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Solar Water Condensation Using Thermoelectric Coolers

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Abstract: Water resources for irrigation can be difficult to obtain specially in the arid regions. However, for high humidity areas such as places close to the sea, water can be condensed from the air. In this paper we build water condensation system based on thermoelectric cooler. The system consists of cooling elements, heat exchange unit and air circulation unit. A solar cell panel unit with a relevant high current output drives the cooling elements though a controlling circuit.

Key words: Water condensation • Irrigation • Solar cells • Thermoelectric

INTRODUCTION

A relatively new method to cool warm air and condensate its contents of moisture is to use thermoelectric (TE) devices when two dissimilar materials form a junction. If a voltage is applied, heat will flow from one end of the junction to the other, resulting in one side becoming colder and the other side warmer, as shown in Fig. 1, what is called Peltier effect and electron hole theory [1]. Peltier coolers consist of a Peltier element and a powerful heatsink/fan combination to cool the thermoelectric cooler. Peltier elements come in various forms and shapes. Typically, they consist of a larger amount (e.g. 127) of thermocouples arranged in rectangular form and packaged between two thin ceramic plates.

Thermoelectric coolers are heat pumps solid state devices without moving parts, fluids or gasses. The basic laws of thermodynamics apply to these devices just as they do to conventional heat pumps, absorption refrigerators and other devices involving the transfer of heat energy. An analogy often used to help comprehend a TE cooling (TEC) system is that of a standard thermocouple used to measure temperature. TEC couples are made from two elements of semiconductor, primarily Bismuth Telluride, heavily doped to create either an excess (n-type) or deficiency (p-type) of electrons. Heat absorbed at the cold junction is pumped to the hot junction at a rate proportional to current passing through the circuit and the number of couples.

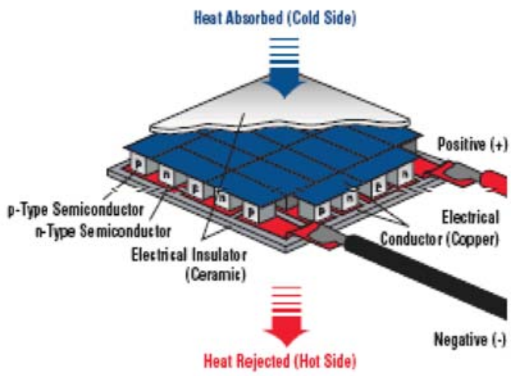

Fig. 1: Overview of the thermoelectric cooler

A conventional cooling system contains three fundamental parts-the evaporator, compressor and condenser. A TE has analogous parts. At the cold junction, energy (heat) is absorbed by electrons as they pass from a low energy level in the p-type semiconductor element, to a higher energy level in the n-type semiconductor element. The power supply provides the energy to move the electrons through the system. At the hot junction, energy is expelled to a heat sink as electrons move from a high energy level element (n-type) to a lower energy level element (p-type).

Parameters Required for Device Selection: In practical use, couples are combined in a module where they are connected electrically in series and thermally in parallel. Modules are available in a great variety of sizes, shapes,

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operating currents, operating voltages and ranges of heat pumping capacity. The present trend, however, is toward a larger number of couples operating at lower currents. Three specific system parameters must be determined before device selection can begin. These are:

- T_C Cold Surface Temperature
- T_H Hot Surface Temperature
- Q_C The amount of heat to be absorbed at the Cold Surface of the TE

Generally, if the object to be cooled is in direct intimate contact with the cold surface of the thermoelectric, the desired temperature of the object can be considered the temperature of the cold surface of the TE (T_C).

The hot surface temperature T_H is defined by two major parameters:

- The temperature of the ambient environment to which the heat is being rejected.
- The efficiency of the heat exchanger that is between the hot surface of the TE and ambient.

These two temperatures (T_C and T_H) and the difference between them (ΔT) are very important parameters and therefore must be accurately determined if the design is to operate as desired.

One additional criteria that is often used to pick the "best" module(s) is the product of the performance (COP) which is the heat absorbed at the cold junction, divided by the input power (Q_C / P). The maximum COP case has the advantages of minimum input power and therefore, minimum total heat to be rejected by the heat exchanger ($Q_H = Q_C + P$). It naturally follows that the major advantage of the minimum COP case is the lowest initial cost.

Single stage thermoelectric devices are capable of producing a "no load" temperature differential of approximately 67°C. Temperature differentials greater than this can be achieved by stacking one thermoelectric on top of another. This practice is often referred to as cascading. The design of a cascaded device is much more complex than that of a single stage device [2].

Another important two parameters for TE devices are the maximum allowed electrical current I_{max} through the device (exceeding the current will damage the TEC) and the geometry factor (G). The number of thermocouples and the geometry factor help to describe the size of the device; more thermocouples means more pathways to pump heat. One thing about G is that it is related to the density of thermocouples per square area and it is also related to the thickness of the TEC.

More widespread use of TE requires not only improving the intrinsic energy-conversion efficiency of the materials but also implementing recent advancements in system architecture [3]. Using nanotechnology, the researchers at BC and MIT produced a big increase in the thermoelectric efficiency of bismuth antimony telluride in bulk form [4]. Specifically, the team realized a 40 percent increase in the alloy's figure of merit. The achievement marks the first such gain in a half-century using the cost-effective material that functions at room temperatures and up to 250°C. The success using the relatively inexpensive and environmentally friendly alloy means the discovery can quickly be applied to a range of uses, leading to higher cooling and power generation efficiency.

Power supply and temperature controller are additional items that must be considered for a successful TE system. Regardless of method, the easiest device parameter to detect and measure is the temperature. Therefore, the cold junction is used as a basis of control. The controlled temperature is compared to some reference temperature, usually the ambient or opposite face of the TE. The various control circuits are numerous, complex and constantly being upgraded [5]. Suffice it to say that the degree of control and consequent cost, varies considerably with the application.

Solar-driven Thermoelectric Dehumidifiers: An additional key concern water scarcity is the water consumption during energy generation. Solar energy has the distinct advantage of low water consumption during its use-phase [6], making it ideal for installation in locations that have a highly variable or scarce freshwater supply. However, close attention was not paid to solar refrigeration until the energy crisis in 1970s [7, 8]. Research in a Peltier's cooling effect integrated with Photovoltaic (PV) also developed around that time [9], primarily for the cold chain project of the World Health Organization and the international Health Organizations specifically for rural areas [10, 11]. Solar cells were used to power small TE operated fridges [6]. Experimental investigation and relevant analysis on a solar cell driven, thermoelectric refrigerator has been conducted [12,13].

The main components of the solar PV/battery thermoelectric dehumidifying system are the PV cell (including the PV array, the storage battery and the controller), the thermoelectric refrigeration system and the cooled object (e.g., a cooling box). The PV array is installed outdoors and the storage battery stores the excess electricity produced during sunshine periods. This stored energy is used for running the system during the night. There are specially designed lead-acid batteries suitable for deep discharge cycles occurring in PV systems. The controller is an electronic device, which controls the system operation according to the state of charge of the battery. Its main duty is to protect the battery against excessive charging or discharging. For the solar-driven thermoelectric systems, the performance of whole system is the COP of the thermoelectric refrigeration system and the PV efficiency. [9] proposed an effective heat rejection method for the hot side of thermoelectric modules to enhance the performance of a laboratory thermoelectric refrigerator and its solar power supply.

Compared with thermoelectric refrigerators and solar-driven thermoelectric refrigerators, fewer thermoelectric air-conditionings and solar-driven thermoelectric dehumidifiers are reported. The service temperature is generally 15-20°C for an air-conditioner system and 2-6°C for the a dehumidifier so the cooling capacity required is higher than a refrigerator system and energy removed from the cooling side has a low potential to convert to a useful energy. The reported solar-driven thermoelectric dehumidifiers were all applied in the cases in which the cooling capacity required is low, or the expense is not the main consideration (such as military or aerospace applications).

System Assembly: The technique used in the assembly of a TE system is as important as the selection of the proper device. It is imperative to keep in mind the purpose of the assembly, namely to move heat. All of the mechanical interfaces between the objects to be cooled and ambient are also thermal interfaces.

Similarly all thermal interfaces tend to inhibit the flow of heat or add thermal resistance. Again, when considering assembly techniques every reasonable effort should be made to minimize thermal resistance. Mechanical tolerances for heat exchanger surfaces should not exceed 0.001 in/in with a maximum of 0.003" Total Indicated Reading. If it is necessary to use more than one module between common plates, then the height variation between modules should not exceed 0.001" (request tolerance lapped modules when ordering). Most TE assemblies utilize one or more "thermal grease" interfaces. The grease thickness should be held to 0.001 ± 0.0005". When these types of tolerances are to be held, a certain level of cleanliness must be maintained. Dirt, grit and grime should be minimized; this is very important when "grease" joints are utilized due to their affinity for these types of contaminants.

RESULTS AND DISCUSSIONS

The solar cell unit used in this system has a 12 V rating output voltage with the maximum output power of 120 W, which is able to supply enough power for three 40 W Pelrier coolers connected in parallel. Each Peltier cooler has a dimension of 4x4x0.8 cm, maximum current of 3.6 A and the maximum temperature difference ΔT of 87°C. The heat sink for each Peltier element is made of aluminum alloy and has a dimension of 15x15 cm making the total heat exchange area to be 45x15 cm on each side of the Peltier elements. The air is pumped into the system using a 6000rpm, 15x15cm, 12 V fan that capable producing airflow of 500 cfm. The moisture air is pumped first into the hot side of the Peltier element to increase the air temperature and in the same time to cool the hot side of the element. The capacity of air to hold water-vapour varies according to the temperature of the air. The warmer the air, the more water-vapour it can hold. As the air cools down, its capacity to hold water will decrease. The air is then pushed to the cold side to condense the water moisture, as shown in Fig. 2. The condensed water falls into a reservoir to be used for irrigation.

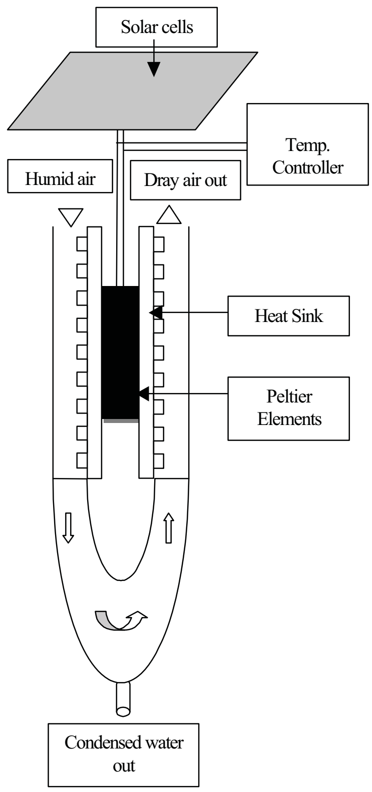

Fig. 2: Block diagram of the built water condensation system

Fig. 3: A picture of the built water condensation system

When testing an assembly of this type it is important to monitor temperature and relative humidity. Measuring the temperature and the humidity of the cooling inlet and outlet air as well as flow rates is necessary. Therefore, a closed loop control unit was built using PIC16f872 microcontroller to control the system keeping the temperature of the circulating air below the water freezing point. A picture of the built system is shown in Figure 3.

Applying this system in a high humidity region such as Yanbu produced almost 1 Litre of condensed water per hour during the day light, which is a promising result for a more sophisticated system that encounter higher power solar cells and facility to store the excessive energy during the day light to be used at night, which we are currently working on.

CONCLUSIONS

A solar water condensation system is built using a TE cooler, solar panels, heat exchange unit and an electronic control unit. The system is self powered and can be used in isolated and desert areas to condensate water from the surrounding humid air. Applying the system in high humidity see area produced 1L of water per hour which can be used mainly for irrigation.

The economical advantage of this kind of system is still obscure due to the relatively high installation cost. This system would be a long-term cost saving system since the energy source is free and the solar sub-system generally requires little maintenance. The development and production of such equipment is a future business possibility.

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