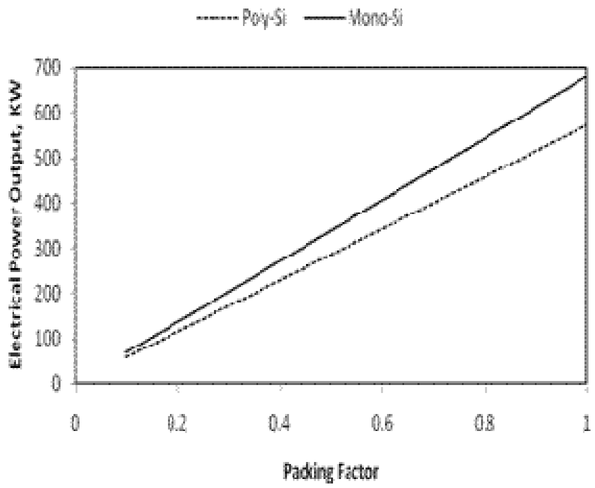

Fig.5 Variations of electrical power output versus the packing factor (No. of glass covers = 0)

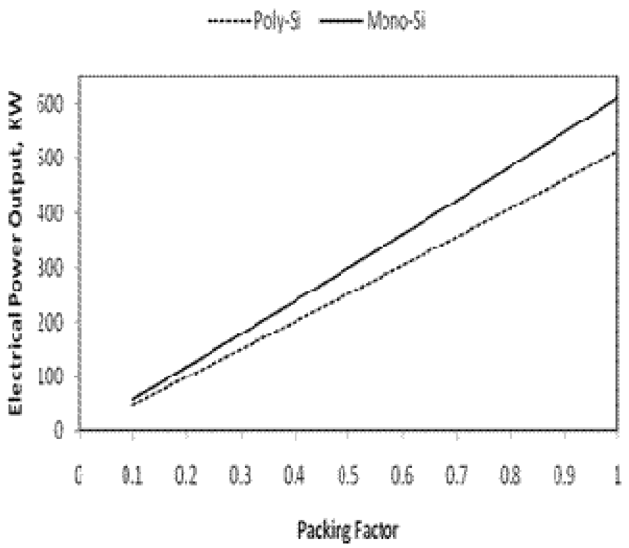

Fig.6 Variations of electrical power output versus the packing factor (No. of glass covers = 1)

4 Conclusion

The effect of packing factor (the fraction of absorber plate area covered by the solar cells) on the performance of the system has been investigated:

- For both glazed and unglazed conditions, the increment of packing factor resulted in the decreasing solar fraction. It appeared that this effect for the coverless PV/T collectors was sharper than the glazed ones.
- A rise in the packing factor means more collector area is covered by the PV cells. Hence, the auxiliary heating rate increases along with the increase in the packing factor.
- It can be seen that, the electrical energy produced by the mono crystalline for the glazed and unglazed collectors was more than that of the polycrystalline cells in different packing factors. Electricity production increased by the increment in the packing factor for both coverless and covered configurations.

Acknowledgment

The authors would like to thank the Solar Energy Research Institute (SERI), University Kebangsaan Malaysia, for support.

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ISBN: 978-960-474-274-5