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Numerical Energy Analysis of Solar Parabolic Dish Thermoelectric Generator

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***Abstract*—The Performance of a thermal system is generally analysed by carrying out energy analysis. In the present study the performance of thermoelectric generator (TEG) is studied numerically by set of equations at constant flow rate of heat transfer fluid by changing concentration ratio.Generally the performance of TEG fully depends upon temperature deference between hot side and cold side of the thermoelectric module. It is found that the energy efficiency and electrical power increases with increasing concentration ratio**

Keywords—parabolic dish; TEG; overall efficiciency; concentration ratio;

I. Introduction

Thermoelectric generators are generally operates from direct sunlight. They possess a great advantage of non-moving parts, long life. High reliability and zero fuel cost.Several theoretical and experimental studies are reported on the thermoelectric generator embedded in receiver of concentrating collector [1-3]. The overall efficiency of conversion of solar energy in TEG depends up on the values of parameters viz. DNI, concentration ratio, cold side temperature, wind velocity, ambient temperature, and optical efficiency of the PDC.Miao et al.[4] have discussed solar thermal simulation based on energy balance and heat transfer to predict the electrical conversion efficiency and solar thermal conversion efficiency for different values of parameters viz. DNI and concentration ratio.YonghuaCai et al.[5]have developed a general model for the electric power and energy efficiency of a solar thermoelectric generator. They considered the influences of the input energy, the thermal conductivity, the absorptivity and emissivity of the heat collector and the cooling water.In the present study, an analysis of energy efficiency is made for solar parabolic dish TEG and receiver plate for different concentration ratios at particular DNI.

Nomenclature

A_r	Receiver plate area (m2)
h_a	Heat transfer coefficient (W/m^2K)
I	Electric current (A)
N	Number of thermocouple
T_h	Temperature of hot side (K)
T_r	Temperature of receiver bottom side (K)
Greek letters	
α	Seebeck coefficient (W/K)
ε	Emissivity of surface
σ	Stefan-Boltzmann constant

II. Description of the System

Figure 1 and 2 show the schematic diagram of the proposed solar parabolic dish thermoelectric generator and exploded view of the entire system. The thermoelectric generator consists of four thermoelectric modules, which are connected in a series. The hot side and cold side of the modules were rigidly attached in between aluminium receiver plate and heat sink. The direct normal irradiation that comes from the Sun is concentrated by a parabolic concentrator that heats bottom surface of receiver plate. The other side of the TEG is cooled by passing water at constant temperature with certain mass flow rate,which acts as a heat sink. External load is connected to TEG and the power generated in the form of a direct current. The nodal temperatures (T_r, T_h,) are found by assuming ambient temperature and initial temperature of water at the inlet of heat sink by using MATLAB simulation. The assumed parameters as shown in Table 1 are used for the present analysis.

III. Thermodynamic Analysis

Amount of solar energy received by the parabolic dish concentrator is given by

$$Q_r = A_r C\ I_b \qquad (1)$$

where C is concentration ratio defined as the ratio of aperture area (A_c) to receiver area (A_r)

$$C = \frac{A_c}{A_r} \qquad (2)$$

The amount of solar energy absorbed by the receiver plate is expressed as

$$Q_S = A_r C \eta_o I_b \qquad (3)$$

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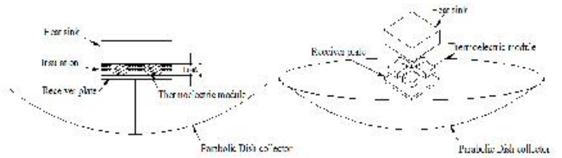

Fig. 1. Arrangement of solar parabolic dish thermoelectric generator.Fig. 2 Exploded view of TEG system.

The useful energy gained (Q_u) on the hot side of TEG is expressed mathematically

$$Q_u = Q_s - [h_w A_r (T_r - T_a) + \sigma \varepsilon A_r (T_r^4 - T_{sky}^4)] \qquad (4)$$

The instantaneous thermal efficiency of the parabolic dish collector is found from the expression

$$\eta_r = \frac{Q_u}{Q_s} \qquad (5)$$

The amount of heat removed from cold side (Q_c)and that supplied (Q_h) to hot side of the TEG are

$$Q_c = SIT_h + K_{teg}(T_h - T_c) + 0.5 I^2 R_i \qquad (6)$$

$$Q_h = SIT_c + K_{teg}(T_h - T_c) - 0.5 I^2 R_i \qquad (7)$$

where S is the Seebeck voltage given by$S=2\sim N$.

The efficiency of the TEG is written as ratio of energy output to energy input, mathematically,

$$\eta_{TEG} = \frac{P}{Q_h} \qquad (8)$$

The overall electrical efficiency ($\eta_{overall}$) of the solar parabolic dish thermoelectric generation system is expressed as

$$\eta_{overall} = \eta_o \eta_r \eta_{teg} \qquad (9)$$

IV. RESULTS AND DISCUSSIONS

The DNI is calculated by using standard equations.The thermal performance of solar dish TEG was studied theoretically for different concentration ratio at a constant flow rate of heat transfer fluid of water. The concentration ratio

values 20, 40, 60, 80 and 100 are taken for this study. Thermonamic Ltd., China make (Model No: TEP1-12656-0.6) was considered in this study. Eq. 1 to 9 were solved simultaneously to obtain common value of the receiver plate temperature for different concentration ratio by using MATLAB.

TABLE I.

PARAMETERS	VALUE
Area of the receiver plate (m^2)	0.1
Area of the heat sink (m^2)	0.04
Ambient temperature, (K)	302
DNI (W/m^2)	985.5
Wind velocity(m/s)	2.2
Optical efficiency of dish(4)	0.7
Number of thermocouple	127
Cold side temperature (K)	300

(4)

Fig. 3. shows the variation of receiver plate temperature with concentration ratio. It can be seen that hot side temperature increases with increasing concentration ratio. Since the hot side temperature increases, the temperature difference between hot side and cold side increases. This temperature difference is directly proportional to the voltage difference. The voltage increases with increasing concentration ratio.

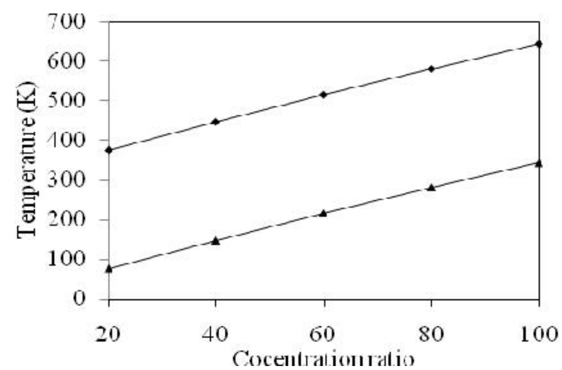

Fig. 3. Variation of receiver plate temperatureand temperature difference with concentration ratio

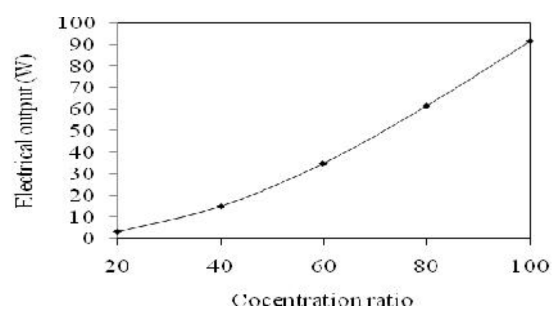

Fig. 4. Variation of electrical output with concentration ratio

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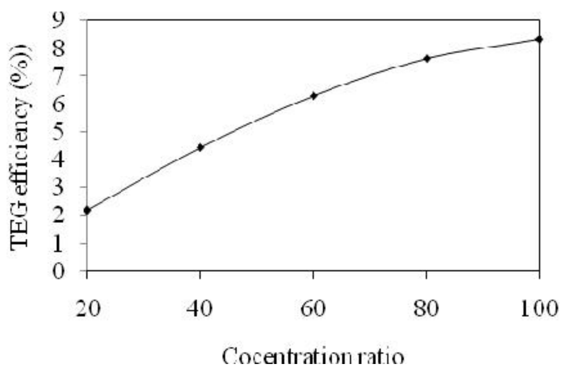

Fig. 5. Variation of TEG efficiency with concentration ratio

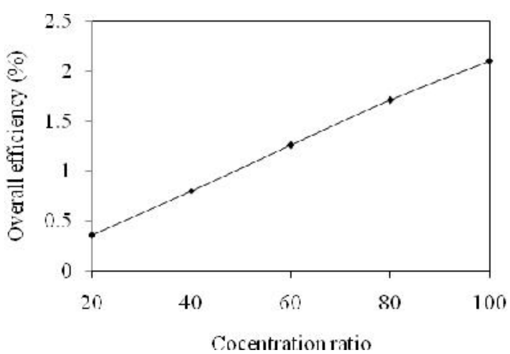

Fig.6.Variation of overall efficiency with concentration ratio

Fig. 4. shows the variation of output power with concentration ratio. It should be noted that electric output exponentially increases with increasing concentration ratio. The maximum output of 91.78 W was obtained at concentration ratio of 100.

Fig. 5. shows the variation of TEG efficiency with concentration ratio. The results show that the TEG efficiency increases significantly with increase in concentration ratio. It is noted that will no appreciable increase in the efficiency beyond concentration ratio of 100.

Fig. 6. shows the variation of overall efficiency with concentration ratio. It can be seen that overall efficiency increases with increasing concentration ratio. The overall efficiency of conversion of solar energy in TEG depends upon the efficiency of both the collector and generator efficiency.

V. CONCLUSIONS

Solar parabolic thermoelectric generator with four modules was studied numerically. Receiver plate temperature, amount of heat transferred through the surfaces, electrical performance and overall efficiency of the system were calculated by changing the concentration ratio at a constant flow rate. The entire analysis is carried out at a constant temperature of cooling water at a particular DNI of 985.5 W/m^2. At concentration ratio of 100 the overall efficiency of the system is found to be 2.1% while the efficiency of TEG is 8.3%

VI. REFERENCES

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