Introduction to Thermoelectric Energy Conversion

GROUP DISCUSSION

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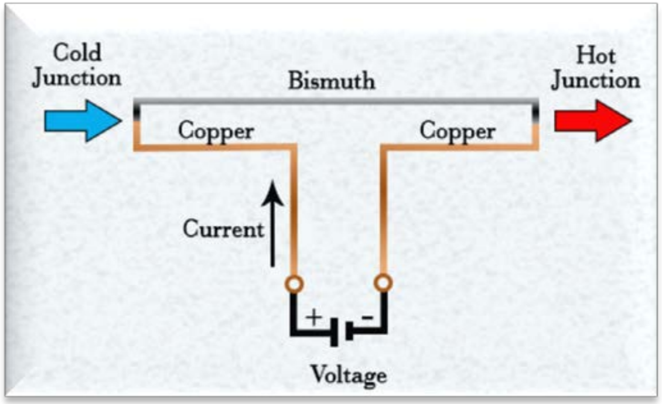
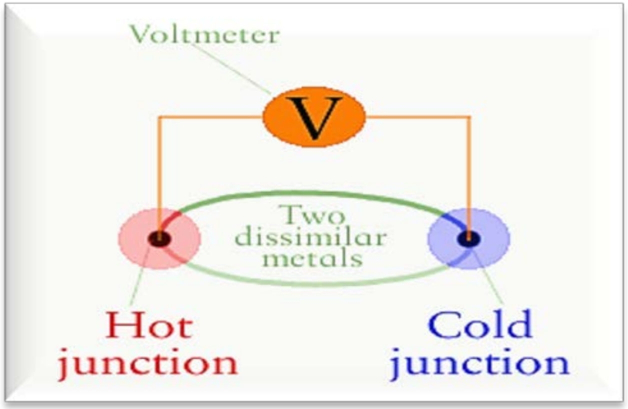
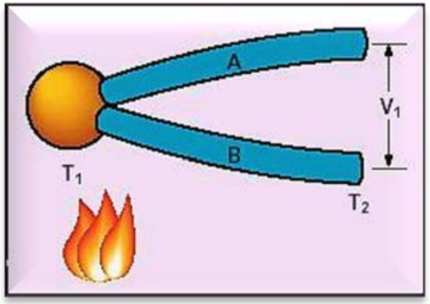
The Thermoelectric: refers to phenomena by which either a temperature difference creates an electrical potential or an electric potential creates a temperature difference.

- Consider two wires made from different metals joined at both ends, as shown in Figure, forming a close circuit. Ordinarily, nothing will happen. However, when one of the ends is heated, something interesting happens. A current flows continuously in the circuit.



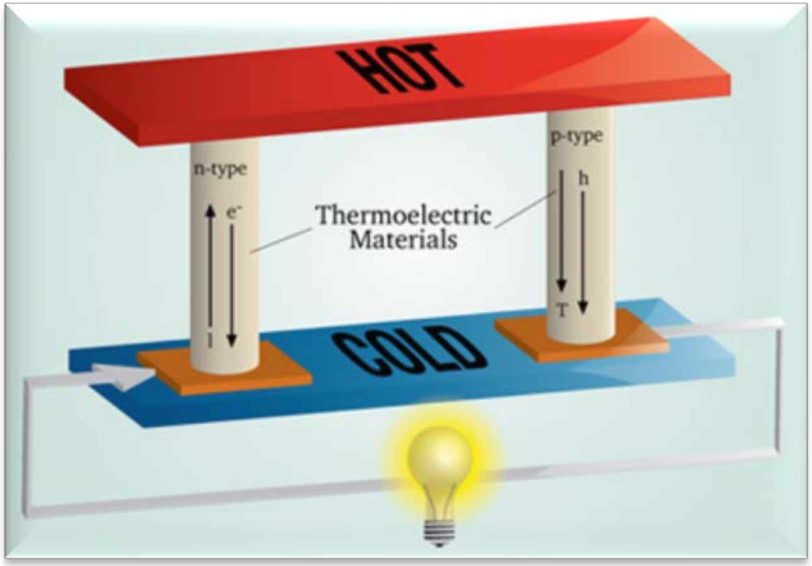


A Thermocouple: uses the electrical potential generated between two dissimilar wires to measure temperature.



Thermoelectric Materials

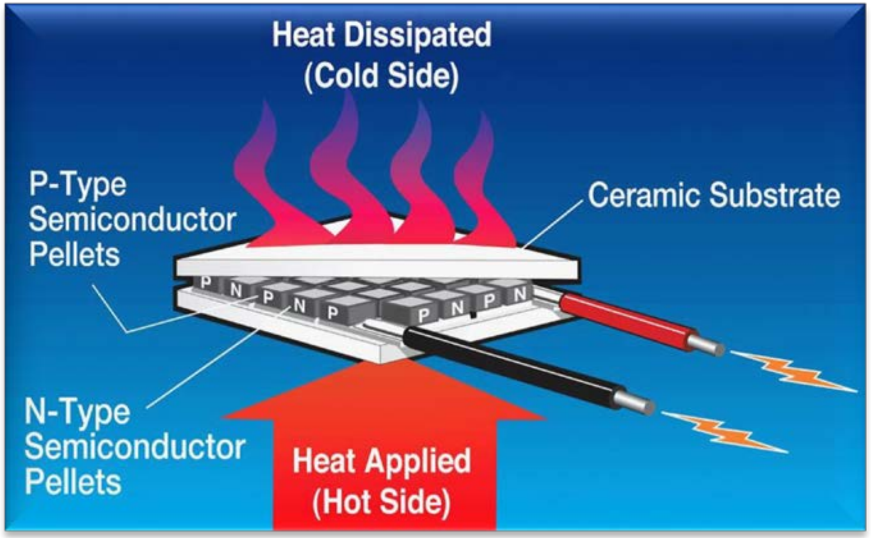
- All materials have a nonzero thermoelectric effect, in most materials it is too small to be useful.
- low-cost materials that have a sufficiently strong thermoelectric effect could be used in applications.
- A commonly used thermoelectric material in such applications is bismuth telluride (Bi_2Te_3). The recent development of nanotechnology has led to remarkable improvement in thermoelectric material performance.

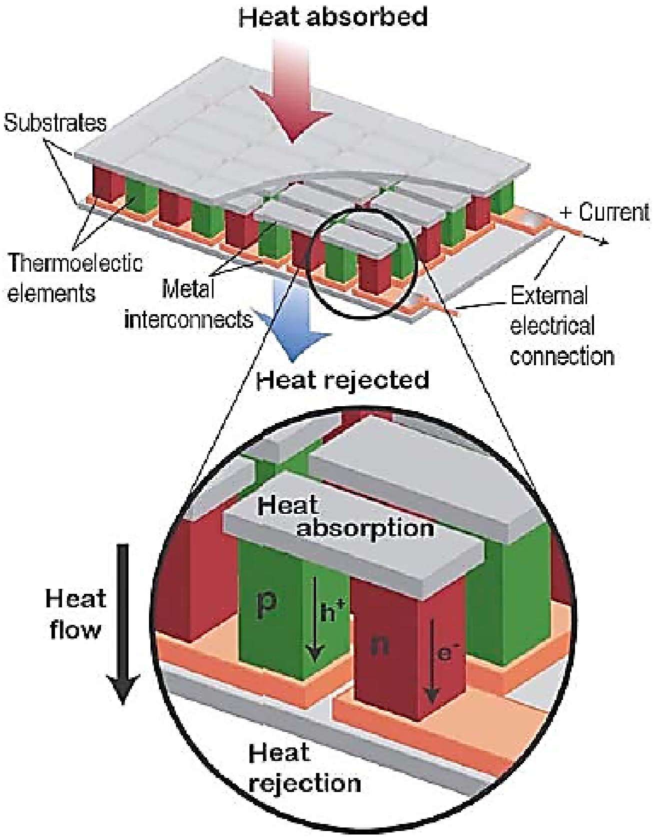


Thermoelectric module

A large number of thermocouples, each of which consists of p-type and n-type semiconductor elements, are connected electrically in series and thermally in parallel by sandwiching them between ceramic plates to form a module

Applying a temperature gradient across the module causes the carriers to diffuse towards the cold side, generating a thermoelectric voltage





Thermoelectric effect

The thermoelectric effect consists of two effects:

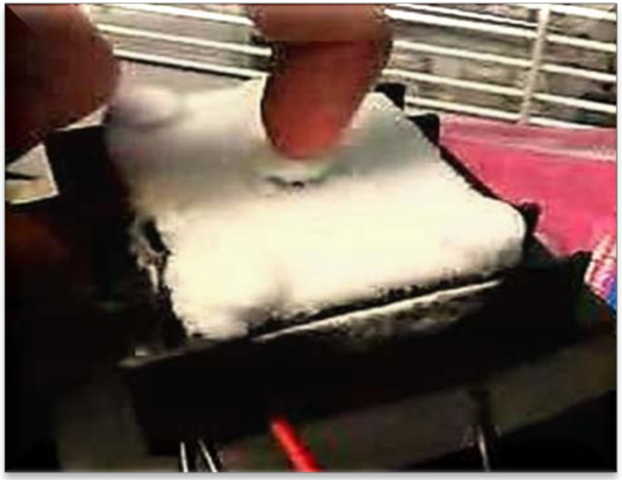
- **Seebeck Effect**

The Seebeck effect is the conversion of a temperature difference into an electric current.

$$V = S\,\Delta T$$

where $\Delta T = T_h - T_h$ and S is called the Seebeck coefficient.

- **Peltier Effect**



Peltier found that an electrical current would produce a temperature gradient at the junction of two dissimilar metals.

The heat is proportional to the current flow and changes sign when the current is reversed.

Device efficiency

The efficiency of a thermoelectric device for electricity generation is given by :

$$\eta = \frac{\text{energy provided to the load}}{\text{heat energy absorbed at hot junction}}.$$

- Defined as: The ability of a given material to efficiently produce thermoelectric power Which is related to its dimensionless figure of merit ZT given by:

$$ZT = \frac{\sigma S^2 T}{\lambda}$$

which depends on the Seebeck coefficient S, thermal conductivity λ, and electrical conductivity σ and temperature T.

- Materials with a high figure-of-merit value are able to 'generate' more energy (extract more energy from heat).
- Commercial available material has ZT = 1, research have developed material with ZT = 3

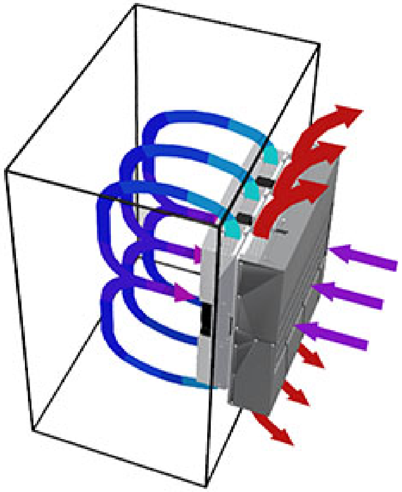
$$\eta_{\max} = \frac{T_H - T_C}{T_H} \frac{\sqrt{1 + Z\bar{T}} - 1}{\sqrt{1 + Z\bar{T}} + \frac{T_C}{T_H}},$$

- the coefficient of performance (COP) of current commercial thermoelectric refrigerators is one-sixth the value of traditional vapor-compression refrigerators

Applications

1. Refrigeration

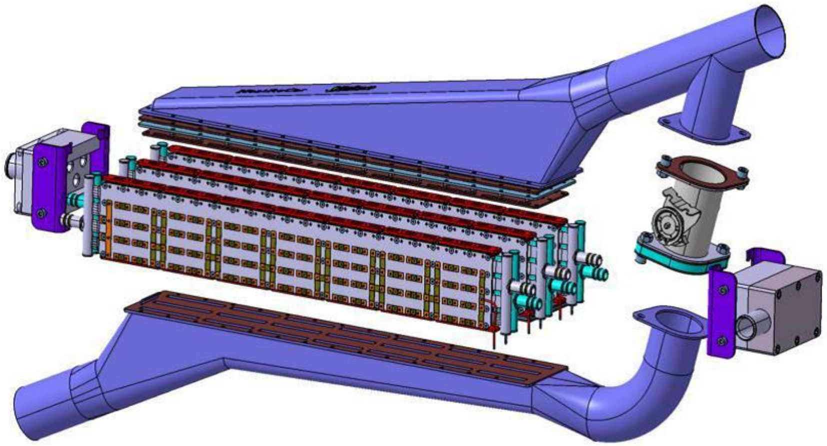
Peltier cooling is far less common than vapor-compression refrigeration. The main advantages are: its lack of moving parts and refrigerant and its small size and flexible shape



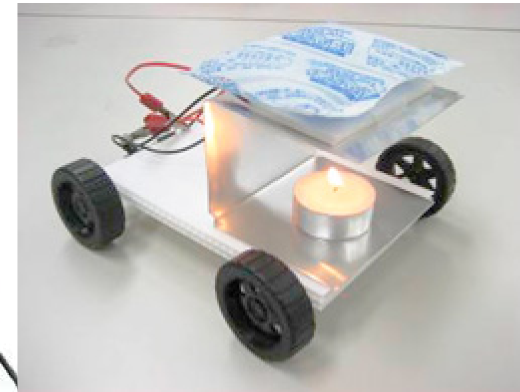
2. Power generation

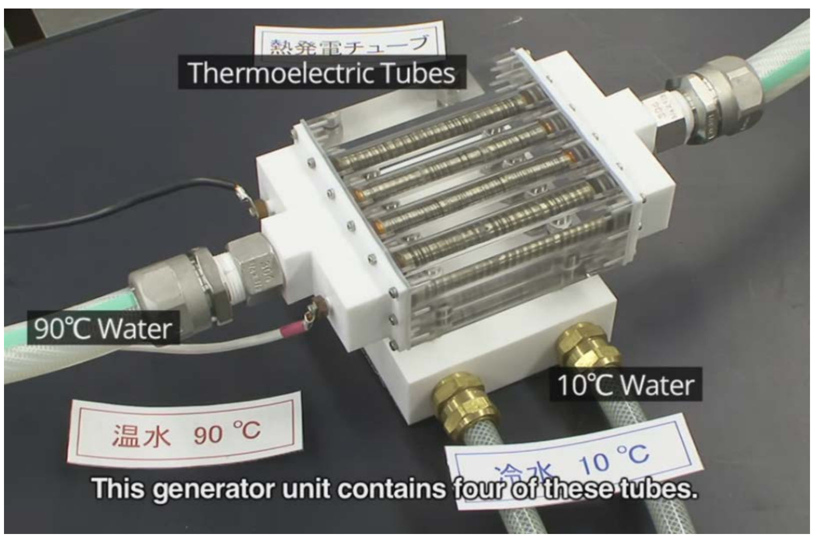
Approximately 90% of the world's electricity is generated by heat energy, typically operating at 30–40% efficiency, losing the rest of power in the form of heat to the environment. Thermoelectric devices could convert some of this waste heat into useful electricity.

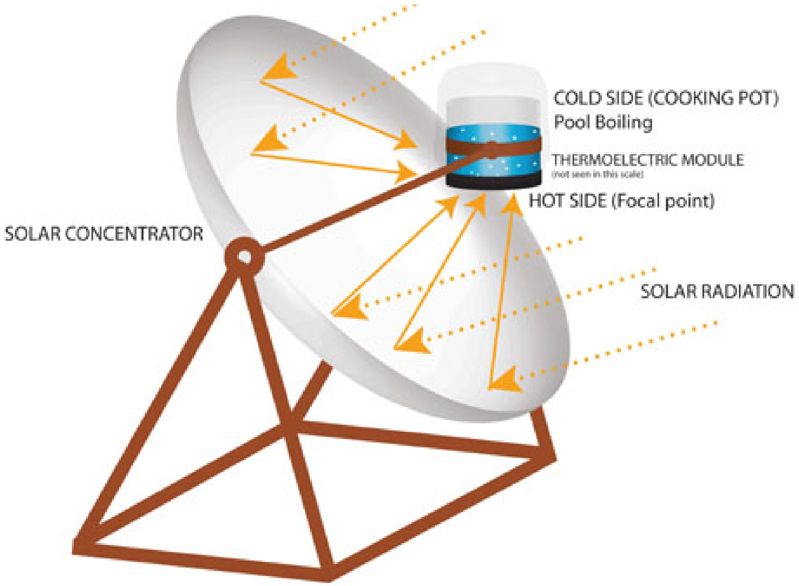
Internal combustion engines capture 20–25% of the energy released during fuel combustion. Increasing the conversion rate can increase mileage and provide more electricity. It may be possible to shift energy draw from the engine (in certain cases) to the electrical load in the car, e.g. electrical power steering or electrical coolant pump operation.

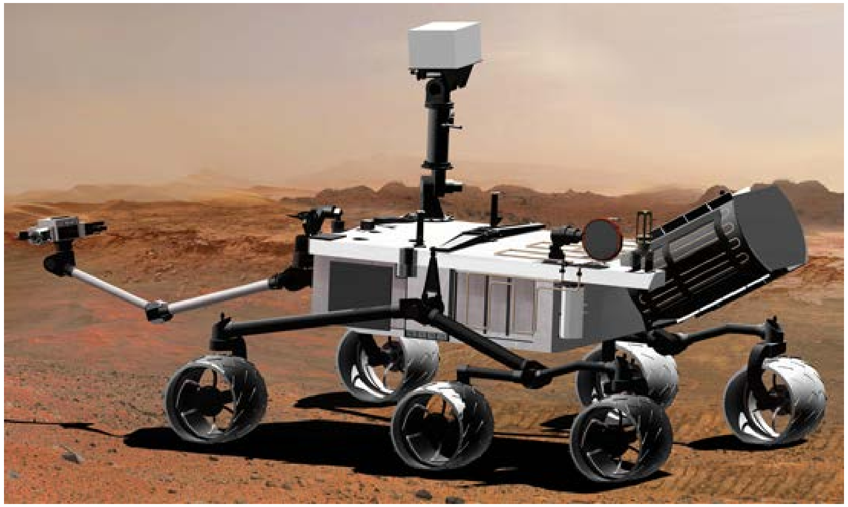


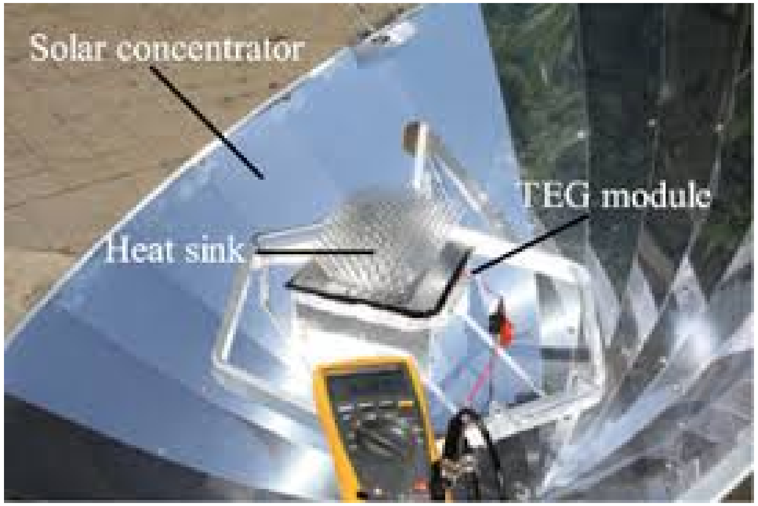

FLUKE
289 TRUE RMS MULTIMETER
-2.941 mVDC
F1
F2
F3
F4
HOLD
MIN MAX
RANGE
info



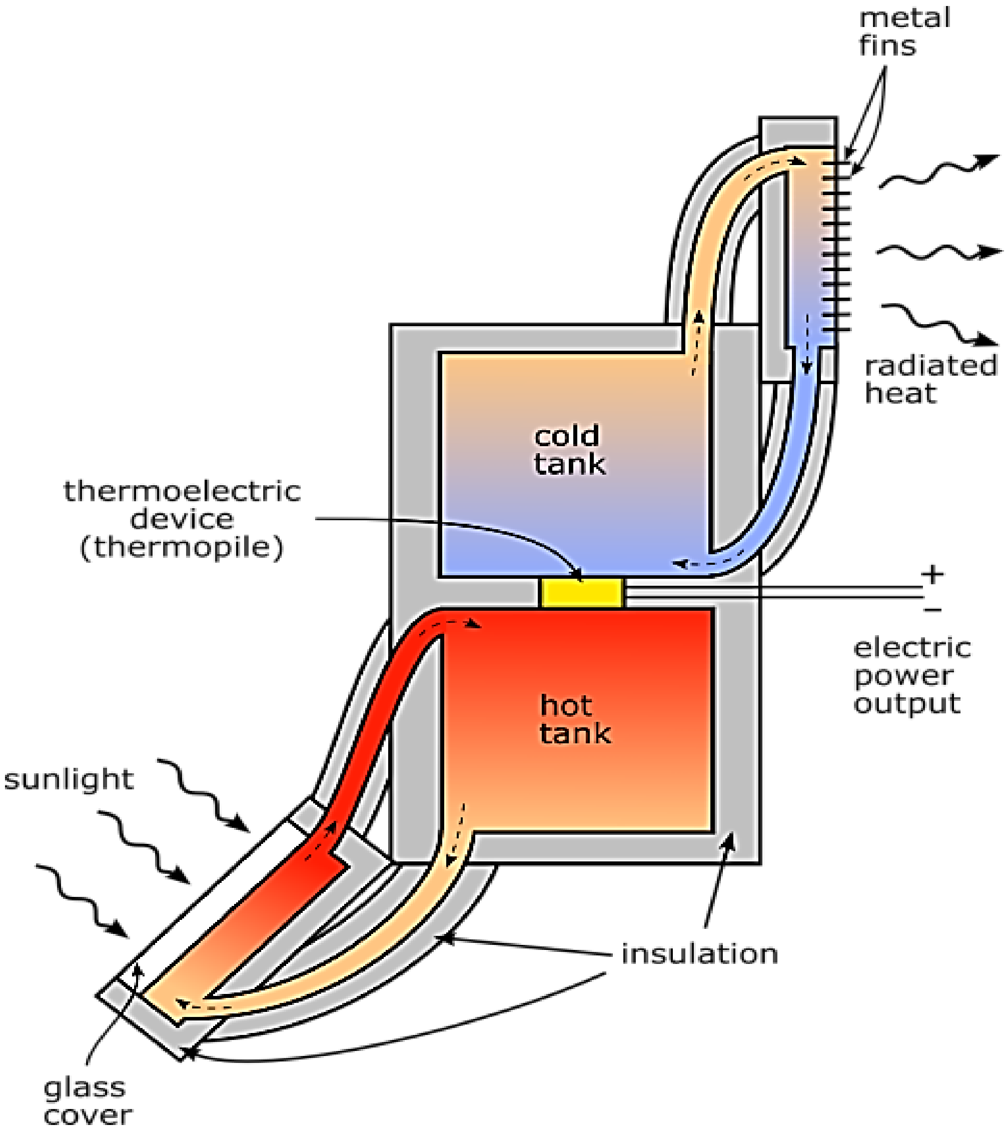

熱発電チューブ
Thermoelectric Tubes
90℃ Water
10℃ Water
温水 90 ℃
冷水 10 ℃
This generator unit contains four of these tubes.


COLD SIDE (COOKING POT)
Pool Boiling
THERMOELECTRIC MODULE
HOT SIDE (Focal point)
SOLAR CONCENTRATOR
SOLAR RADIATION




Solar concentrator
TEG module
Heat sink

Solar- Thermoelectric



Case Study

- A thermoelectric generator is to be designed to recover the waste thermal energy from the exhaust pipeline in a vehicle for the battery charging.
- The hot and cold junction temperatures are estimated to be 250◦C (measured) and 50◦C (ambient temperature = 25), respectively.
- The power generated should be no less than 150 W. The output voltage is required to be 14V to charge the battery (12V) in the vehicle.
- Design the thermoelectric generator using the TEG modules listed in Table 1 to provide the power, the current, the voltage, the heat absorbed at the hot junction, the heat dissipated at the cold junction, the thermal efficiency, and the number of modules.

Design procedure

The specifications of the selected module TEG-3b:

Table 1 Multiple Modules of TEG

	$T_h = 230°C$ and $T_c = 30°C$, $ZT_{ave} = 0.4$					Dimension (mm)		
Module	R (Ω) (internal resistance)	$\dot{W}_{max}$* (Watts)	I_{max}** (Amps)	V_{max}** (Volts)	Number of couples	Width	Length	Height
TEG-3b	0.3	19	16	5.0	71	75	75	5.08

For single module

$W/W_{max} = 1$ from Figure 1, $W = W_{max} = 19W$

$I/I_{max} = 0.5$ from Figure 1, $I = 0.5 \times I_{max} = 8A$

$V/V_{max} = 0.5$ from Figure 1, $V = 0.5 \times V_{max} = 2.5V$

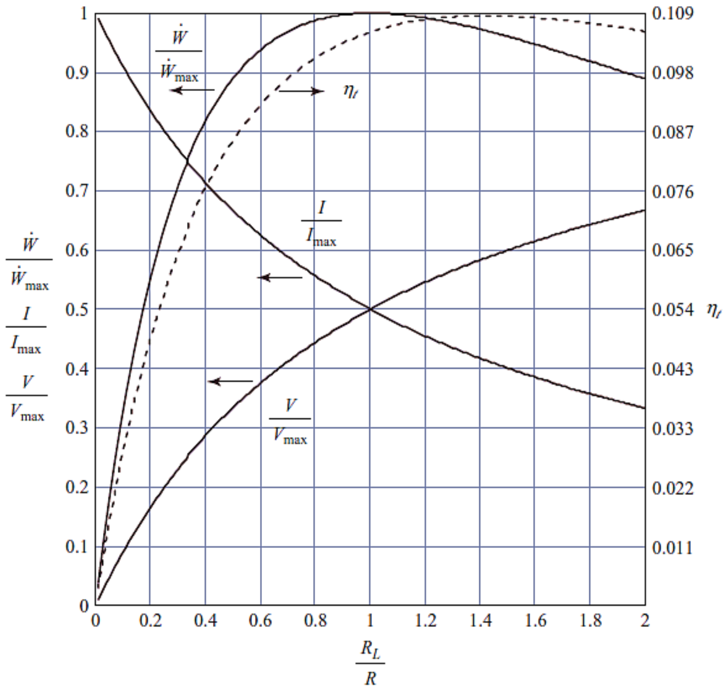
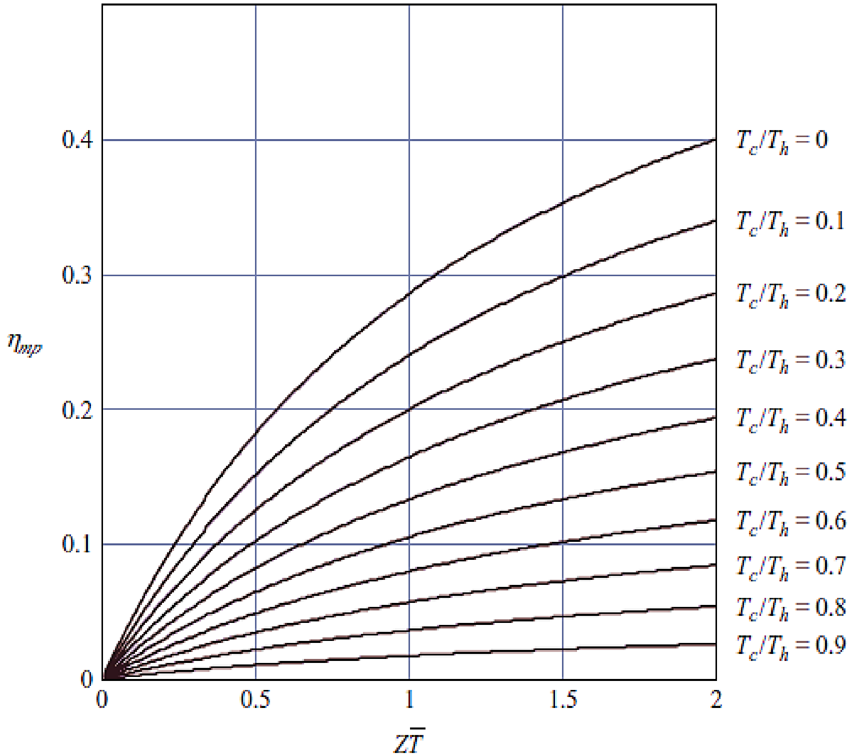


Figure 1 Generalized chart of TEG characteristics.

T_c/T_h = (50 + 273)K / (250 + 273)K = 0.6

Using T_c/T_h= 0.6 and ZT= 0.4,

it is found from Figure 2 that



$$\eta_{mp} = \frac{W}{Q_h} \approx 0.05$$

$$Q_h = \frac{W}{\eta_{mp}} = 19W/0.05 = 380W$$

The heat rejected at the cold junction is obtained from the first law of thermodynamics applied to the system.

$Q_c = Q_h - W$

$Qc = Q_h - W = 380W - 19W = 361W$

Number of Modules = power required/ one module power

$$N = \frac{150}{19} = 7.8 = 8 \text{ Modules}$$

Eight modules are arranged electrically in series and thermally in parallel as shown in Figure 3

The modules are arranged as in figure, to meet the available area of silencer.

The total power is

$$W \times N = 19 \times 8 = 152 \text{ W}$$

The calculated panel power of 152W is satisfied to meet the power requirement of 150 W.

$$I_N = I = 8 \text{ A}$$

$$V_N = N \times V = 8 \times 2.5V = 20V$$

A DC/DC converter is used to bring down the voltage of 20V to 14V.

The total heat absorbed at the hot junction temperature should be

$$Q_{h\_N} = Q_h \times N = 8 \times 380W = 3040W$$

The heat sink in the exhaust gas passage should be properly designed to meet the heat transfer rate of 3040W absorbed at the hot junction.

The heat dissipated at the cold junction temperature is

$$Q_{c\_N} = Q_c \times N = 8 \times 361W = 2888W$$

Heat sink or cooling water (by circulating the vehicle's cooling water) should be designed to meet the heat dissipation of 2888 W.

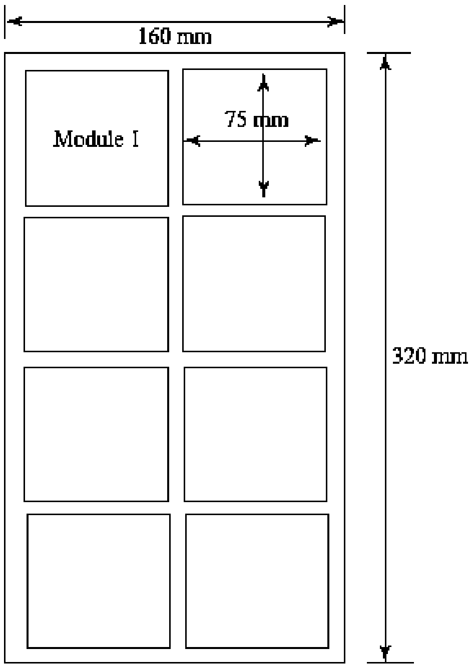


Figure 3 TEG Panel

Thanks