DESIGN OF PCM BASED SOLAR POWERED THERMOELECTRIC COOLING DEVICE AND OPTIMIZATION OF PARAMETERS BY GREY RELATIONAL ANALYSIS

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Abstract

Now-a-days there is increasing demand for low temperature applications in various fields. The devices which are used to produce low temperatures are consuming a lot of electricity. In addition to the increased consumption of electricity, these devices also release large amounts of harmful gases such as CFCs, CO2 that leads to ozone layer depletion, global warming. In this technical paper, an attempt is made to produce a device that produces low temperature with the help of TEC module, which leads to reduction in consumption of electricity, reduction in parts i.e., compressor, condenser etc. The TEC module works on thermoelectric effect, which is the direct conversion of temperature differences into electrical voltage and vice versa. In present work, a model of thermoelectric cooling device which utilizes the advantages of solar energy is designed and fabricated. The model consists of a cooling cabin, which is the core area to be maintained at low temperature. Based on the temperature to be attained by the cooling cabin and passive heat load calculations, model of the TEC module is selected. After fabricating the thermoelectric cooling device, experimental runs are carried out for cooling and discharging processes with and without the application of PCM. The values are tabulated and graphically represented. To obtain the multi goal optimum solution Grey Relational analysis is used and the value that has the highest grey relational grade is considered as optimum solution.

1. INTRODUCTION:

The main objective of this study is designing and fabricating a working model of thermoelectric device for cooling which employ Peltier effect, i.e., lowering the temperature at one junction and increasing the temperature at the other junction when electric current is passed in a circuit which consists of two dissimilar conductors; the effect in circuits which contain dissimilar semiconductors is more effective. The model is designed in such a way that the volume inside the cabin should be cooled and maintained within the temperature ranging 4 °C to 10 °C. Organic phase changing materials
Glycerin and Formic acid are used additionally to achieve the advantages of their charging and discharging processes. During the charging process PCM absorbs chillness and reaches to its freezing point. Once the PCM is fully charged it releases large amount of energy, with which the cabin can be cooled comparatively faster than the cabin without PCM. Also when the power input to the cabin of the thermo electric device is off then the heat enters into the cabin through the TEC module. To avoid this heat absorption into the cabin PCM undergoes discharging process so that the temperature inside the cabin can be retained for some time. In present work, the times taken by two different volumes of cabins to attain desired temperature with and without the application of PCM are tabulated. Further the parameters like passive heat load, COP, time, temperature and volume are optimized using GRA technique. In this work organic PCM is preferred than inorganic PCMs because organic PCMs are chemically stable, environmentally safe, non-toxic and are non-corrosive in nature. This device can be used in remote locations where generation of electric power is less and uncertain because it is powered from battery which can be charged through solar panel.

1.1 OBJECTIVE OF THE WORK:
- To maintain temperature inside the cabin ranging from 4 °C to 10 °C
- Determining the multi goal optimum solution through grey relational analysis.

2. SELECTION OF CONDUCTING MATERIAL ON COLD SIDE OF TEC MODULE:

Study of best conducting materials between the cold side of the TEC module and the cooling cabin is done. The conducting materials studied were aluminium, copper and Brass.

<table>
<thead>
<tr>
<th>Conducting Material</th>
<th>Thermal Conductivity (W/m K)</th>
<th>Density (Kg/m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminium</td>
<td>205</td>
<td>2698</td>
</tr>
<tr>
<td>Copper</td>
<td>385</td>
<td>8940</td>
</tr>
<tr>
<td>Brass</td>
<td>115</td>
<td>8470</td>
</tr>
</tbody>
</table>

Although copper has high thermal conductivity, it is highly corrosive. In present work the conducting material should be in direct contact with the phase changing material, it limited the use of copper irrespective of its advantages. Similarly Brass forms blackish tarnish when comes into contact with PCM. So Aluminium which has low density, high corrosive resistance is found to be the best conducting material in the present work. Also by using aluminium the discharging process of the PCM will be improved.

In present work, the PCM used will convert from liquid to solid and vice versa. To carry the liquid PCM a pocket or socket is required. The socket with required dimensions is designed in solid works and then the socket is manufactured with the conducting material aluminium as shown below.
Aluminium sheets of thicknesses 1mm and 2mm, which have thermal conductivity of 205 W/ m-K, are used to make sockets. Aluminium sheets of 2mm thickness are in direct contact with the cold sides of TEC modules. The sheets of 1mm thickness are bent in L- shape at the corners and then joined to the 2mm thick sheets with the help of an adhesive material silicone. Socket design is done in solid works as shown in fig(2.1). The gap between the sheets is filled with organic PCMs glycerine and formic acid one at a time.

Expanded polystyrene sheets (EPS) which are 50mm thick, 30kg / m³ density and 0.033W/m-K thermal conductivity are used to provide shielding for temperature losses from the cabin. Organic PCMs Formic acid with properties as shown in the table 1 is poured into two aluminium sockets of inner dimensions 10cm×10cm×1cm. These aluminium sockets are attached on the cold side of the TEC module.

**Table 2.1 Properties of formic acid and Glycerin**

<table>
<thead>
<tr>
<th></th>
<th>Formula</th>
<th>Density</th>
<th>Boiling point</th>
<th>Melting point</th>
<th>Heat of fusion</th>
</tr>
</thead>
<tbody>
<tr>
<td>CH₃O₂</td>
<td>1.220g/ m-L</td>
<td>101 °C</td>
<td>7.8 °C</td>
<td>247 kJ/kg</td>
<td></td>
</tr>
<tr>
<td>CH₃O₂</td>
<td>1.26g/ m-L</td>
<td>290 °C</td>
<td>17.9 °C</td>
<td>198.7 KJ/kg</td>
<td></td>
</tr>
</tbody>
</table>

### 3. EXPERIMENTAL SETUP

A schematic diagram of the experimental setup is shown in figure 3.1. It consists of a solar panel from which the solar irradiance is converted into electricity and is stored in the battery. As the power obtained from the battery is low to amplify the power obtained, inverter is used. Inverter converts DC power into AC power. Then again the AC power from the inverter is converted to DC power with the help of rectifier, so that uninterrupted power supply can be given to the thermoelectric cooling device. The TEC modules which are present in the thermoelectric cooling device, receives the DC power supply from the rectifier and creates hot and cold sides on its either faces. To the cold side of the TEC module aluminium socket is attached. This aluminium socket holds the PCM as well as it increases the thermal conductivity. During charging of the PCM the temperature of the cabin will decrease slowly but when the PCM is completely charged the
temperature of the cabin falls down rapidly. The benefits of the discharging process of the PCM is utilized when the power supply is interrupted, the cabin remains at the low temperature.

3.1 Fabrication of thermoelectric device.
The model with the required dimensions is assembled as shown in the figure. The device is powered from a battery which is charged from the solar energy. A digital thermometer is fixed to check the temperature inside the cabin.

3.2 EXPERIMENTAL DATA FOR COOLING AND DISCHARGING PROCESS:

Figure 3.2 Graphical representation of cooling behavior of 16 L cabin with and without PCM

Figure 3.3 Graphical representation of cooling behavior of 30 L cabin with and without PCM

Figure 3.4. Graphical representation for discharging capacity 16 L cabin with and without PCM

Figure 3.5. Graphical representation for discharging capacity 30 L cabin with and without PCM
4. RESULTS AND DISCUSSIONS:

4.1 Calculation of solar power:
- Total number of cells used in solar panel 54
- Voltage of each cell 0.5 V
- Maximum voltage obtained from panel=54*0.5=27 V
- Capacity of battery used is 12 V-26Ah
- Average current available =2.3A
- Number of hours required to charge the battery =26/2.3=11.3 hrs
- Capacity of battery is 26Ah
- Refrigerator capacity is 12V-92W
- Current consumed by battery is 6A
- Time taken for discharge of battery is 26/6= 4.3 hrs

4.2 Heat load Calculations:
To maintain a temperature difference between the thermal load of the system and the ambient environment, a small amount of energy must be continually moved into and out of the load. The rate at which this energy is moved is the passive load.
Including both the conductive and convective heat transfer components of the load, we can use this equation:

\[ Q = \frac{\Delta T \cdot A}{R + \frac{A}{h}} \]

4.3 COP
COP is defined as the ratio of desired effect to the work input. Higher COP indicates lower operating cost.

4.3.1 Calculation of COP
While calculating the COP the efficiency of the TEC module is considered as 15%.
- COP = \frac{Q/time}{W_in} ; \frac{Q}{time} = m \cdot C_v \cdot \Delta T ;
  - Win = V\times I + fans (without PCM)
- COP = \frac{Q/time}{W_in} ; \frac{Q}{time} = m \cdot C_v \cdot \Delta T + mL ;
  - Win = V\times I + fans (with PCM)

5. ANALYSIS OF PROCESS PARAMETERS

5.1 Grey Relational Analysis
Grey relational analysis or Deng’s grey incidence analysis is a Chinese optimization method used for idealized situations. Here, the situations are classified into colors, namely, black, grey, hazy and white. This is used to find out the optimal value from a set of multi response parameters. For the sake of real time usage, the process parameters are ranked to find out the optimal solution. Parameters to be optimized are shown in table 5.1

5.2 Formulae and corresponding values

STEP 1: Grey Relational Generation
- For minimization function,
  \[ \theta = \frac{y_{max} - y}{y_{max} - y_{min}} \]
  where \( y_{max} = 6.7 \) ; \( y_{min} = 3.97 \) (temperature of the cabin)
- For maximization function,
  \[ \theta = \frac{y - y_{min}}{y_{max} - y_{min}} \]
where $y_{\text{max}}=30; y_{\text{min}}=16$ (Volume of the cabin)

$y_{\text{max}}= 700; y_{\text{min}}= 220$ (Discharging Time)

$y_{\text{max}}= 6.404; y_{\text{min}}= 5.65$ (Passive Heat Load)

$y_{\text{max}}= 0.848; y_{\text{min}}= 0.103$ (COP)

The calculated values are tabulated as shown in table 5.2. Deviational sequence is obtained as shown in table 5.3.

**STEP - 2: Calculation of Grey Relational Grade**

- To calculate grey relational co-efficient by using the formula,

$$
\xi(y) = \frac{(\theta_{\text{min}} + \xi \theta_{\text{max}})}{(\theta_{\text{0}} + \xi \theta_{\text{max}})}
$$

Where, $\xi = 0.5$, which is taken randomly,

$\theta_0$ is the deviation sequence and,

$\theta_0 = | \theta_{\text{max}} - \theta |$

$\theta_{\text{max}} = 1; \theta_{\text{min}} = 0$

The values are calculated and tabulated as shown in table 5.4

**STEP – 3: Calculation of Grey Relational Grade**

$$
\gamma = (\xi_1 + \xi_2 + \ldots + \xi_n)/n
$$

Here, $\xi_1$ = Grey relation coefficient of volume

$\xi_2$ = Grey relation coefficient of charging time

$\xi_3$ = Grey relation coefficient of discharging time

$\xi_4$ = Grey relation coefficient of Temperature of the cabin

$\xi_5$ = Grey relation coefficient of passive heat load

$\xi_6$ = Grey relation coefficient of COP

The values are calculated and tabulated as shown in table 8.5.

**Table 5.1 Parameters to be optimized**

<table>
<thead>
<tr>
<th>S no</th>
<th>Vol</th>
<th>$T_c$</th>
<th>$T_d$</th>
<th>$T_{\text{cab}}$</th>
<th>QP</th>
<th>COP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>16</td>
<td>120</td>
<td>260</td>
<td>3.97</td>
<td>6.404</td>
<td>0.103</td>
</tr>
<tr>
<td>2</td>
<td>16</td>
<td>300</td>
<td>700</td>
<td>5.51</td>
<td>5.89</td>
<td>0.397</td>
</tr>
<tr>
<td>3</td>
<td>16</td>
<td>300</td>
<td>700</td>
<td>6.5</td>
<td>5.69</td>
<td>0.483</td>
</tr>
<tr>
<td>4</td>
<td>30</td>
<td>130</td>
<td>220</td>
<td>4.29</td>
<td>6.34</td>
<td>0.177</td>
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<tr>
<td>5</td>
<td>30</td>
<td>320</td>
<td>560</td>
<td>5.55</td>
<td>5.882</td>
<td>0.698</td>
</tr>
<tr>
<td>6</td>
<td>30</td>
<td>320</td>
<td>560</td>
<td>6.7</td>
<td>5.65</td>
<td>0.848</td>
</tr>
</tbody>
</table>

Where $T_c$ = cooling time (min);

$T_d$ = Discharging time (min); $T_{\text{cab}}$ = Cabin temperature (°C); QP=Passive heat load (W)

**Table 5.2 Grey Relational Generation**

<table>
<thead>
<tr>
<th>S no</th>
<th>Vol</th>
<th>$T_c$</th>
<th>$T_d$</th>
<th>$T_{\text{cab}}$</th>
<th>QP</th>
<th>COP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0</td>
<td>0.916</td>
<td>0</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>0.9</td>
<td>0</td>
<td>0.564</td>
<td>0.682</td>
<td>0.605</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>0.9</td>
<td>0</td>
<td>0.926</td>
<td>0.946</td>
<td>0.489</td>
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<tr>
<td>4</td>
<td>0</td>
<td>0.05</td>
<td>1</td>
<td>0.117</td>
<td>0.084</td>
<td>0.900</td>
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<tr>
<td>5</td>
<td>0</td>
<td>1</td>
<td>0.292</td>
<td>0.578</td>
<td>0.692</td>
<td>0.201</td>
</tr>
<tr>
<td>6</td>
<td>0</td>
<td>1</td>
<td>0.292</td>
<td>1</td>
<td>1</td>
<td>0</td>
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</table>
Table 5.3 Deviational Sequence

<table>
<thead>
<tr>
<th>S no</th>
<th>Vol</th>
<th>Tc</th>
<th>Td</th>
<th>Tcab</th>
<th>QP</th>
<th>COP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0</td>
<td>1</td>
<td>0.083</td>
<td>1</td>
<td>1</td>
<td>0</td>
</tr>
<tr>
<td>2</td>
<td>0</td>
<td>0.1</td>
<td>1</td>
<td>0.318</td>
<td>0.435</td>
<td>0.318</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>0.1</td>
<td>1</td>
<td>0.073</td>
<td>0.073</td>
<td>0.053</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>0.95</td>
<td>0</td>
<td>0.882</td>
<td>0.915</td>
<td>0.915</td>
</tr>
<tr>
<td>5</td>
<td>1</td>
<td>0</td>
<td>0.708</td>
<td>0.421</td>
<td>0.307</td>
<td>0.798</td>
</tr>
<tr>
<td>6</td>
<td>1</td>
<td>0</td>
<td>0.708</td>
<td>0</td>
<td>0</td>
<td>1</td>
</tr>
</tbody>
</table>

Table 5.4 Grey Relational Coefficients

<table>
<thead>
<tr>
<th>S no</th>
<th>Vol</th>
<th>Tc</th>
<th>Td</th>
<th>Tcab</th>
<th>QP</th>
<th>COP</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1</td>
<td>0.333</td>
<td>0.857</td>
<td>0.333</td>
<td>0.333</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
<td>1</td>
<td>0.833</td>
<td>0.333</td>
<td>0.534</td>
<td>0.611</td>
<td>0.558</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>0.833</td>
<td>0.333</td>
<td>0.872</td>
<td>0.904</td>
<td>0.495</td>
</tr>
<tr>
<td>4</td>
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<td>0.345</td>
<td>1</td>
<td>0.361</td>
<td>0.353</td>
<td>0.834</td>
</tr>
<tr>
<td>5</td>
<td>0.33</td>
<td>1</td>
<td>0.413</td>
<td>0.542</td>
<td>0.619</td>
<td>0.385</td>
</tr>
<tr>
<td>6</td>
<td>0.33</td>
<td>1</td>
<td>0.413</td>
<td>1</td>
<td>1</td>
<td>0.333</td>
</tr>
</tbody>
</table>

Table 5.5 Grey Relational Grades

<table>
<thead>
<tr>
<th>GRG</th>
<th>RANK</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.642857</td>
<td>4</td>
</tr>
<tr>
<td>0.645137</td>
<td>3</td>
</tr>
<tr>
<td>0.739661</td>
<td>1</td>
</tr>
<tr>
<td>0.537891</td>
<td>6</td>
</tr>
<tr>
<td>0.548988</td>
<td>5</td>
</tr>
<tr>
<td>0.680077</td>
<td>2</td>
</tr>
</tbody>
</table>

5.3 Optimum Solution Obtained By GRA:

Therefore from the GRA method, the optimum results are obtained in 16L cabin using organic PCM Glycerin.

- Time taken to cool the cabin = 300 min
- Time taken for discharging the temperature of the cabin = 700 min
- Temperature of the cabin obtained = 6.5 degrees
- Volume of the cabin = 16 L
- COP of the model = 0.483
- Passive heat load through the cabin = 5.69 W

6. CONCLUSION

From the results the following conclusions are drawn:

- GRA is able to select the optimum combination of parameters.
- The system has the advantage of utilising the renewable energy i.e., solar power and the cooling inside the cabin will retain for more time with the help of PCM which made the system energy efficient
- In the present work, the cooling effect is produced in the cabin of thermoelectric device with and without the application of PCM.
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