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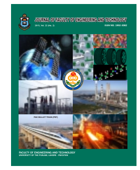

EFFECT OF HEAT SINK CONFIGURATION ON THE COP OF THERMOELECTRIC VACCINE REFRIGERATOR

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Abstract

Polio vaccines are significantly sensitive to temperature and environment. During polio vaccination campaigns in far off villages of Pakistan, it is one of the biggest challenges to store and transport the vaccine without affecting its quality. Various refrigeration techniques are used to keep the vaccine below ambient temperature. The energy consumption of conventional refrigeration systems is too high and the refrigerants having CFCs are hazardous to environment, contributing to global warming by depleting ozone layer. These are also slightly difficult to be developed into a lightweight and portable solar devices used outside. Solar Powered Thermoelectric Refrigerator (SPTR) is a distinct type of refrigeration system which runs on solar energy rather than that of conventional source of electrical energy, based upon the peltier effect to create hot and cold sides. The current research work was carried out at the Mechanical Engineering Department, U.E.T. Lahore (KSK Campus). The experimental results indicated the unit is capable to maintain a temperature of 6 ^{0}C at an ambient temperature below that of 50 ^{0}C. The maximum coefficient of performance was recorded as 0.78. Special configuration of heat sink was used to get maximum heat dissipation with minimum cost. An optimal value of solar irradiance let the cooling rate and coefficient of performance to attain maximum value. The designed SPTR would be of a great potential for cold storage in the areas where electricity supply is absent. It has the advantages of being small, lightweight, low running cost, noiseless, portable, reliable, and also low initial cost in mass production.

Key Words: Thermoelectric Cooler; Peltier Effect; Polio Vaccine Cooler; Solar Refrigerator

1. INTRODUCTION

Most of the world's energy consumption and electricity generation is principally dependent on fossil fuels and is being used extensively due to continuous increase in the world's population and development [1]. In the recent times, the increased worldwide demand of refrigeration directed to produce more and more electricity using conventional energy resources. The use of these conventional resources is the one of the major factors for production of carbon dioxide and subsequently the global warming [2]. The process of refrigeration is commonly used for the cooling of polio vaccine during transportation and storage.

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1. INTRODUCTION

Most of the world's energy consumption and electricity generation is principally dependent on fossil fuels and is being used extensively due to continuous increase in But this facility cannot be enjoyed while door to door visits in remote areas having no access to grid electricity. Hence, to use solar energy for efficient refrigeration process in outdoor activities is a thought of one of the best practices to discourse this issue [3--5]. A distinct type of refrigeration system is a solar powered thermoelectric refrigerator which employs solar energy as a substitute of traditional electrical energy to supply power to a thermoelectric module which can be used for the cooling of portable refrigerator. Thermoelectric refrigeration system (TER), which has the benefits of being light, noiseless, reliable, and low cost in mass production, uses electrons rather than the refrigerants as a heat carrier and is feasible to be used with solar cells [6]. The performance investigation of the system under sunshine in the present climate of the country is the main heart of this experimental work.

The current progress in thermoelectrics has led to substantial reductions in fabrication costs of peltier modules and heat exchangers along with the enhancements in module performance. Now it is probable to develop an economically feasible TER which has better performance and inherent benefits of being ecologically-friendly, silent operation, high reliability than conventional systems, and the ability to function in any orientation [7]. TER uses Peltier Module which is a semiconductor based electrical component and serves as a heat pump. When a low voltage direct current is applied across Peltier Module, heat moves from one side of the module to the other side and hence one side become cool while other become hot. On the cold end of semi-conductor material, heat absorbed by the electron movement, moves through the material, and is expelled at the hot side [8-9].

TER system has the advantages of being low weight, solid state construction, provide precise temperature control, vibration free operation, CFCs free, and can perform in any physical orientation. However the COP of TER system is not as high as of conventional refrigeration systems but because of its advantages, it is being used today for vaccine storage and other industrial applications. The objective of present research is to design and fabricate a portable thermoelectric refrigerator directly powered by solar energy as well as using a backup battery bank and to analyze the effect of heat sink configuration on the COP of the system under the same environmental and load conditions. The designed refrigerator is especially to facilitate the vaccination teams with its low weight, size, and advantage to operate on solar power to keep the vaccine at a temperature lower than that of ambient temperature i.e. 4 ^{0}C to 8 ^{0}C for the areas which do not have access to electricity but are suitable for solar energy extraction.

2. MATERIALS AND METHODS

2.1 Design of Thermoelectric Refrigerator (TER)

The basic components used in the design of TER are acrylic plastic body, insulation, inner box (cold sheet), thermoelectric module, heat sink, photovoltaic cells and a cooling fan [10-12]. Plastic is used for the body of refrigerator. Acrylic is chosen due to its properties of hard, clear, and durable for outdoor use. It is an excellent electrical insulator and is a safe medium for vaccine storage. It has a medium cost having thermal conductivity of 0.20 W/m ^{0}C [13]. Foamed polyurethane in form of thin layers is sandwiched between the plastic panels of acrylic to make a protective layer to keep the refrigerator insides at low temperature. This insulation is appropriate for small range of temperatures (-178 ^{0}C to 4 ^{0}C). It is of high cost having thermal conductivity of 0.03 W/m ^{0}C [14]. An insulation of thickness 50 mm was used in the refrigerator. For uniform cooling effect inside the refrigerator cabinet, aluminum has been used. Its density is too low, and is excellent conductor of heat and electricity. It is highly resistant to corrosion and has a thermal conductivity of 205 W/m ^{0}C. The specifications of the thermoelectric module, aluminum based sun flower heat sink (SFHS) and rectangular heat sink (RHS) and heat sink fan are listed in Tables 1, 2, and 3 respectively. Since the refrigerator is to be designed for the local climate region of Lahore-Pakistan, to meet the maximum cooling requirements, its input parameters are selected according to the peak load conditions of the region.

Table 1: Characteristic and Specifications of Thermoelectric Module [15-17]

S/N	Specifications	Value
1	Model Number of Thermoelectric Cooler	TEC1-12706
2	Seebeck Coefficient of Thermoelectric Cooler (α)	0.04224 (V/ºC)
3	Electrical Resistance of Thermoelectric Cooler ®	2.90 (Ω)
4	Thermal Conductivity of Thermoelectric Cooler ($\kappa_{t)}$	0.495 (W/mºC)
5	Sealant used in Sealing of Thermoelectric Cooler	Epoxy
6	Maximum voltage of Thermoelectric Module	15.40 Volts
7	Maximum Current of Thermoelectric Module	6.50 Amperes

Table 2: Characteristics Sunflower and Rectangular Aluminum Heat Sink [18-20]

S/N	Specifications	SFHS	RHS	Unit
1	Width of heat sink base	105.0	100	mm
2	Thickness of heat sink base	4.0	5	mm
3	Heat Sink Fin Length	70.0	110	mm
4	Heat Sink Fin Thickness	1.0	2	mm
5	Heat Sink Fin Height	26.0	26	mm
6	Area of Heat Sink Base	11025.0	11000	mm^2
7	Number of fins of Heat Sink	32.0 (96 splitted)	18	-----
8	Thermal Resistance of Heat Sink	0.0160	0.0148	˚C/W
9	Thermal Conductivity of Heat Sink	205.0	205	W/m˚C

Table 4: Cooling Fan Specifications [21]

Manufacturer	Delta Electronics
Model	FFB 0612 MARRIAGE
Dimensions	60mm x 60mm x 38mm
Connector	3 Wire without plug
Speed	8000 RPM
Air flow	1.42 m^3/min
Noise	54.5 dBA

Table 4: Characteristic and Specification of Desired Thermoelectric Cooler

Item	Symbol	Value	Unit
Total amount heat (cooling load)to be impelled	$\dot{Q}c$	37.455	Watts
Minimum heat load temperature	T_R	3.0	^{0}C
Maximum ambient temperature	T_a	40.0	^{0}C
TEC hot side temperature	T_h	50.0	^{0}C
TEC cold side temperature	Tc	0.0	^{0}C
Temperature gradient of hot and cold sides	∇T	50.0	^{0}C
TEC maximum temperature gradient for Module	DTmax	68.0	^{0}C
Number of stages necessary for DTmax	Single stage TEC	1.0	--

The average maximum ambient temperature (Ta) for Lahore was taken as 40^{0}C, while the minimum temperature of water (Tw) to be set inside the refrigerator cabinet was 5 ^{0}C .The safe range of temperature provided in literature for polio vaccine is -2 ^{0}C to 15 ^{0}C; hence the selected minimum temperature is just close to this range. To make the refrigerator portable, small and light weight the cabinet volume has been chosen as 7.5 liters. The maximum cooling load of the TER is found to be 37.455 Watts [22]. The characteristics of desired Thermoelectric Cooler (TEC) are shown in Table 4.

2.2 Selection of Energy Source

The solution to unravel the fear of fossil fuel reduction and global warming is definitely in the use of renewable resources, especially solar energy for country like Pakistan. Thermoelectric Refrigeration system powered by renewable energy using photovoltaic (PV) cells has been used in the present research work because it directly gives electricity through solar energy. Hence two solar panel of 75 Watt each is selected for designed thermoelectric refrigerator. The key specifications of Thermoelectric Module (TEM), cooling fan and solar panel are enlisted in Table 5. A 20% factor of safety is added to overcome the power fluctuations due to variations in solar intensity. The total power consumption of the refrigeration system is rounded up to 125 watts.

Table 5: Thermoelectric Module and Cooling Fan Specifications

Item	Value	Units
Maximum voltage of TE Module	15.4	Volts

Maximum current of TE Module	6.5	Ampere
Maximum Power of TE Module	100.1	Watts
Power consumed by fan	4	Watts
Total Power consumed by system	104	Watts
By adding 20% Factor of safety	124.8	Watts
Maximum power of PV panel	75.0	Watts
Maximum rated power of PV panel	63.3	Watts
Maximum voltage of PV panel	17.2	Volts
Maximum current of PV panel	4.36	Amperes
Open circuit voltage of PV Panel	21.6	Volts
Short circuit current of PV panel	4.7	Amperes

2.3 Climate Conditions of the Site

The weather data for the site Mechanical Engineering Department, University of Engineering & Technology Lahore (KSK Campus) was collected. Altitude of Lahore is about 214 meter from sea level and latitude and longitude angles are 31.54˚N and 74.34˚N respectively. Weather conditions of Lahore are hot and humid. In the month of June summer season is at its peak and the rise in temperature is about 40˚C. The temperature range of Lahore during the summer season is about 40 ^{0}C to 46 ^{0}C. The typical temperature of Lahore falls below 5 ^{0}C in the month of January and the temperature range is about 5˚C to 8˚C.

3. EXPERIMENTAL SETUP AND PROCEDURE

3.1 Experimental Setup

The experimental work to check the performance of TER is carried out in the Refrigeration & Air Conditioning Laboratory of the Mechanical Engineering Department U.E.T. Lahore KSK Campus. The experimental setup includes solar panel, 12 volt battery, charge controller, as shown in Figure 1.

3.2 Experimental Procedure

The components of the experimental setup solar panel, charge controller, battery and TER were connected with each for experiment as shown in Figure 1. First a single 12 volt battery was used to operate TER and the values of temperatures were taken at different points. The module hot side temperature and cold side temperature were found by using temperature sensors and water temperature was found by using infrared temperature gun. Then the solar panel is directly connected with TER. Again the values taken for module cold side, hot side temperatures and water temperature. A volume of 7.5 liter water was placed inside the refrigerator and system was closed for about nine hour. The TER test unit used in experimentation has maximum cooling capacity of 63 watt.

Figure 1: Experimental setup of designed system

4. EXPERIMENTAL RESULT AND DISCUSSION

4.1 Experimental Strategy

First weather data was collected for the site under consideration as shown in Figure 1. The experimental work was carried out in four different phases.

Phase 1 [P1]: Performance analysis of thermoelectric refrigerator directly coupled with 12 volt battery using sunflower heat sink.

Phase 2 [P2]: Performance analysis of thermoelectric refrigerator directly coupled with photovoltaic cells using sunflower heat sink.

Phase 3 [P3]: Performance analysis of thermoelectric refrigerator directly coupled with 12 volt battery using rectangular heat sink.

Phase 4 [P4]: Performance analysis of thermoelectric refrigerator directly coupled with photovoltaic cell using rectangular heat sink.

4.2 Variation of Current and Voltage with Solar Irradiance

Two photovoltaic panels were attached in parallel to get maximum current and experimental results were found from refrigerator unit. Figure 2 shows the solar insolation rate, current and voltage variations for Phase 1, 2, 3 and 4 respectively. Figure 2 shows that in case of battery based thermoelectric refrigerator (P1&P3) there is continuous decrease in input current and voltage to the system from 8:00AM to 5:00PM from 11.68V, 2.75A to 11.0V, 2.22A. This decrease is due to discharging of battery during operational hour as there was no charging mechanism for battery. The battery voltage dropped to 11V from 11.68V after a continuous operation of nine hours. The battery was fully charged by solar panel and then it was connected with TER without using solar panels. A fully charged battery is approximated to show a maximum short circuit voltage of 13.50V while a fully discharged battery shows a minimum short circuit voltage of 10.50V. Solar insulation rate is greatly dependent upon the intensity of solar radiations. The solar insulation rate increases from early morning to its maximum value of 890 W/m^2 when sun is exactly at the middle of the sky and then it again decreases until the sunset. Solar insulation rate has its maximum value at 12:00 noon. With the change in solar insolation there is a change in the output voltage and current from the photovoltaic cells. As the output voltage from solar cells depends upon the solar insolation rate so the output voltage increase as solar insolation increase and decreases as the solar insolation decreases.

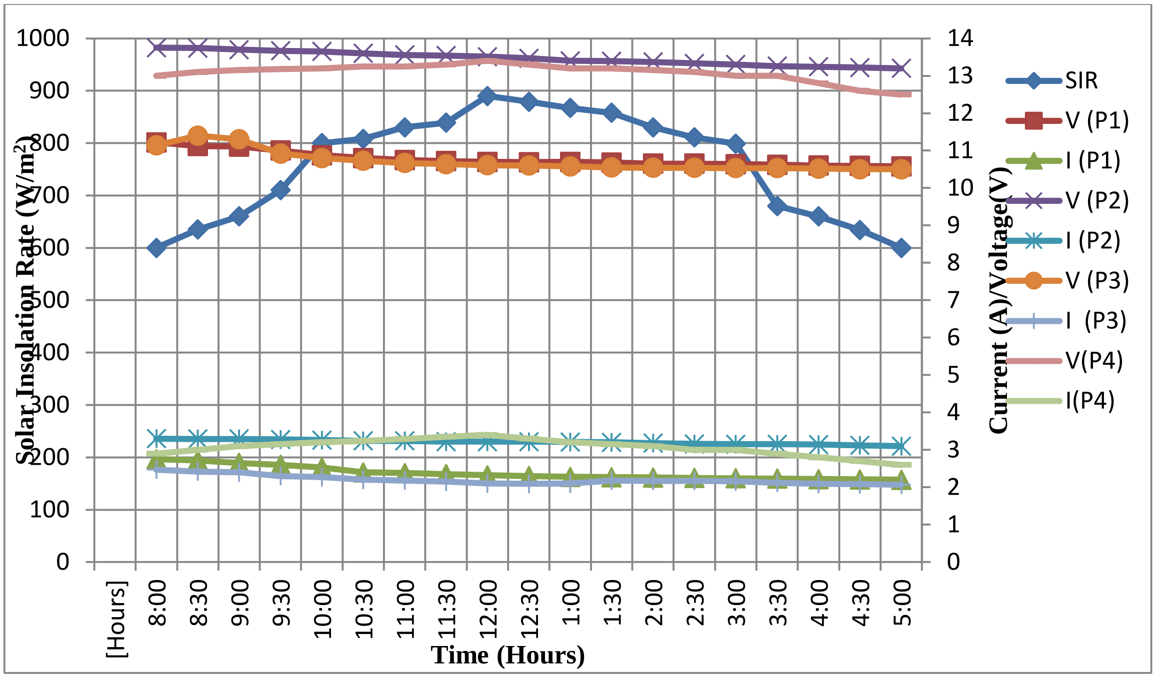

Figure 2: Variation of Solar insolation rate, voltage and current (P1, P2, P3 & P4)

The designed maximum power consumption of directly coupled with photovoltaic cell thermoelectric refrigerator is 45.37 watts as shown in Figure 2 (P2 & P4). The output voltage from photovoltaic cells attached in parallel is remained above 13 volts and current is above 3 ampere. The difference in the input power is due to different solar insolation rate because power is depending upon the voltage and current, which depend upon the solar insolation rate. As the solar insolation rate increases the current and voltage increases which increases the power input. The solar panels are attached in parallel to get more current and same voltage.

4.3 Variation of Module, Heat Sink, Ambient and Water Temperature

The change in temperature of hot side, cold side of thermoelectric module, the ambient temperature and temperature of stored water are shown in Figure 3 (P1 & P3) for battery based system. It was observed that cold side temperature was drop from 29 ^{0}C to 14 ^{0}C in case of sunflower heat sink and from 29 ^{0}C to 12.5 ^{0}C in case of rectangular heat sink. The temperature of water was drop from 29 ^{0}C to 20.4 ^{0}C and from 29 ^{0}C to 23.5 ^{0}C in case of sunflower heat sink and rectangular heat sink respectively. The cooling rate seems better in case of sunflower heat sink. Figure 3 shows the variations in temperatures for system directly coupled with solar panels (P2 & P4). It was observed that cold side temperature was drop to 29 ^{0}C to 10 ^{0}C in case of sunflower heat sink and from 30 ^{0}C to 10 ^{0}C in case of rectangular heat sink.

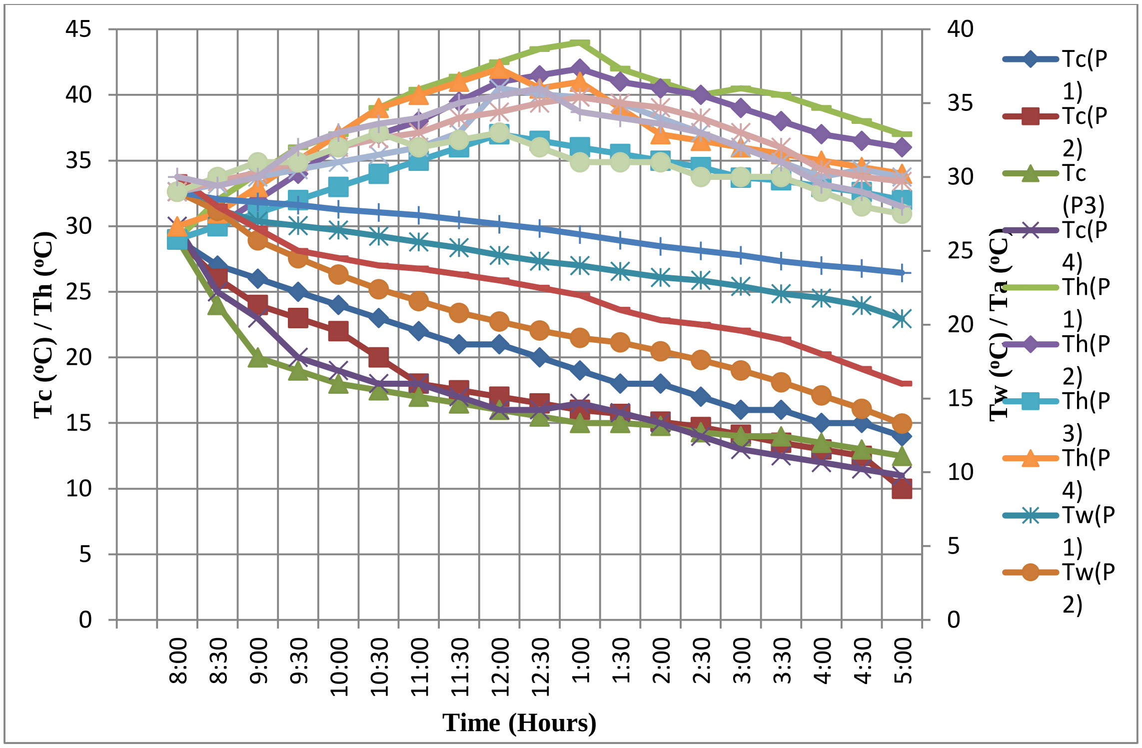

Figure 8: Variation of Module, Heat Sink, Ambient and Water Temperature with time (P1, P2, P3 & P4)

The temperature of water was drop from 29 ^{0}C to 13.3 ^{0}C and from 30 ^{0}C to 16 ^{0}C in case of sunflower heat sink and rectangular heat sink respectively. Hence the cooling rate seems better for sunflower heat sink in case of directly coupled thermoelectric refrigeration system. The temperature of hot side and cold side of module and surface temperature of heat sink depend upon the ambient temperature. When ambient temperature varies with respect to time, these parameters also vary. This is due to the reason that heat is rejected to atmosphere and with the change in ambient temperature heat rejection rate varies which result in change in temperatures. A lower ambient temperature means that very low temperature can be attained inside the refrigerator cabinet cabinet and hence a better refrigeration effect. This is also one of the drawbacks of TER that higher ambient temperature results in poor refrigeration effect.

4.4 Variation of Input Power, Cooling Rate and Coefficient of Performance

Figure 4 shows the variation of input power, cooling rate and COP of the system with respect to time for directly coupled TER with 12 volt battery (P1 & P3) using sunflower and rectangular heat sink configuration respectively. It shows that COP directly depends upon the input power of the system and cooling rate. The COP of the system varies with respect to change in input power and cooling load. For maximum cooling load and minimum input power COP has its maximum value. The maximum and minimum values of COP are recorded as 0.67 and 0.32 respectively. The maximum power was in the morning because the battery was fully charged. For battery based system the COP

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value is more in case of sunflower heat sink as compared to rectangular heat sink configuration.

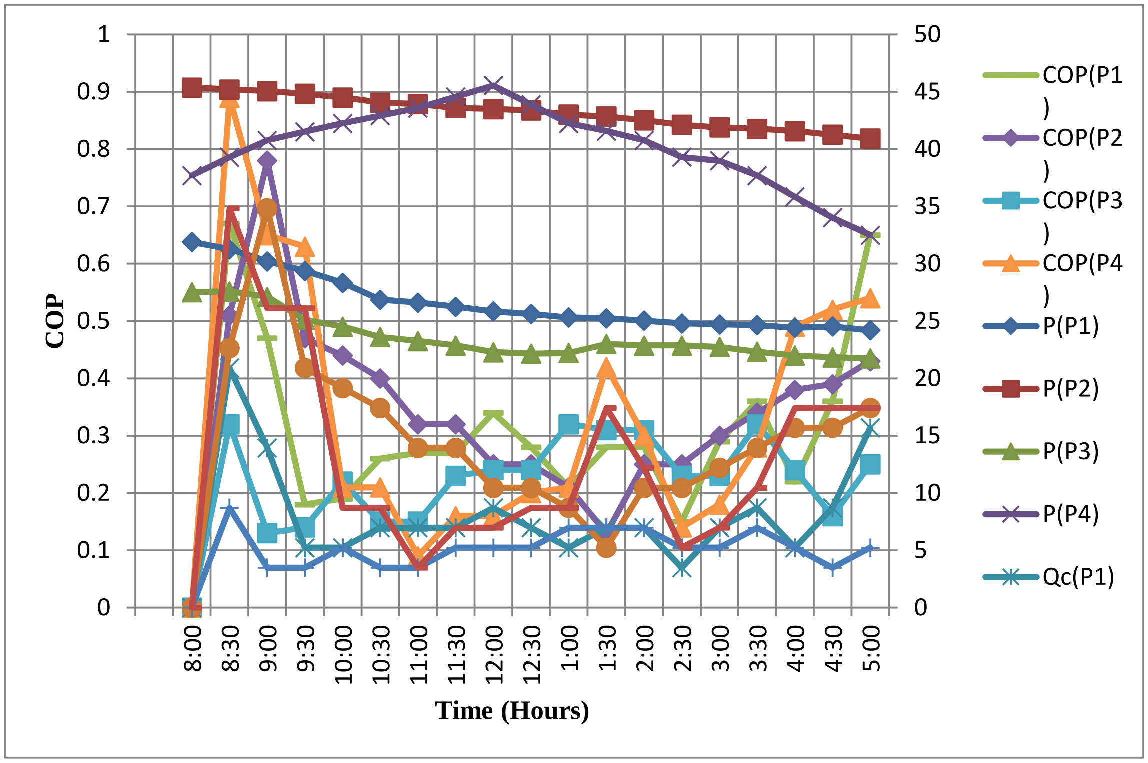

Figure 4: Variation of Cooling Rate, Input Power and COP of TER with Time (P1, P2, P3 & P4)

Figure 4 also shows the variation of input power, cooling rate and COP of the system with respect to time for directly coupled solar powered TER (P2 & P4) using sunflower and rectangular heat sink configuration respectively. The maximum and minimum value of COP is 0.78 and 0.65 respectively. Again the COP is more in case of sunflower heat sink as compared to rectangular heat sink configuration. From Figure 4 it is clear that in the morning the input power is low due to lower insolation rate but due to high indoor and outdoor temperature gradient the heat transfer rate is maximum which result in maximum cooling rate. Hence the COP of the system is maximum in the morning. But with the passage of time cooling rate decreases with the fall of temperature gradient and work input also decreases. But this decreased work input is still more than that of cooling rate compared to the morning. Hence COP of the system also decreased.

5. Conclusion

In the present research effect of heat sink configuration on the performance of thermoelectric refrigerator is presented. The Maximum COP has been recorded for both battery based system and solar based system in case of sunflower configuration heat sink i.e. 067 and 0.78 respectively. While the COP recorded in case of rectangular heat sink is found to be 0.32 and 0.65 for battery based system and solar powered system respectively. The designed thermoelectric refrigerator can be used commercially to keep Polio vaccine at a desired temperature and also for domestic purpose. The conclusions of the experimentation is that the TER operating on 12 volt battery with sunflower heat sink, has more value of COP than with simple rectangular heat sink of the same base area under the same environmental and load conditions. From the results it is also concluded that performance of thermoelectric refrigerator operated with photovoltaic cell depends upon the solar insolation rate. As solar panels are directly attached with the thermoelectric refrigerator so solar radiation is essential for continuous operation of TER. The one factor upon which the performance depends is temperature difference of two side of thermoelectric module (TEM). The relation between the electric current from solar panel and solar irradiance is linear. The ambient temperature has significant influence on the cooling capacity hot side temperature of TEM. The hot side temperature of TEM is approximately 10^0C higher than the ambient temperature. The temperature drop of wall of refrigerator cabinet and of water stored in it depends upon the heat absorbed by the thermoelectric module. The maximum cooling capacity of thermoelectric refrigerator is approximated to be 25-30 ^{0}C below that of ambient temperature. By comparison between the photovoltaic based TER and battery based TER it is analyzed in solar base system has more COP with maximum power fluctuations while the battery based system has less COP with very smooth operation.

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