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Design and Development of Control System for Thermoelectric Generators

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ABSTRACT

Our current problems include rising power prices, environmental pollution, and global warming. Scientists are concentrating on enhancing energy-harvesting-based power generators to lessen their consequences. The see-beck effect has been used by thermoelectric generators (TEGs) to show that they can transform thermal energy directly into electrical energy. They function quietly because they lack mechanical parts and structures, are environmentally beneficial because they don't include chemical products, and can be made from a variety of substrates, including silicon and polymers, making them appropriate for integration into bulky and flexible systems. In this project, a control system for a thermoelectric generator will be designed and developed. The electricity generated by the TEG module will be connected to a booster (voltage) module that will provide stable voltage to charge the battery. To obtain 110/240 volts AC, which needs to be connected to the LOAD, the battery output is delivered into the DC to AC converter. A voltage sensor is attached to the DC to AC converter, a current sensor module is further connected to the battery, and the temperature and humidity sensors are connected to the entire circuit. To test the output power under various circumstances, such as series-parallel connections of thermoelectric generator modules with variable mechanical architectures and varying temperature differences between the hot and cold sides, laboratory studies have been carried out. Many thermal and geothermal sites with low-temperature resources, such as oil fields where fossil and geothermal energy are produced in tandem, can use this type of thermoelectric generator power system.

KEYWORDS:Thermoelectric effect, see beck effect, Pollution, Voltage, Electric power, Heat.

1. INTRODUCTION

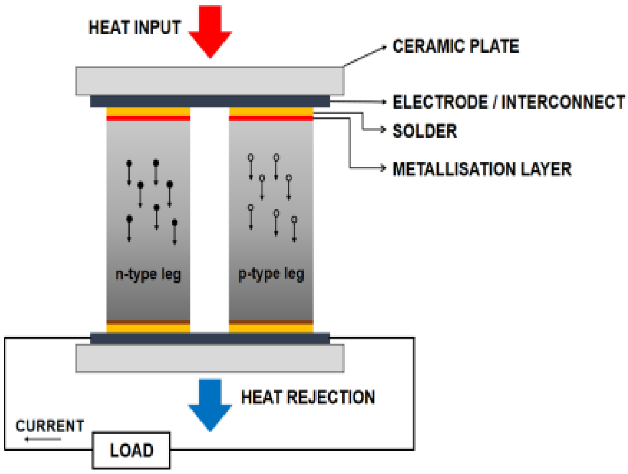
Energy-related issues including the oil crisis, climatic and environmental changes, and a significant rise in electrical power demand because of population explosion have all become more prevalent globally in recent decades. Nonrenewable energy sources are used not only to produce electric power but also for transportation, commercial uses, and other needs. As a result, these resources are depleting more quickly. [1-2] Careless use of these resources increases carbon emissions, which in turn increases greenhouse gas emissions and the effects of global warming. Most of the electrical energy is produced through the conversion of thermal energy, either through material combustion or isotope nuclear decay. As a result, it is not sustainable to rely solely on thermal energy sources. [2-3] A low-cost, clean energy source that produces no pollution must be used to meet the electricity demand. Renewable sourced energy is increasingly being used in place of non-renewable energy sources. Wind, solar, hydro, geothermal, and biomass are examples of renewable energy sources (also known as green or clean energy). [4-6]. Power can be produced either nearby the resource area or away from populous load centers, depending on the availability of resource 2. At the resource location, distribution generation enables the production of electric power from renewable sources. As a result, they improve power quality while lowering long-distance transmission losses. Today, effective waste management and electricity generation from biomass-based resources are given a lot of attention. [7-9] This dissertation examines efficient electric power generation from biomass waste using a hybrid thermoelectric generator for domestic use and industrial waste-heat recovery applications using biomass crops like non-edible, gasified, de-oiled Pongamia cake, with synthetic oil suspended with graphene nanoparticles as heat transfer fluid.

2. LITERATURE REVIEW

Electromotive force (EMF) is produced when two dissimilar metals are linked at two ends and subjected to different temperatures; this EMF drives an electric current in the circuit. This effect, sometimes known as the See beck effect, was discovered in 1821 by Thomas Johann See beck. It displays two distinct conductors, A and B, connected at both ends and supporting T1 and T2 (T1 > T2). A temperature difference (T=T2-T1) results in an EMF (Vs) that is proportionate to the T produced. [8-10] The See beck coefficient or thermopower is the name given to the proportionality constant (). Merkisz et al. and Ziolkowski, both from the same group, examined the AETEG conversion efficiency for gasoline and diesel engines. A 1200 cc gasoline engine and a 1300 cc diesel engine both had the AETEG fitted after the EATS. The tests were conducted on a dynamometer test bench that mimicked the circumstances of metropolitan traffic. For the gasoline and diesel engines, they were able to achieve maximum efficiencies of 1.3% and 0.29%, respectively [11–12] (Merkisz et al., 2016 Ziolkowski, 2017). Investigations on AETEG performance were also carried out under transient conditions, which were both approximated using an energy model and recreated in a test rig (Brito et al., 2016). (Massaguer et al., 2017, Fernandez-Yanez et al., 2018, Mohamed, 2019). To evaluate various vehicle performance parameters under diverse driving circumstances, there are some standard-specific driving cycles. [13-15] Different versions, such as the New European Driving Cycle (NEDC) and the Worldwide Harmonized Light Vehicles Test Procedures (WLTP), illustrate the changes in vehicle speed over time. Massager et al. tested the performance of AETEG using a 4-cylinder gasoline engine running under NEDC and found that thermal inertia caused the power output in the transient state to be lower than in the steady-state (Massaguer et al., 2017).

i) Thermoelectric device :

A TE device or module is made up of several uncouples connected in series, which act as the device's fundamental building blocks and display the uncoupling's schematic.



An uncoupled comprises of p- and n-type legs connected in series by metal interconnects or electrodes, with most of the legs being formed of degenerate semiconductors. In the n-type and p-type legs, respectively, the main charge carriers are electrons and holes. Most charge carriers in both legs are moved from one end to the other by the heat input, which results in a potential difference. Electric current flows through the circuit because of the movement of the charge carriers when an external load is applied. A T is maintained across the TE legs thanks to the heat input via one end and rejection at the other end, which also produces an EMF that drives current through an external load.

ii) Automotive Exhaust Thermoelectric Generator (AETG) :

Since internal combustion (IC) engines do not efficiently employ the energy produced by 20 fuel combustion, research on energy recovery from exhaust gases has increased over the past few decades. This image illustrates the usual thermal energy flow pattern in an IC engine. Only about 25% of the energy from gasoline combustion is thought to be utilized for driving a car and powering additional accessories (Stabler, 2002). The remaining 70% is lost via exhaust gases and as heat to the coolant. If the 40% of thermal energy that escapes through the exhaust gases is partially recovered, it will increase fuel efficiency and lower greenhouse gas emissions from the vehicle.

- It shouldn't increase parasitic losses to the engine's functioning or put too much back pressure on the exhaust system. The pressure decrease should ideally be between a few tens and hundreds of millibars.
- At the location where the AETEG is installed, the materials used in the TE modules should perform at their highest level of efficiency in the exhaust temperature range. To avoid damage from temperature overshooting, the exhaust temperature must also be controlled appropriately utilizing exhaust bypass systems.
- The TE resources and modules ought to be economical and environmentally responsible.
- The lowest cost per unit of power produced by AETEG should be considered when evaluating its economic viability.

3. DESIGN CALCULATIONS

Depending on the operation, waste heat might be rejected at practically any temperature, from the ice-cold cooling water to the hot engine exhaust from such an electric furnace or kiln. At higher temperatures, heat recovery is often more effective and economical. Any study on heat recovery must have a use for the heat that is gathered. Common uses include raising the temperature for combustion air, heating rooms, and preheating boiler feed water or process water. To ensure that the greatest amount of heat is recovered at the best efficiency, a cascade system featuring waste heat recovery can be utilized in conjunction with high-temperature recovery. An example of this waste heat recuperation strategy would be the use of the higher level for air preheating as well as the decreased stage for processing feed heating steam and water rising.

Heat Losses - Quantity The amount of heat that may be regained in any reheating scenario must be understood. How to locate waste heat is described below. 2100 m3 of exhaust fumes at a temperature of 900 0C are released into the air every hour in a high-temperature furnace. Q = V x x C p x T can be used to compute the total heat recovered from the final exhaust gas at 180 degrees Celsius. The heating value in kCal is Q. V represents the substance's flow rate in m3 per hour.

Heat available (Q) = 431,827 kCal/hr = 2100 x 1.19 x 0.24 x (900-180). This heat can be obtained by installing a recovery and used to warm the combustion air. The fuel savings will amount to 33% (at a fuel decrease of 1% for every 22oC drop in flue gas temperature).

a. Two Stroke Petrol Engine:

Type: two strokes Cooling System

Air Cooled Bore/Stroke: 50 x 50 mm

Piston Displacement: 98.2cc

Compression Ratio: 6.6: 1

Maximum Torque: 0.98 kg-m at 5,500RPM

Compression ratio = (Swept Volume + Clearance Volume)/ Clearance Volume Here, Compression ratio = 6.6:1 ∴ 6.6 = (98.2 + Vc)/Vc = 19.64

b. Design of aluminum block:

Dimensions of the specimen used

Length=170mm

Width=40mm Height=40mm

c. Heat Sink

Dimensions of heat sink: Length = 280mm,

Width = 43mm, Height = 28mm.

Fin thickness Δ = 1.5 mm = 1.5*10^-3 m

Length of each fin L = 28 mm = 28*10^-3m,

Breadth of each fin b = 300 mm = 300*10^-3m

Atmospheric temperature T_∞ = 34ºC

Base fin temperature T_o = 346ºC

Thermal conductivity K = 205 W/Mk
Heat transfer co-efficienth=70W/m^2k

Perimeter of finP = 2(b+Δ) = 2(0.3+0.0015) = 0.603 m

Area A = b*Δ = 0.3*0.0015 = 4.5*10-4 m^2

Slope m = √(hP/KA)

= √ (70*0.603)/(205*4.5*10^-4)

= 21.39

Heat transferred by each sink Q1 = n√ (hPKA) (To-T∞) tanh mL

= 11*√ (70*0.603*205*4.5*10^-4)

*(346-34)*tanh (21.39*0.028)

= 3631.3 W

There are 11 fins in a single heat sink n = 11 Total heats obtained from three heat sink

Q2 = 3* Q1

= 3* 3631.3

= 10.89*103 W

Maximum heat transferred by each sink

Qmax = nhPL (To-T∞)

= 11* 70*0.603*28*10^-3(346-34)

= 4056.25 W

Fin efficiency = Heat transferred by each sink / Maximum heat transferred by each sink

= 3631.3 / 4056.25

= 0.8952

= 89.52 %

A wall = (Total area of the wall) - (Number of fins*area of each fin)

= (L*b) - (11*b*Δ)

= [(300*53) - (11*300*1.5)] *10^-6

= 0.0109 m^2

Heat lost from the wall,

Qwall = 3* h*Awall (To-T∞)

=3*70*0.0109*(346-34)

=714.168 W

Total heat obtained, Q = Q2 + Qwall

Q = 10.89*103 + 714.68 Q = 11.60*103 W

= 11.60 KW

4. EXPERIMENTATION WORK

The TEGs can be connected in parallel and series to create electricity, which is the consequence of voltage and current at varying temperatures and considering the load resistance. the thermoelectric components, including such asp-type pellets or n-type pellets. The thermoelectric module selected is the TEP -1264-1.5, which spans 40mm by 40mm and runs at 3000 ⁰C. The temperature difference will result in the generation of electrical power. The graphic shows both heat absorption and heat rejections from the cold end to the hot side.

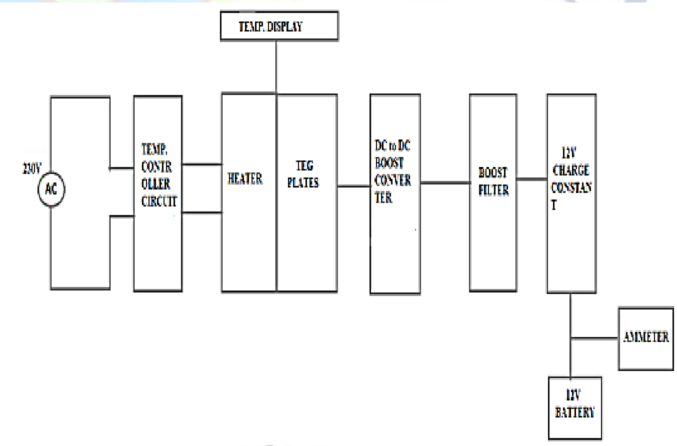


Fig.1: Block Diagram of Thermoelectric Module

Boost converter:

The boost converter's output voltage is greater than that of the applied voltage. The boost converter functions as just a step-up convert because it controls voltage. When the output of the load resistance steps down the current, a converter from DC to DC stabilizes the voltage. To store energy and lower voltage, it comprises two ends of a diode with the capacitors or an inductor. Rectifiers and batteries can be used to produce electrical power for the converter. The process of converting one voltage to some other voltage is referred to as DC-to-DC conversion.

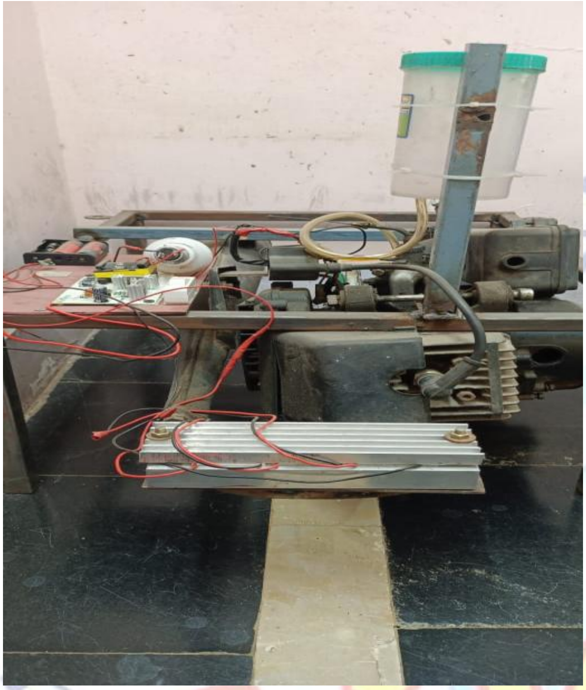


Fig.2: Experimentation setup

TEGs were set up in the experiment as shown in fig. 2 on an aluminum plate. On the cold side of the aluminum plate cooling, fans were set up, and a heat sink was set up beneath it. Two multimeters were set up to monitor electrical potential and current, and a rheostat was used to adjust the load resistor in ohms. At a load resistance of 12, the output voltage & output current was measured. In addition, the output power & efficiency are computed.

Table.1: Specifications of Thermoelectric Module

Size	**40mmx40mm**
Hot side temperature	300(°C)
Cold side temperature	30(°C)
Open circuit voltage	9.4(V)
Match load resistance	2.8(Ω)
Match load output voltage	4.7(V)
Match load output current	1.56(A)
Match load output watts	7.3(W)
Heat flow across the module watts	133W
Heat flow density	8.4(cm)

5. RESULTS AND DISCUSSION

CASE:1 The greatest power output is P=2.05 W if four TEGs are connected in series.

The related readings were noted, then graphs are made, for R = 10 load resistance and various temperatures. Calculations were made to determine its output power for each output voltage and output current for each temperature.

Table.2 lists the input and output voltage values as well as the current and power output at various temperatures.

S.NO.	**Temperature (°c)**	**Voltage generated (V)**	**Voltage of input (V)**	**Current produced (m A)**	**Output power (W)**
1.	50	0.95	0.4	50	0.04
2	60	1.4	1	100	0.14
3	70	1.8	1.5	150	0.27
4	80	2.2	2	200	0.44
5	90	2.6	2.5	230	0.59
6	100	3.1	2.9	270	0.83
7	110	3.6	3.3	300	1.08
8	120	4	3.8	350	1.40
9	130	4.3	3.9	360	1.54
10	140	4.5	4.1	370	1.66
11	150	4.6	4.2	380	1.74
12	160	4.8	4.4	400	1.92
13	170	5	4.6	410	2.05

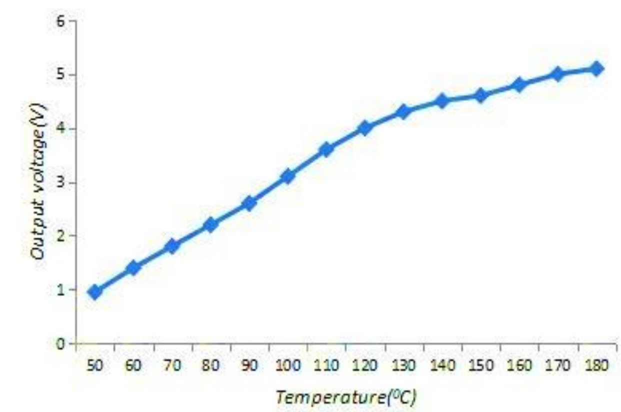


Fig.3: Output voltage(V) as a Function of temperature (°C)

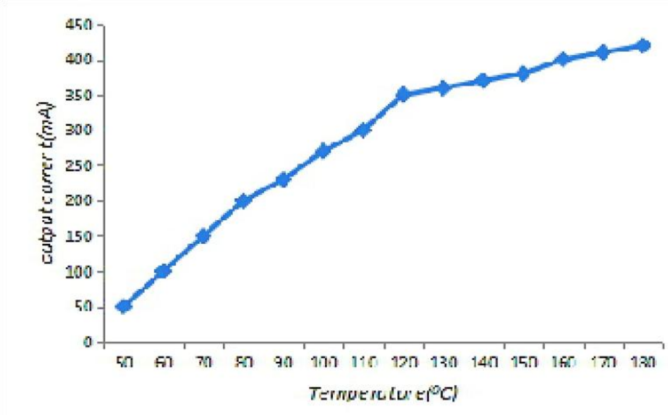


Fig.4: Output current Vs Temperature

According to Fig. 3, which depicts output voltage as solely a function of temperature, the output voltage will increase as the temperature increases. When the load impedance is 10 and the temperature is 180 ^{0}C, the maximum voltage is 5.1V. Output current increases as temperature increases, as shown in Fig. 4, which only depicts output current as a function of temperature. The greatest current that could be drawn at a temperature of 170 ^{0}C and a resistive load of 10 was 0.41A.

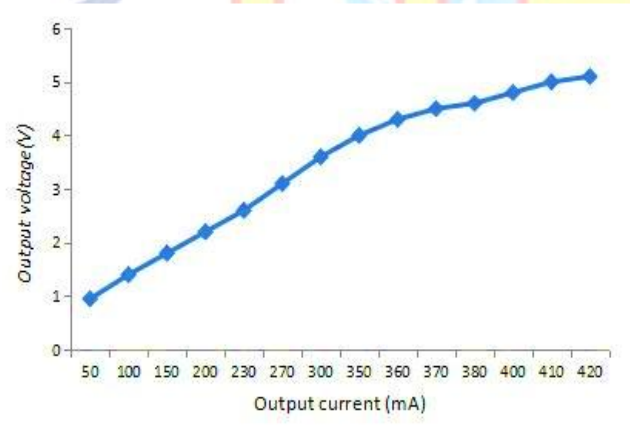


Fig.5: Voltage (V) as a function oftemperature (^{0}C)

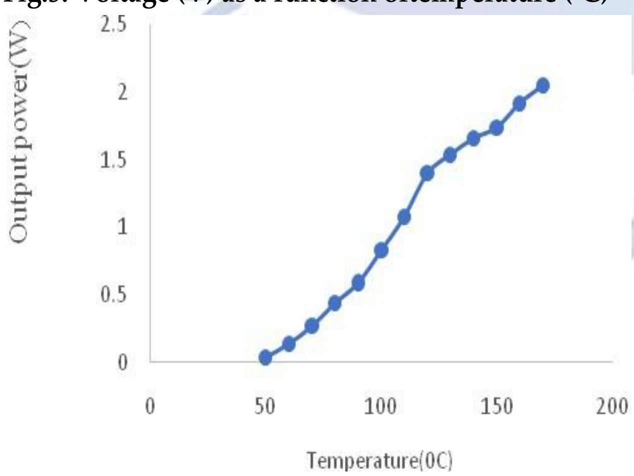


Fig.6: Output power as a function temperature (^{0}C)

Between voltages, Fig. 5 was drawn. With a load resistance of 10 and a maximum output voltage of 5.1 V, the highest output current was 0.42 A. The output power as a function of temperature is shown in Fig. 6. The output power was 2.05W, and the power obtained increased with temperature from 0.04W at 50^{0}C, to 0.04W at 170^{0}C.

Case 2: Parallel connection of four thermoelectric generators

The output voltage and output current data were noted at various temperatures, and P = 12.91 W was used to compute the maximum power.

Table. 3:output power, voltage, and current values at various temperatures

S.NO.	Temperature (^{0}C)	the voltage generated(V)	Voltage given (V)	Current produced (m A)	Output Power (W)
1.	50	5.1	3	300	1.53
2.	60	6.7	3.5	350	2.34
3.	70	8.4	3.8	360	3.02
4.	80	10	4.4	380	3.80
5.	90	11.9	4.9	430	5.11
6.	100	13.7	5.5	480	6.57
7.	110	15.4	6.1	540	8.31
8.	120	17	6.5	570	9.69
9.	130	18	6.8	600	10.80
10.	140	19	6.9	610	11.59
11.	150	20.1	7	620	12.46
12.	160	20.5	7.1	630	12.91

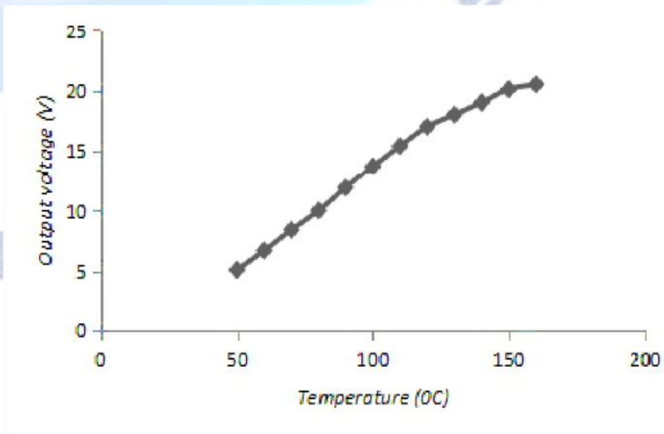


Fig.7: Voltage as a function of temperature

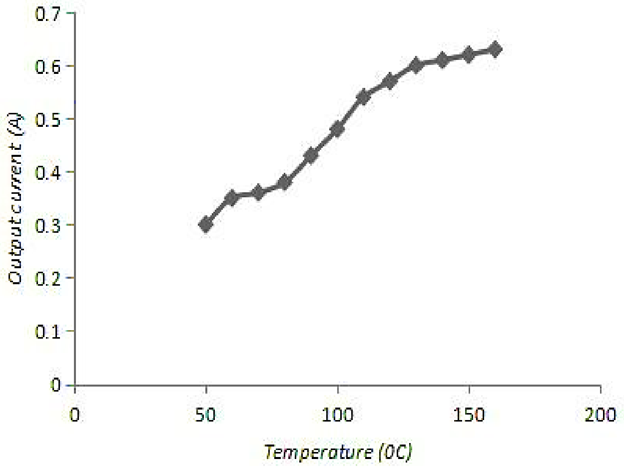


Fig.8: Current as a function of temperature

In Fig. 7, the voltage is depicted because of the temperature. As the temperature increases, so does the output voltage. The highest output voltage, 20.5V, was reached at 160 ⁰C. Figure 8 depicts the output current because of the temperature. The output currents increase as the temperature rises. The highest current produced was 0.63A at 160 ⁰C.

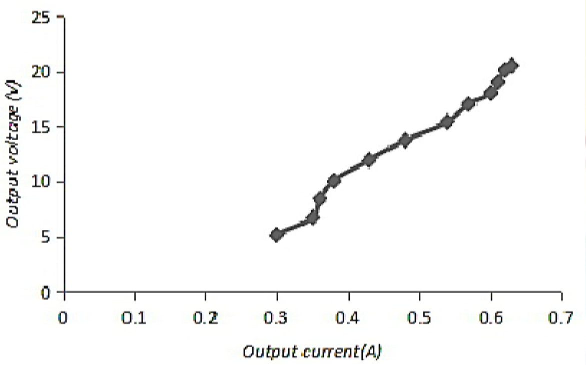


Fig.9: Voltage as a function of output current

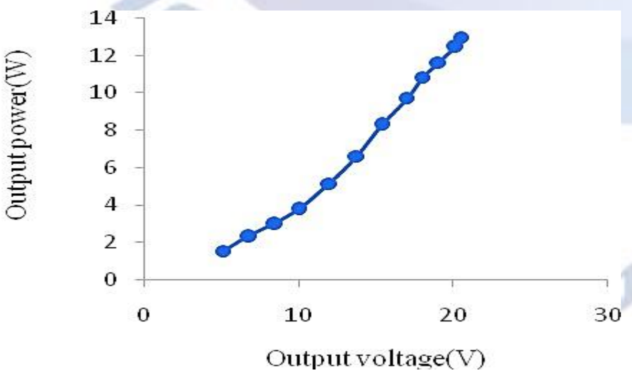


Fig.10: Output power as a function of output voltage

Fig. 10 displays the voltage as a proportion of output current. The output current and output voltage both rise with temperature. At 160 ⁰C, the current was 0.63A and the voltage rating was 20.5V. The output power is shown as a function of output voltage in Figure 5.8, with the values obtained at 500C at 5.1V and 1.53W. The maximum power output and voltage were 12.91W and 20.5V respectively at 160 ⁰C.

6. CONCLUSION

As is well known, p-type and n-type semiconductors make up a thermoelectric generator. This pair can be combined to create a thermocouple. When numerous thermocouples are connected in series, the voltage is increased, and when they are connected in parallel, the current is increased. The heat rejection and absorption continue to this TEG. The temperature differential causes it to generate electricity. The thermocouples are electrically connected in series to improve generated voltage and power. When only one thermocouple was used, the power output was measured in mW. The current in amps and the voltage in volts increase when TEGs are coupled in parallel and series, respectively. TEGs are widely used nowadays due to their advantages of direct thermal energy into electrical energy conversion, compactness, high reliability, low noise, excellent durability, minimal moving parts, cost-effectiveness, and high efficiency. A higher figure of merit can be expected to result in a higher conversion efficiency.

Case:1 The power output and efficiency estimated when four thermocouples are linked in series were I = 0.41A, V = 5.0V P = 2.05W = 4.25%, at a temperature of 1700 0C. The greatest output power and efficiency were given by I = 0.42A and V = 5.1V P= 2.14W = 4.35% at 180 0C.

Case:2 The output power and efficiency if four thermocouples are connected in parallel were computed as follows: The maximum current, I = 0.63A V = 20.5V P = 12.91W = 5.15%

Conflict of interest statement

Authors declare that they do not have any conflict of interest.

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