

The Novel Solar Water Heating by Means of Thermoelectric Modules

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ABSTRACT

This paper is to investigate the use of solar energy for water heating by means of a couple of Thermoelectric (TE) modules i.e. TE cooling modules and TE power generation modules. Solar energy is applied to produce heat by the absorber plate at the hot side of TE modules creating the temperature difference that generates power. This power is used to drive a pumping for circulate the water which is passed the cold side of TE module for cooling and preheat water before into the solar collector. This proposed concept is very suitable for a hot country like Thailand where the solar radiation is rather high all year-round. The main objective of investigation is to study the characteristic and performance of TE modules for power generation at the low temperature which is considered as the solar energy. The maximum hourly temperature of the hot side of TE modules that can be obtained under Bangkok solar radiation intensity. It can be observed that the hot side temperature never exceed 120°C. Therefore, we select the temperature range in the range of 40-150°C. In order to investigate which type of TE module is suitable for the power generation at low temperature of hot side of TE, three TE modules were considered: two TE cooling modules (model B; TEC1-12708 and model C; MT2-1, 6-127) and one TE power generation module (model A; TEP1-1264-3.4) respectively.

1. INTRODUCTION

Energy plays an important role in world today. Power generation from the fossil fuel causes the emission of CO₂ and other harmful trace gases resulting the climate change i.e. global warming. The utilization of solar energy in Thailand is now being promoted as it is abundant and environmental-friendly. Nowadays, the heating and cooling processes for improving the human thermal comfort require enormous amount of energy for driving the heater and air conditioner. The CFCs releasing from vapor compression refrigeration is now being concern and taken into account in the use of vapor compression. Apart from the conventional refrigeration, thermoelectric (TE) cooling system is being interested as one of the alternative technologies that would help to reduce the rate of CFCs refrigerants emission to the atmosphere, as this do not employ working fluids that are harmful to the environment. Since the TE heat pump phenomenon has been discovered by Peltier in 1834 [1-2]. The development of TE is in progress either in the point of view of TE materials or TE applications by using TE module. TE module is composed of a number of TE elements, connected electrically in series and thermally in parallel, integrated two ceramic plates, which from the cold and the hot surfaces of the module. In 1909, Altenkirch presented a theory of TE power generation and TE refrigeration [3].

During the last two decades, the development of TE industry extremely increased. The cost of TE modules continually and substantially decrease. Consequently, TE is triple function for heating-cooling-power generate systems are widely applied for many applications [4-6]. TE cooling/heating units are of small size, silent and without moving parts. Moreover, it is very simple to control the rate of cooling/heating by adjustment of the direct current [7-9]. Generally, the TE cooling/heating system consists of two major subsystems, namely, the electrical supply and the thermoelectric modules. In recent years it has been realized that in situations where the supply of heat is cheap or free, as in the case of waste heat, efficiency of the thermoelectric generation system is not an overriding consideration. The use of waste heat as an energy source particularly at temperatures below 140 °C substantially increases the commercial competitiveness of this method of generating electrical power [10]

This research is aimed to investigate the characteristic and performance of TE modules for power generation at the low temperature which is considered as the solar energy for power generate and production of domestic hot water by combining solar energy with preheat water from a thermoelectric power generation. The proposed concept is very suitable for hot countries such Thailand as we have abundant sun's ray.

2. DESCRIPTION OF SOLAR THERMOELECTRIC WATER HEATING SYSTEM

Fig 1 shown the schematic of solar thermoelectric water heating system (STE-WHS). STE-WHS is combines a solar thermal collector with thermoelectric modules. Thermoelectric power generation packet (TEPG) was composed of a transparent glass, absorber plate, heat exchanger and thermoelectric (TE) modules with the hot side attached directly to the copper plate acting as absorber heat from solar intensity, and heat exchanger directly attached to the cold side of modules as shown in Fig 2.

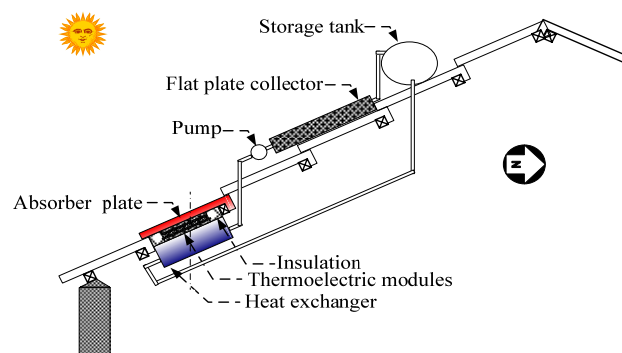


Fig. 1 Schematic of solar thermoelectric water heating system

TABLE 1 CHARACTERISTICS OF SOME COMMONLY AVAILABLE COMMERCIAL Bi_2Te_3 MODULE

Parameter	Cooling modules			Power modules	
	HT6-12-40	TEC1-12708	MT2-1,6-127	TEP1-1264-3.4	BT -18/4
Leg length x width (mm)	1.35x1.35	1.4x1.4	1.4x1.4	1.4x1.4	5.0 x 5.0
Leg height (mm)	1.6	1.2	1.5	1.2	6.0
Area of the thermoelement (mm^2)	1.82	1.96	1.96	1.96	25
Contact height (mm)	0.6	1.0	1.0	1.0	None
Insulator plate thickness (mm)	0.8	0.63	0.70	0.63	None
Module height (mm)	3.8	3.46	3.90	3.46	8.5
Area to length ratio	1.14	1.63	1.27	1.63	4.17
No. of couple (number)	127	127	127	127	83
Max. operating hot side temp.($^{\circ}\text{C}$)	160-170	160-170	140-150	225-250	270
Module cost (US\$)	22	8	8.5	65	150

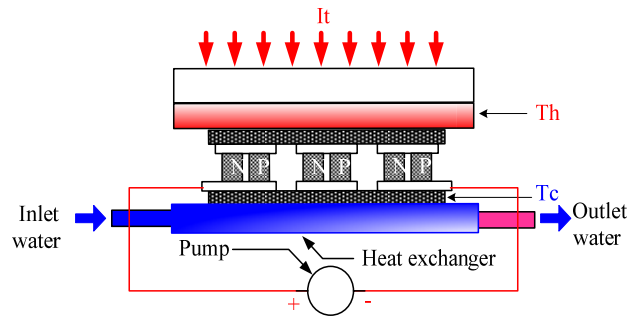


Fig. 2. Schematic of the thermoelectric power generator

3. PRELIMINARY THERMOELECTRIC MODULE SELECTION

Simulation results indicated that the maximum temperature of the hot side of TE modules (absorber) under Bangkok ambient conditions. It can be seen that this temperature never exceed 120 °C. Therefore, using the data given in table 1, thermoelectric module HT6-12-40, MT2-1,6-127, TEC1-12708, TEP1-1264-3.4 and BT -18/4.

Table 1 gives some characteristics of some commercially available thermoelectric modules. Fig. 2 It can be seen that the thermoelectric cooling module model HT6-12-40, TEC1-12708 and MT2-1,6-127 have to be considered as they are appropriate to operate at low temperature (below 160 °C). In this study, we select thermoelectric model TEC1-12708 and MT2-1,6-127 (thermoelectric cooling module) and TEP1-1264-3.4 (thermoelectric power module) for the experiment as it is cheaper.

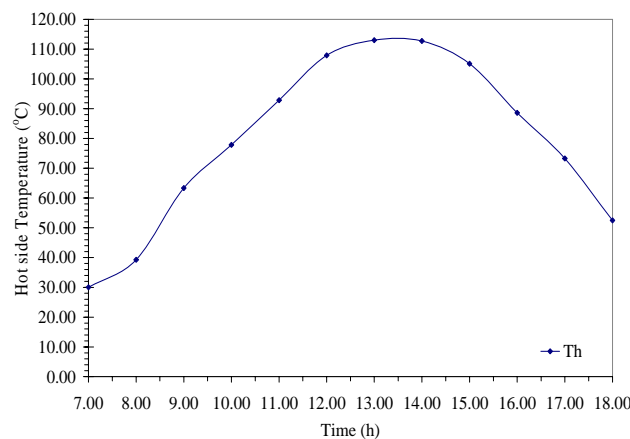


Fig. 3 Variations of maximum hot side temperature during ten years (1990-2000).

4. EXPERIMENTAL SET-UP AND METHODOLOGY

In the performance test of thermoelectric modules, we need to measure the power at steady state under various hot side temperature. Shown Fig. 3 is the experimental set-up for thermoelectric modules test. One thermoelectric power modules (model;A TEP1-1264-3.4) and two thermoelectric cooling module (model B;TEC1-12708, model C;MT2-1,6-127) were selected for test purposes.

The thermoelectric modules are clamped between cooling jacket and a heater block. The heater block is made from aluminum. The electric heater are inserted inside the block to provide an emulated heat source which is proportional to applied voltage. The heating jacket is a plate-type heat exchanger with coolant (water) flowing through the interior channels for controlling the cold end temperature of thermoelectric module. The coolant is supplied from a constant-temperature bath at a fixed temperature. Immersed in the bath are cooling coil that is operated by a small refrigerator. The temperature of coolant in bath is controlled by a PID controller to with (0.5oC uncertainly).

Investigations were done by varying the temperature of the hot side of TE modules and to control the temperature of the cold side. Simulated by using a heater, between 40 to 150 oC. An experimental set-up was built to comparisons the power generation and the effect of load resistance (0 to 8 Ohm) between TE cooling and power modules (see Fig. 4).

The instrumentation in the test setup included sensors for temperature, voltage and current output. The distribution of the temperature sensors is shown in Fig.5. All the temperatures are measured by T-type thermocouples and recorded by data logger Hioki 8422. The voltages and currents erected from thermoelectric module are measured by Hioki 3801. Each test run will take about 1 min to reach a steady state.

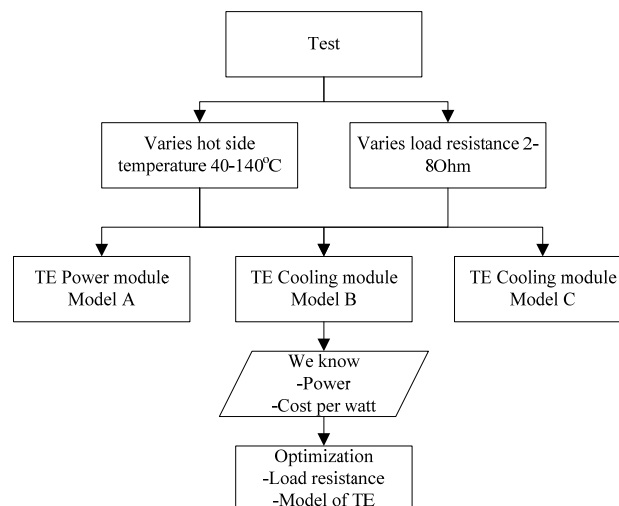


Fig. 4 Diagram of the design concept

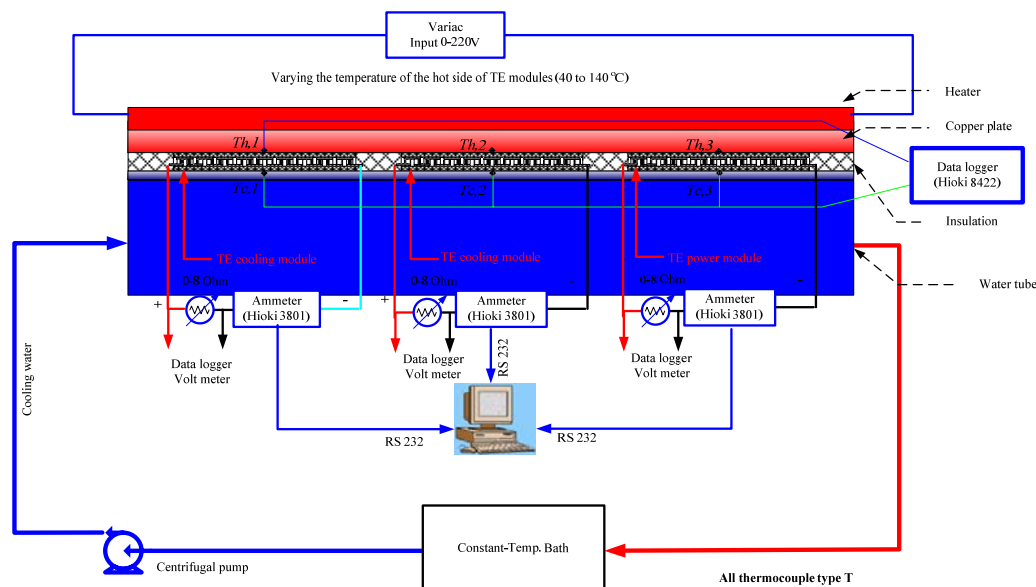


Fig. 5 Diagram of the experimental set-up and the lab-scale testing facilities.

This section data was recorded every 1 minute's interval, to measure the surface temperature of the hot and the cold sides of thermoelectric module assembly at 6 points (see Fig. 6).

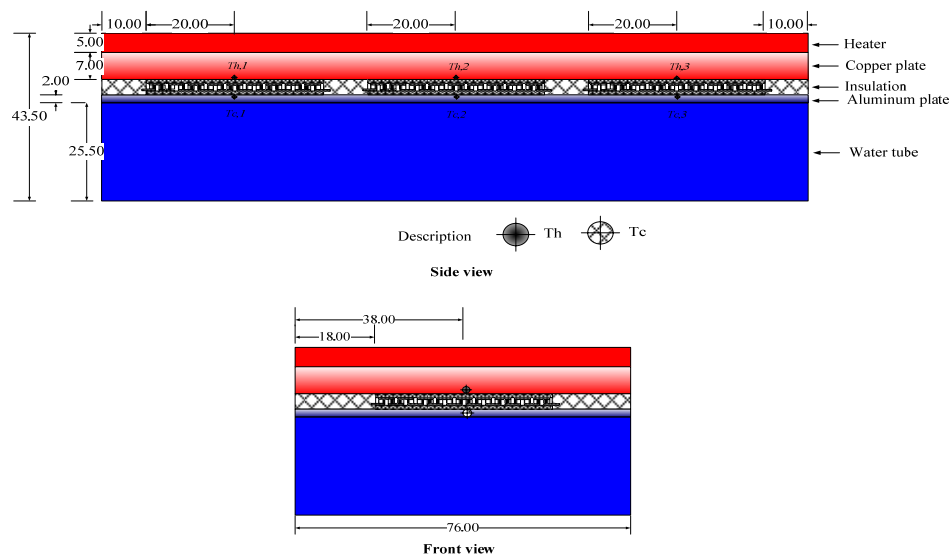


Fig. 6 Locations of the thermocouples fixed at the hot and cold sides.

5. EXPERIMENTAL RESULTS AND DISCUSSION

The hot and cold side temperature control

Fig. 7 shown variations to the temperature of the hot and the cold sides of thermoelectric module. It can be seen that the hot side temperature is varying between 40 to 140 °C. There is a limitation of the maximum operating hot side temperature of the thermoelectric cooling module of about 160 °C and to the cold side temperature of between 32-35°C.

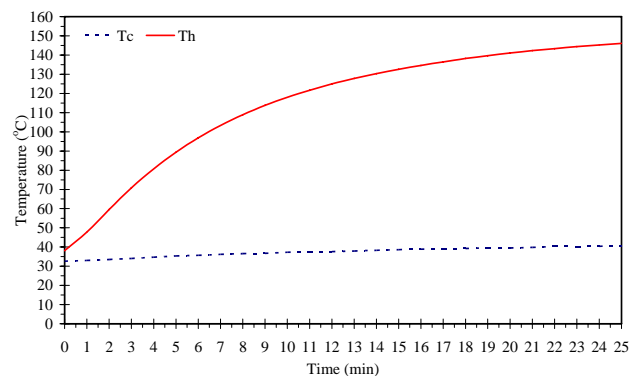


Fig. 7 Variations the temperature of the hot and the cold sides of thermoelectric module

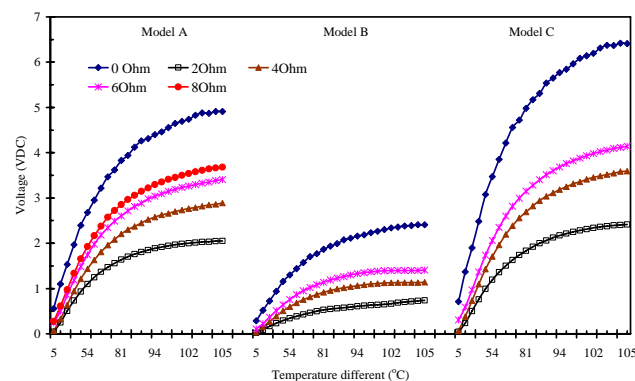


Fig. 8 Comparisons voltage output between thermoelectric power and cooling module

The effect of load resistance on power generation

Fig. 8 shows comparisons of voltage output between the thermoelectric power (model A) and cooling modules (model B and C). It can be seen that the trend line of the voltage output of thermoelectric cooling is similar to that of the thermoelectric power module. It can be seen that the open circuit thermoelectric power module can generate a voltage of about 5 VDC, while cooling module model C can generate a voltage of about 6.5 VDC. In this section we analyze the effect of load resistance on the output power of the thermoelectric cooling and power module. Fig. 9 illustrates the evolution of the power output versus the temperature difference between the hot and cold side temperature of the thermoelectric module, for load resistances (0 - 8 Ohm). The thermoelectric power module could generate a power output of about 2 W per module higher than the thermoelectric cooling module. When the load resistance increases the thermoelectric power module power output decreases

Electric cost per watt

Fig. 9 shows comparison of the electrical cost per module between thermoelectric cooling and power modules. The thermoelectric power module can generate higher power outputs than the thermoelectric cooling module. The output power produced by each module in the thermoelectric module is shown in Fig. 10. It was found that the thermoelectric power module produced more electrical power than the thermoelectric cooling module at all loads. However, the price of thermoelectric power module is five times greater than the thermoelectric cooling module. Therefore, the thermoelectric cooling module is an interesting and new alternative for application of power generation by solar energy, especially in the low heat region. This new roof-integrated solar thermoelectric generation system for cooling load reduction is highly efficient in the preliminary study. Therefore, for the prototype of this novel system, we selected thermoelectric model C for the experimental model as it is cheaper.

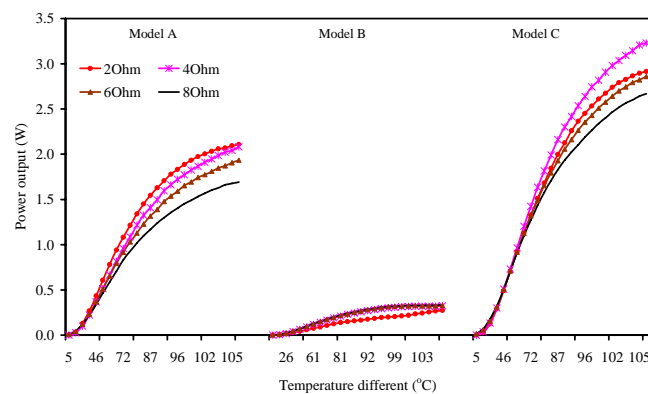


Fig. 9 Comparisons of power output between thermoelectric power and cooling module

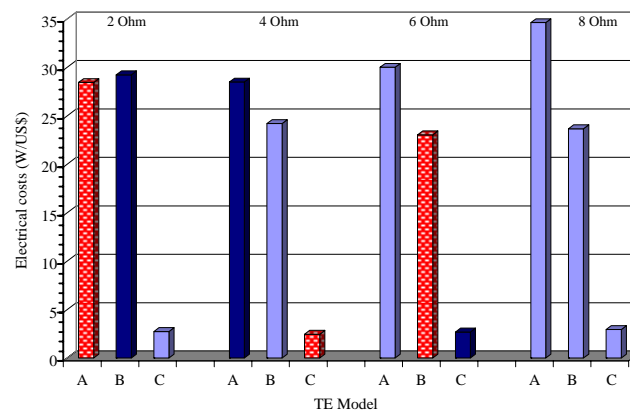


Fig. 10 Comparisons the electrical costs between thermoelectric power and cooling module (at temperature different 105°C)

The temperature of water preheat

Fig. 11 shows the temperature of outlet temperature of heat exchanger. It was found that heat release of the cold side of TE is can heat up water from 30 °C to 40 °C within 25 minute under water flow rate 20 l/min. It can increasing temperature of water outlet by decreased water flow rate. However, water flow rate decreases limiting, therefore, the performance of TE power generation.

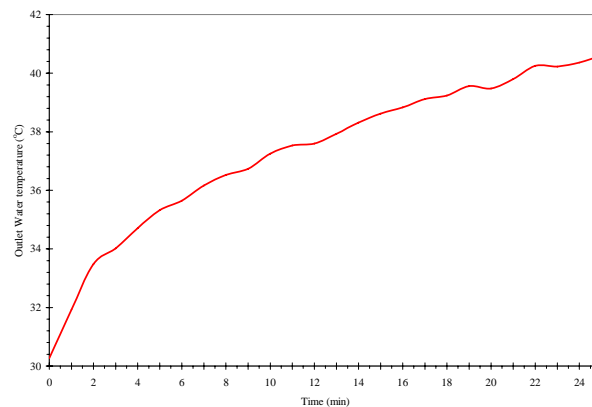


Fig. 11 Outlet water temperature from heat exchanger at the cold side TE (flow rate 20 l/min)

6. CONCLUSION

A lab-scale solar thermoelectric water heating system was built and tested. Under the test design for Thailand conditions used here, test results show that the suitable TE cooling model C to applied for preheat water. Furthermore, it was found that the efficiency of TE cooling modules was nearly closed to the TE power generation modules. However, the prices of TE power generation modules are higher than the TE cooling modules about 7 times. Therefore, the TE cooling modules is an interesting and is the new alternative for application of power generation by solar energy especially at low temperature. As this new solar water heating satisfactorily performs high efficiency under the preliminary study, therefore, the performance of the prototype of this novel system should be investigated for further study.

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