Using the Analytic Hierarchy Process (AHP) method for selection of phase change materials for solar energy storage applications

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Abstract. Selection of a suitable phase change material (PCM) for thermal energy storage systems is important. There are an enormous number of available PCM and hence choosing a particular PCM for a certain application is difficult. Many researchers rely on their expertise or the material available to use PCM for a specific application. The purpose of the selection of a certain PCM is to choose the best material from the commercially available PCM for a given application. An effective evaluation approach is essential to enhance the quality of the decisions. The issue of choosing a material for different applications can be managed as a multi-criteria decision-making issue. In this paper, the Analytic Hierarchy Process (AHP) method is used to select between five PCM for solar heating systems considering both the technical specification and the criteria of the materials. The selected materials have a melting temperature in the required working temperature range. Seven criteria are used in this study and these include the latent heat of fusion, thermal conductivity of the material, specific heat, density, thermal stability, cost, and corrosion. The results show that the paraffin is the best material from the selected PCM using the AHP method for this solar heating system using all known thermo-physical properties and the weights of these criteria to achieve the objective.

1. Introduction

The use of Phase Change Materials (PCMs) for thermal energy storage is regarded as hopeful technology. Thermal energy storage can be divided into three types: sensible heat, latent heat and chemical storage system. Such materials are classified into organic, inorganic and eutectic materials. The melting temperature, high heat latent fusion, high thermal conductivity, high density, thermal stability, cost and compatibility with the container of phase change materials (resistant corrosion) are the key principles which control the choice of phase change materials. It is important to study the ability of the material to resist the corrosion when using it for thermal storage systems [1–5]. The effect of thermal cycling on various PCM has been studied in details [1,6–12]. Some PCMs have good thermal stability and can be used for solar thermal energy storage applications such as paraffin wax and fatty acids [1,6–9].

Few researchers who work in thermal energy storage systems used the Analytic Hierarchy Process (AHP) procedure for choice phase change material. Socaciu Lavinia et al. [13] used AHP procedure for rating ten commercial PCMs, taking into account the materials’ technical specification. With these PCMs, the most relevant parameters (thermophysical properties) are weighed as 36.34% for the thermal conductivity and latent fusion heat, 13.25% for the phase change temperature and 6.91% for...
the specific heat capacity. Based on their analysis for this particular application using AHP process taking into account all the thermophysical properties known and the weights of those parameters to achieve the target (select the appropriate PCMs which can be used to preserve the thermal comfort of the occupants of the vehicle), they found that the best material is PCM 7 (SavEnrg PCM-Hs01P).

The AHP has been used to evaluate and identify the appropriate PCMs in residences for comfort application [14]. The temperature of the phase change for PCMs which is used in this system are between 22 and 28°C. Throughout this analysis five criteria were used: phase change temperature, latent heat capacity, solid-phase density, specific heat capacity and material thermal conductivity. Based on certain criteria, there is a range of PCMs that can be used for comfort use.

The purpose of this research paper is to select the appropriate PCM with the AHP method for solar thermal energy storage applications. Using the AHP method is a new technique in this field. This research paper is restricted to deciding the weight of five PCMs, taking into account only the PCM’s technical requirements and criteria.

2. Materials and Analytic Hierarchy Process (AHP) method

In this analysis, the AHP approach has been used to evaluate five selected PCMs for solar thermal energy storage applications. Table 1 shows the thermophysical properties of the selected PCMs.

Analytic Hierarchy Process (AHP) is a basic approach to decision making. It is a method to solve complex problems involving multiple criteria developed by Saaty [15]. Determining the relative value of a set of criteria in a Multiple Attribute Decision Making (MADM) problem is useful. Instead of decision making, AHP offers a result, which is the best suitable answer for the studied problem [16]. The complete procedure of AHP method [13,14,16] is as follows:

**Step 1**: Define the objectives.

The objective of this study is the selection of the best PCM used for solar thermal energy storage application.

**Step 2**: Identify the principles criteria

The thermophysical properties of PCMs represent the criteria’s used for selecting the optimal material. The criteria used in this study are the latent heat of fusion (LH), thermal conductivity of the material (K), specific heat (CP), density (D), thermal stability (ST), cost (CO), and corrosion (COR.).

**Step 3**: Select the alternatives

The five commercial PCMs represent the selected alternatives. The selected PCMs have a melting temperature in the required working temperature range. The alternatives are the Paraffin (P), Lauric acid (LA), Myristic acid (MA), Palmitic acid (PA), and Stearic acid (SA).

| Table 1. The thermophysical properties of the selected PCMs. |
|-------------------------------------------------------------|
| Melting temperature (°C) | Latent heat of fusion (kJ/kg) | Thermal conductivity(K) W/m K | Specific heat (CP) (kJ/kg K) | Density (D) (kg/m³) | Thermal stability(latent heat after 900 cycles) | Average Cost($) /kg | Corrosion Effect | Reference |
|--------------------------|-------------------------------|-------------------------------|-------------------------------|---------------------|---------------------------------------------|-------------------|------------------|-----------|
| Paraffin (P)             | 57.1                          | 220                           | 0.21                          | 2.2-2.8             | more stable (224)                          | 1.9               | no               | [6, 17, 18] |
| Lauric acid (LA)         | 42.6                          | 211.6                         | 0.16                          | 1.7-2.3             | less stable(132.8)                         | 4.5               | mi               | [9, 19]   |
| Myristic acid (MA)       | 53.8                          | 192                           | 0.17                          | 1.7-2.4             | stable(159.1)                               | 5                 | mi               | [9, 17, 18] |
| Palmitic acid (PA)       | 60.9                          | 197.9                         | 0.159                         | 1.9-2.8             | stable(162.9)                               | 1.6               | mi               | [9, 19]   |

Based on their analysis for this particular application using AHP process taking into account all the thermophysical properties known and the weights of those parameters to achieve the target (select the appropriate PCMs which can be used to preserve the thermal comfort of the occupants of the vehicle), they found that the best material is PCM 7 (SavEnrg PCM-Hs01P).

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ic acid (PA)

Seric acid (SA)

|          | dly | 17, 18 |
|----------|-----|--------|
| Stearin  | 53.8| 174.6  |
|          | 0.172| 1.6-2.2 |
|          | 965 | Less stable (118.9) |

Step 4: The objectives, criteria and alternatives are organized in a hierarchical structure.

A hierarchy tree has at least three levels: the goal of the problem at the top, several criteria identifying alternatives in the middle, and alternatives of the decision at the bottom. The hierarchical tree for selecting the appropriate PCM used for solar thermal energy storage applications is shown in figure 1.

![Hierarchical Tree for PCM Selection](image)

**Figure 1.** The hierarchical tree for identifying the suitable PCM used for applications for solar thermal energy storage.

Step 5: Create a matrix for a pair-wise comparison, using a relative significance scale. Every matrix variable is based on a nine-point scale of Saaty as shown in table 2. Let \( C = \{ C_{ij} = 1, 2, \ldots, n \} \) be the set of criteria. The outcome of the pair-wise comparison on \( n \) criteria is outlined in an \((n \times n)\) assessment matrix \( A \). Each component \( a_{ij} \) \((i, j = 1, 2, \ldots, n)\) indicates the comparative significant of criterion \( i \) with regard to criterion \( j \). A criterion compared with itself is continuously assigned the esteem 1 so the major diagonal inputs of the pair-wise comparison network are all 1.

\[
A = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix} \quad a_{ji} = \frac{1}{a_{ij}} \cdot a_{ij} \neq 0
\]  

(1)

| Description (i over j) | Relative importance \((a_{ij})\) |
|------------------------|-------------------------------|
| Equal importance       | 1                             |
| Moderate importance    | 3                             |
| Strong importance      | 5                             |
| Very strong importance | 7                             |

Table 2. Relative importance of factors [20].
Absolute importance 9
Intermediate values 2,4,6,8

Step 6: Calculating the geometric mean of i row and normalizing the geometric means of rows in the comparison matrix to obtain the relative normalized weight (Wi) of each criterion:

$$\text{GM}_i = \left\{ a_{i1} \times a_{i2} \times a_{i3} \times \cdots \times a_{ij} \right\}^{\frac{1}{n}} \quad (2)$$

$$w_i = \frac{\text{GM}_i}{\sum_{j=1}^{n} \text{GM}_j} \quad (3)$$

Step 7: Obtain matrix X that denotes an n-column vector representing the sum of the weighted values for the degrees of significance of alternatives

$$X = A \times W = \begin{bmatrix} 1 & a_{12} & \cdots & a_{1n} \\ a_{21} & 1 & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & 1 \end{bmatrix} \begin{bmatrix} w_1 \\ w_2 \\ \vdots \\ w_n \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \\ \vdots \\ c_n \end{bmatrix} \quad (4)$$

Step 8: Calculate the consistency value:

$$CV_i = \frac{c_i}{w_i} \quad (5)$$

Step 9: Calculate the average consistency values which represent the highest eigenvalue \( \lambda_{\text{max}} \).

$$\lambda_{\text{max}} = \frac{\sum_{i=1}^{n} CV_i}{n} \quad (6)$$

Step 10: Calculate the consistency index

$$CI = \frac{\lambda_{\text{max}} - n}{n - 1} \quad (7)$$

It ought to be noted that the quality of the solution of the AHP is entirely related to the consistency of the pair-wise comparison judgments.

Step 11: A random index (RI) of the number of parameters used in the decision-making process can be found in Table 3.

Table 3. Average Random index (RI) values [20].

| Criteria | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  |
|----------|-----|-----|-----|-----|-----|-----|-----|-----|
| RI       | 0.52| 0.89| 1.11| 1.25| 1.35| 1.4 | 1.45| 1.49|

Step 12: Calculate the consistency ratio

$$CR = \frac{CI}{RI} \quad (8)$$

The number 0.1 is the agreeable number upper restrict for CR is 0.1 [14,16]. In the event that the ultimate consistency proportion surpasses this value, the evaluation method has got to be iterated to make efficient consistency. The measurement of consistency can be used to evaluate the consistency of decision-makers as well as the consistency of the overall hierarchy.
Step 13: The general performance of output of each alternative in terms of the criteria and objective of the choice is obtained as:

\[ P_k = \sum_{i=1}^{n} w_i \cdot \sum_{j=1}^{m} w_j \cdot P_{ik} \quad i=1, \ldots, n, \quad j=1, \ldots, m \]  

(9)

Where \( w_i \) (i=1,...n) are the weights of criteria, \( w_j \) (j=1,...m) are the weights of alternatives with respect to criterion \( i \). The appropriate material will be the one with the greatest in general weight with regard to the decision objective.

3. Results and discussions

The goal is to identify the best choice of PCM to be used to store large amounts of heat in solar water heating systems. The five selected of PCMs for the above system having melting point 40–60 °C and undergo about 900 thermal cycles. It is significant to study the influence of thermal cycling on the melting temperature, latent heat of fusion due to its effect on thermal energy storage system efficiency. Therefore, the five PCMs were chosen due to having good thermal stability. After forming the decision hierarchy for the issue, the weights of the criteria to be utilized in assessment prepare are calculated by utilizing AHP procedure. In this stage, an individual matrix for pair-wise comparison is constructed using the scale given in Table 2. The decision makers use the following assignments for PCM selection:

The decision matrix for the criteria used in this study.

In PCM selection, latent heat (LH) is considered much more significant than thermal conductivity (K). Therefore LH is given a relative importance value of 5 over K (i.e., \( a_{12} = 5 \)) and K over LH is given a relative importance rating of 1/5 (i.e., \( a_{21} = 1/5 \)). Similarly, LH is seen as more significant than specific heat (CP). So LH is given a relative importance value of 7 over CP (i.e., \( a_{14} = 7 \)) and CP over LH a relative importance value of 1/7 (i.e., \( a_{41} = 1/7 \)). So also, the relative significance among other criteria can be clarified. In any case, it may be concluded that, in effective practice, these values of relative significance can be reasonably chosen by the user/experts depending on the necessities.

The decision matrix of five alternatives respecting the criteria used in this study is:

1. The criteria of Latent heat (LH)

|   | P | LA | MA | PA | SA |
|---|---|----|----|----|----|
| LH | 1 | 3  | 3  | 3  | 5  |
|    | 1/3 | 1  | 3  | 3  | 5  |
|    | 1/3 | 1/3 | 1 | 1/3 | 3 |
|    | 1/3 | 1/3 | 3 | 1  | 3  |
|    | 1/5 | 1/5 | 1/3 | 1/3 | 1  |

2. The criteria of thermal conductivity (K)

|   | P | LA | MA | PA | SA |
|---|---|----|----|----|----|
| K | 1 | 3  | 3  | 3  | 3  |
|   | 1/3 | 1  | 1/3 | 1 | 1/3 |
|   | 1/3 | 3  | 1  | 3  | 1  |
|   | 1/3 | 1/3 | 1 | 1/3 | 1  |
|   | 1/3 | 3  | 1  | 3  | 1  |
3. The criteria of density (D)

\[
P = \begin{bmatrix}
    P & LA & MA & PA & SA \\
    1 & 1/3 & 3 & 1/3 & 1/3 \\
    1/3 & 1 & 5 & 3 & 3 \\
    3 & 1/3 & 3 & 1 & 3 \\
    3 & 1/3 & 3 & 1/3 & 1 \\
\end{bmatrix}
\]

5. The criteria of thermal stability (ST)

\[
P = \begin{bmatrix}
    P & LA & MA & PA & SA \\
    1 & 7/15 & 5 & 5 & 7 \\
    1 & 1/5 & 1/5 & 1/5 & 1/3 \\
    1/5 & 5 & 1 & 3 & 5 \\
    1/5 & 1/3 & 1 & 3 & 5 \\
    1/7 & 3 & 1/5 & 1/3 & 1 \\
\end{bmatrix}
\]

7. The criteria of corrosive (COR.)

\[
P = \begin{bmatrix}
    P & LA & MA & PA & SA \\
    1 & 3 & 5 & 5 & 3 \\
    1/3 & 1 & 3 & 3 & 1 \\
    1/3 & 1/3 & 1 & 3 & 1/3 \\
    1/5 & 1/3 & 1 & 1 & 1/3 \\
    1/3 & 1 & 3 & 3 & 1 \\
\end{bmatrix}
\]

4. The criteria of specific heat (CP)

\[
P = \begin{bmatrix}
    P & LA & MA & PA & SA \\
    1 & 5 & 5 & 3 & 5 \\
    1/5 & 1 & 1 & 1/3 & 1 \\
    1/5 & 1 & 1 & 1 & 3 \\
    1/3 & 3 & 3 & 1 & 3 \\
    1/3 & 1 & 1 & 1/3 & 1 \\
\end{bmatrix}
\]

6. The criteria of thermal stability (CO)

\[
P = \begin{bmatrix}
    P & LA & MA & PA & SA \\
    1 & 5 & 5 & 1 & 5 \\
    1/5 & 1 & 1 & 1/5 & 1/3 \\
    1/5 & 1 & 1 & 1/5 & 1/3 \\
    1/5 & 3 & 3 & 1/3 & 1 \\
\end{bmatrix}
\]

Results obtained from a matrix of pair-wise comparison are given in table 4 and 5. In Figure 2 the local weights gotten by utilizing each criterion of the case study are outlined. Figures 3-9 show weights obtained of alternatives respecting each criterion. Table 6 presents the final results of weights and ranking of the alternatives obtained from AHP method with each criterion.

Table 4 shows the results obtained from the pair-wise comparison matrix of criteria used in this study. The pair-wise comparison matrix consistency ratio is estimated as 0.07799 which is far less than the allowed CR value of 0.1. Consequently, the weights are appropriate and used in the selection process. Figure 2 shows that the weights for the criteria of latent heat of fusion (LH) is about 40.16% and is considered the most important. In addition, the thermal stability (ST) is about 24.17% and is considered the second most important. The weights for the criteria of thermal conductivity (K) and density (D) are the same 11.56% and considered less significant. Criteria of corrosion and cost are regarded as the least significant.

**Table 4. Results obtained from the pair-wise comparison matrix of criteria used in this study.**

| Criteria                  | Geometric mean(GM) | Weights (W) | Matrix X=A.W | Consistency value (CV) | Maximum eigenvalue (λmax) | Consistency index (CI) | Consistency ratio (CR) |
|---------------------------|--------------------|-------------|--------------|------------------------|---------------------------|------------------------|------------------------|
| Latent heat (LH)          | 4.066              | 0.402       | 3.082        | 7.67                   |                           |                        |                        |
| Thermal conductivity (K)  | 1.17               | 0.115       | 0.847        | 7.33                   |                           |                        |                        |
| Density (D)               | 1.17               | 0.115       | 0.847        | 7.33                   |                           |                        |                        |
Specific heat (CP)  |  0.514  |  0.051  |  0.387  |  7.62  |  7.63  |  0.10529  |  0.07799
Thermal stability (ST) |  2.448  |  0.242  |  1.767  |  7.31  |
Cost (CO) |  0.358  |  0.035  |  0.268  |  7.58  |
Corrosion (COR.) |  0.398  |  0.039  |  0.337  |  8.56  |

Figure 2. Weights of the criteria obtained from AHP method.

Table 5 indicates the results obtained from pair-wise comparison matrix of alternatives considering all criteria. The pair-wise comparison matrix consistency ratio is estimated as 0.07985, 0.09412, 0.0877, 0.0094, 0.08374, 0.03076, and 0.09361 for criteria of latent heat (LH), Thermal conductivity (K), Density (D), Specific heat (CP), Thermal stability (ST), Cost (CO), and Corrosion (COR.) respectively, which are far less than the allowed CR value of 0.1. Therefore the weights are appropriate and used in the selection process.

Table 5. Results obtained from pair-wise comparison matrix of alternatives considering all criteria.

| Alternatives with criteria | The maximum eigenvalue (λmax) | The consistency index (CI) | The consistency ratio (CR) |
|----------------------------|-------------------------------|---------------------------|---------------------------|
| Alternatives with (LH))   | 5.35                          | 0.08864                   | 0.07985                   |
| Alternatives with (K)     | 5.20                          | 0.04894                   | 0.09412                   |
| Alternatives with (D)     | 5.39                          | 0.0974                    | 0.0877                    |
| Alternatives with (CP)    | 5.04                          | 0.01043                   | 0.0094                    |
| Alternatives with (ST)    | 5.45                          | 0.11306                   | 0.08374                   |
| Alternatives with (CO)    | 5.14                          | 0.03415                   | 0.03076                   |
| Alternatives with (COR)   | 5.42                          | 0.10390                   | 0.09361                   |

Figure 3 indicates the weights of the alternatives obtained from AHP method respecting criteria of latent heat (LH). It is noted that the most suitable material for criteria of latent heat (LH) is paraffin (P) with a weight of 41.88% and the next materials are lauric acid (LA) and palmitic acid (PA) with a weight of 26.99% and 15.7%, respectively. The least weights of materials are myristic acid (MA) and stearic acid (SA) with a weight of 10.12% and 5.31%, respectively.
Figure 3. Weights of the alternatives obtained from AHP method respecting criteria of latent heat (LH).

Figure 4 indicates the weights of the alternatives obtained from AHP method respecting criteria of thermal conductivity (K). It is shown that the most proper material for criteria of thermal conductivity (K) is paraffin (P) with a weight of 40.58% and the next materials are myristic acid (MA) and stearic acid (SA) with a weight of 20.99% and at two times less compared to alternative ranking on first place. The least weights of materials are lauric acid (LA) and palmitic acid (PA) with a weight of 8.72%.

Figure 5 indicates the weights of the alternatives obtained from AHP method respecting criteria of density (D). It is shown that the most proper material for criteria of density (D) is lauric acid (LA) with a weight of 42.76%, the next materials which can be used are palmitic acid (PA) and stearic acid (SA) with a weight of 24.88% and 16.03%, respectively. The least weights of materials are paraffin (P) and myristic acid (MA) with a weight of 10.33% and 6.01%, respectively, and at four and seven times less compared to alternatives ranking on first place.
Figure 5. Weights of the alternatives obtained from AHP method respecting criteria of density (D).

Figure 6 indicates the weights of the alternatives obtained from AHP method respecting criteria of specific heat (CP). It is found that the most suitable material for criteria of specific heat (CP) is paraffin (P) with a weight of 49.81% and the next material is palmitic acid (PA) with a weight of 23.62%. The least weights of materials are lauric acid (LA), myristic acid (MA) and stearic acid (SA) with a weight of 8.86% and at about five times less compared to paraffin(P) ranking on first place.

Figure 7 indicates the weights of the alternatives obtained from AHP method respecting criteria of thermal stability (ST). It is noted that the most proper material for criteria of thermal stability (ST) is paraffin(P) with a weight of 54.26%. The next materials which can be used are myristic acid (MA) and palmitic acid (PA) with a weight of 22.49% and 13.09%, respectively. The least weights of materials are stearic acid (SA) and lauric acid (LA) with a weight of 6.43% and 3.74%, respectively.
Figure 7. Weights of the alternatives obtained from AHP method respecting criteria of thermal stability (ST).

Figure 8 indicates the weights of the alternatives obtained from AHP method respecting criteria of cost (CO). It is noted that the most suitable materials for criteria of cost (CO) are paraffin (P) and palmitic acid (PA) with a weight of 38.94% and 35.16%, respectively. The next material which can be used is stearic acid (SA) with a weight of 13.39%. The least weights of materials are lauric acid (LA) and myristic acid (MA) with a weight of 6.25%.

Figure 9 indicates the weights of the alternatives obtained from AHP method respecting criteria of corrosion (COR.). It is noted that the most proper material for criteria of corrosion (COR.) is paraffin (P) with a weight of 45.49%. The next materials which can be used are stearic acid (SA) and lauric acid (LA) with a weight of 19.18% and at two times less compared to paraffin (P) ranking on first place. The least weights of materials are myristic acid (MA) and palmitic acid (PA) with a weight of 8.96% and 7.19%, respectively.
Figure 9. Weights of the alternatives obtained from AHP method with criteria of corrosion (COR).

Table 6 and Figure 10 indicate the final results of weights and ranking of the alternatives obtained from AHP method with each criterion. It is found that the best proper phase change material obtained from AHP method which can be used for solar water heating applications taking into account all the criteria analyzed is paraffin (P) with an overall weight of 41.52%. The next alternatives materials which can be used are lauric acid (LA) and palmitic acid (PA) with an overall weight of 19.12% and 16.08%, respectively.

Table 6. Final results of weights and ranking of the alternatives obtained from AHP method with each criterion.

| Alternative / Criteria | LH  | K    | D    | CP   | ST   | CO   | COR. | Global weight | Ranking |
|------------------------|-----|------|------|------|------|------|------|---------------|---------|
| weight                 | 0.402 | 0.116 | 0.116 | 0.051 | 0.242 | 0.035 | 0.039 |               |         |
| Paraffin (P)           | 0.419 | 0.406 | 0.103 | 0.498 | 0.543 | 0.389 | 0.455 | 0.4152        | 1       |
| Lauric acid (LA)       | 0.27  | 0.087 | 0.428 | 0.089 | 0.037 | 0.063 | 0.192 | 0.1912        | 2       |
| Myristic acid (MA)     | 0.101 | 0.21  | 0.06  | 0.089 | 0.225 | 0.063 | 0.09  | 0.1364        | 4       |
| Palmitic acid (PA)     | 0.157 | 0.087 | 0.249 | 0.236 | 0.131 | 0.352 | 0.072 | 0.1608        | 3       |
| Stearic acid (SA)      | 0.053 | 0.21  | 0.16  | 0.089 | 0.064 | 0.134 | 0.192 | 0.0965        | 5       |
4. Conclusions
The use of phase change materials is considered a promising technology for thermal energy storage. The choice of the phase change material is difficult due to the large number of available Phase Change Materials (PCMs). The proper selection of the phase change material leads to efficient utilization of latent heat thermal energy storage system. The availability of PCM and experience of the researchers play an important role in the selection of PCM for a specific application. However, several alternatives must be considered and evaluated in terms of many different conflicting criteria in a PCM selection problem. Hence, an influential assessment approach is preferred to make decision quality. The Analytic Hierarchy Process (AHP) method was used for the selecting of the most appropriate PCM out of the five selected PCMs for solar heating systems with taking the technical specification and criteria of the materials. The results showed that the most suitable PCM from AHP method is paraffin (P) with an overall weight of 41.52%. The other suitable alternatives materials which can be used are lauric acid (LA) and palmitic acid (PA) with an overall weight of 19.12% and 16.08%, respectively.

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