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Selection of phase change material based on AHP and TOPSIS method

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ABSTRACT

Selection of PCM plays an important role in storing latent heat in a thermal energy storage system. PCM can be selected by different methods such as; AHP (Analytical Hierarchy Process), ENTROPY, FUZZY TOPSIS METHODS. This paper contains AHP and TOPSIS method calculation. AHP method is used to determine weight criteria while TOPSIS is used for obtaining the rank of criteria. A drawback to select an appropriate PCM used in domestic water heater system using Triplex Tube Heat Exchanger (TTHX) is coping up by desired methods. PCM liquidification and solidification under different mass flow rates are investigated. Internal and external fins are used to improve the heat transfer rate during charging and discharging of PCM.

Keywords— *AHP, TOPSIS, RTD, PCM*

1. INTRODUCTION

Phase change materials are based on energy storage materials. A phase change material is a substance with a high heat of fusion with melting and solidifying at a certain temperature, capable of storing and releasing a large amount of energy. Heat is absorbed or released when the material changes from solid to liquid or liquid to solid. The high thermal energy storage can be done in PCM in the form of latent heat. There is three types of PCM materials; Organic, Inorganic and Hygroscopic materials. As no single material can have all the required properties for an ideal thermal storage media one has to select such PCM which will give the desired thermal performance at a low cost. The various methods of using the PCM materials like Multiple Attribute Decision Making (MADAM) method, AHP method, TOPSIS method. The basically AHP and TOPSIS are most important to select the PCM material. The AHP method is developed by Prof. Thomas L. saaty. The AHP method is basically used to solve the complex problems involving multiple criteria. An Analytical Hierarchy Process (AHP) was used to determine the local weights of the criteria. The TOPSIS method was used to determine the rank of Phase Change material. The AHP and TOPSIS method is used to select the PCM material for latent heat storage. The TOPSIS / FUZZY TOPSIS is used to obtain the performance ranking of the feasible alternatives.

Table 1: Summary of Performance Rating

Parameters	LH	D	Cp(s)	Cp(l)	K
Calcium Chloride hexa hydrate	169.8	1560	1.46	2.13	1.03
Stearic acid	186.5	903	2.83	2.38	0.18
Paraffin Wax RT 30	206	789	1.8	2.4	0.18
n-Nonadecane	222	775.8	1.7189	1.921	0.142
n-Eicosane	247	776.33	0.7467	2.377	0.13836

1.1 Analytic Hierarchy Process (AHP)

The complete procedure of AHP method is as follows:

(a) Construct a pair-wise comparison matrix using a scale of relative importance. Let C = {cj|j = 1, 2 . . . n} be the set of criteria. The result of the pair-wise comparison on n criteria can be summarized in an (n n) evaluation matrix A. The every element aij (i, j = 1, 2 . . . n) denotes the comparative importance of criteria i with respect to criteria j. A criteria compared with itself is always assigned the value 1 so the main diagonal entries of the pair-wise comparison matrix are all 1.

Table 2: Relative Importance of Properties

	LH	D	Cp(s)	Cp(l)	K
LH	1	5	7	7	2
D	1/5	1	5	5	1/7
Cp(s)	1/7	1/5	1	1	1/5
Cp(l)	1/7	1/5	1	1	1/5
K	½	2	5	5	1

$$A = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ a_{21} & 1 & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & 1 \end{bmatrix} \quad a_{ji} = 1/a_{ij}, \; a_{ij} \neq (\qquad (1)$$

(b) Find the relative normalized weight (W_i) of each criteria by calculating the geometric mean of ith row and normalizing the geometric means of rows in the comparison matrix.

$$GM_i = \{a_{i1} \times a_{i2} \times a_{i3} \times \dots \times a_{ij}\}^{1/n}$$

$$W_i = \frac{GM_i}{\sum_{j=1}^{j=n} GM_i} \qquad (2)$$

(c) Obtain matrix X which denote an n-dimensional column vector describing the sum of the weighted values for the importance degrees of alternatives.

$$W = [W_1, W_2, W_3, \dots, W_n]^T$$

$$X = A * W = \begin{bmatrix} 1 & a_{12} & \dots & a_{1n} \\ a_{21} & 1 & \dots & a_{2n} \\ \dots & \dots & \dots & \dots \\ a_{n1} & a_{n2} & \dots & 1 \end{bmatrix} \begin{bmatrix} W_1 \\ W_2 \\ \dots \\ W_n \end{bmatrix} = \begin{bmatrix} c_1 \\ c_2 \\ \dots \\ c_n \end{bmatrix} \qquad (3)$$

(d) Calculate the consistency values (CV) for the cluster of alternatives represented by the vector.

$$CV_i = \frac{c_i}{W_i} \qquad (4)$$

(e) Find out the maximum Eigen value λmax that is the average of the consistency values.

(f) Calculate the consistency index. It should be noted that the quality of the output of the AHP is strictly related to the consistency of the pair-wise comparison judgments.

$$(CI) = (\lambda_{max} - n)/(n - 1). \qquad (5)$$

(g) Obtain the Random Index (RI) for the number of criteria used in decision making from the table.

Table 3: Random Index (RI) values [21]

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

(h) Calculate the consistency ratio. The number 0.1 is the accepted upper limit for CR. If the final consistency ratio exceeds this value, the evaluation procedure has to be repeated to improve consistency. The measurement of consistency can be used to evaluate the consistency of decision-makers as well as the consistency of overall hierarchy.

$$CR = CI/RI = 0.0411 < 0.1$$

The acceptable value of consistency ratio (CR) is below 0.1 for a reliable result. If this value exceeds 0.1 then to improve consistency, evaluation procedure of the pair-wise comparison matrix has to be repeated. This consistency ratio gives a basis to evaluate the consistency of user as well as the consistency of overall hierarch.

Table 4: Weights of the Criteria obtained from AHP Method

Parameters	GM	W	X	CV
1	3.4518	0.4749	2.5112	5.2879
2	1.2011	0.1653	0.8812	5.3309
3	0.3560	0.0490	0.2513	5.1286
4	0.3560	0.0490	0.2513	5.1286
5	1.9037	0.2619	1.3190	5.0363
TOTAL	7.2686	1.0001	$\frac{A_{veg}}{5}$ =5.1825	25.9123

1.2 Topsis method

(a) Establish a decision matrix for the ranking in which column indicate criteria or attributes ($C_{1,}C_2, C_{3,....}C_n$) while rows list the competing alternatives ($A_1, A_2, A_3, \ldots A_n$).

$$A = \begin{bmatrix} 1 & a_{12} & \ldots & a_{1n} \\ a_{21} & 1 & \ldots & a_{2n} \\ \ldots & \ldots & \ldots & \ldots \\ a_{n1} & a_{n2} & \ldots & 1 \end{bmatrix} \quad a_{ji} = 1/a_{ij}, \quad a_{ij} \neq (\tag{6}$$

An element X_{ij} of the performance rating of the itch alternative, A_{ij}
With respective to the jth criteria C_j, as Eq. (6).

(b) Calculate the normalized rating for each element in the decision matrix. The normalized value r_{ji} of X_{ij} is calculated as defined in Eq. (7).

$$r_{ij} = \frac{x_{ij}}{\sqrt{\sum_{i=1}^{i=m} x_{ij}^2}} \text{ , i=1, 2…m; j=1, 2, 3…n} \tag{7}$$

Table 5: Normalized decision matrix for TOPSIS analysis

Material	LH	D	CP(l)	CP(s)	K
Calcium Chloride hex hydrate	0.3650	0.6924	0.4234	0.3552	09589
Stearic acid	0.4009	0.4008	0.47732	0.6886	0.1585
Paraffin Wax RT 30	0.4429	0.3502	0.4771	0.4380	0.1585
PCM4 n-Nonadecane	0.4773	0.3443	0.3819	0.4182	0.125
n-Eicosane	0.5311	0.3446	0.4726	0.1817	0.1218
A*(best)	0.5311	0.6924	0.4771	0.6889	0.9589
A'(worst)	0.3650	0.3443	0.3815	0.1817	0.1218

(c) Calculate the weighted normalized value v_{ij} by multiplying the normalized decision matrix by its associated weights which are obtained by the AHP method.

$$\mathrm{v_{ij} = w_j r_{ij}} \tag{8}$$

Table 6: Weighted Normalised values

0.1733	0.1144	0.2070	0.1740	0.2511
0.1903	0.2775	0.0231	0.03744	0.0415
0.2103	0.05788	0.0133	0.0446	0.0415
0.2266	0.05691	0.0187	0.02049	0.03273
0.2522	0.05696	0.02315	0.0089	0.03189

(d) Determine the positive ideal (v^+) and negative ideal solution (v^-).The ideal and negative ideal solutions can be expressed as

$$v^+ = \{(\sum_i^{max} {}^{v_{ij}}/_{j \in J}), (\sum_i^{min} {}^{v_{ij}}/_{j \in J'}) / \text{ i =1, 2 ...m}$$

$$= \{v_1^+, v_2^+, v_3^+, \ldots . v_n^+\} \tag{9}$$

$$v^- = \{(\sum_i^{min} {}^{v_{ij}}/_{j \in J}), (\sum_i^{max} {}^{v_{ij}}/_{j \in J'}) / \text{ i =1, 2,….m} \quad \}$$

$$8\backslash. \quad = \{v_1^-, v_2^-, v_3^-, \ldots . v_n^-\} \tag{10}$$

Where J= (j=1, 2…., n)/j is set of beneficial criteria (large –the-better type) and J'= (1, 2,…..n)/j is set of non-beneficial criteria (small-the –better type).

(e) Obtain separation measures. The separation (distance) between alternatives can be measured by the n-dimensional Euclidean distance. The separation of each alternative form the positive –ideal solution given as

$$S_i^+ = \sqrt{\sum_{j=i}^{n} v_{ij} - v_j^{+2}} \quad \text{i= 1, 2……, m} \tag{11}$$

Table 7: Result of Separation Measures

Material	S*1	S*2	S*3	S*4	S*5	Total S*
Calcium Chloride hexa hydrate	0.006196	0	0.000006	0.1274	0	0.5553
Stearic acid	0.0038	0.0266	0.0000000002	0	0.0439	0.2725
Paraffin Wax RT 30	0.0017	0.00291	0.0000000002	0.1246	0.0439	0.4162
n-Nonadecane	0.00065	0.0033	0.00019	0.1252	0.4763	0.4207
n-Eicosane	0	0.00329	0	0.1335	0.04805	0.4299

Similarly, the separation form the negative ideal solution is as follows:

$$S_i^- = \sqrt{\sum_{j=i}^{n} v_{ij} - v_j^{-2}} \qquad i= 1, 2……, m \qquad (12)$$

Table 8: Results for the separation form of the negative ideal solution

Material	S'1	S'2	S'3	S'4	S'5	Total S'
Calcium Chloride hexa hydrate	0	0.0003	0.000004	0.000072	0.04805	0.2261
Stearic acid	0.00128	0.0486	0.000019	0.00081	0.000092	0.2231
Paraffin Wax RT 30	0.0013	0.0000009	0.000021	0.00015	0.000092	0.03954
n-Nonadecane	0.0028	0	0	0.00013	0.0000007	0.05413
n-Eicosane	0.0062	0.000000002	0.000019	0	0	0.07886

(f) Calculate the relative closeness to the ideal solution. The relative closeness of the alternative A_{ij} can be expressed as;

$$R_i = \frac{S_i^-}{S_i^+ + S_i^-} \qquad (13)$$

(g) Choose an alternative with maximum R_i in descending order.

Table 9: Rank according to consistency index

Material	CI	Rank
Calcium Chloride hexahydrate	0.2893	2
Stearic acid	0.4501	1
Paraffin Wax RT 30	0.0867	5
n-Nonadecane	0.1139	4
n-Eicosane	0.1550	3

2. PROPOSED EXPERIMENTAL SETUP

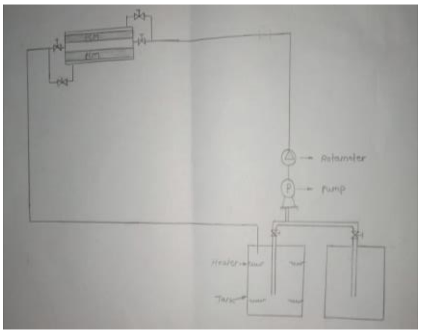

Fig. 1: Schematic diagram of the latent heat storage system using TTHX

The schematic diagram of the latent heat storage system using TTHX is shown in the figure. The test apparatus consists of TTHX, 2 tanks(One for hot water in which heater is used to heat the water and another for cold water), rotameter, electric heater, RTD, power supply arrangements. The TTHX consists of three tubes. The middle tube consists of PCM to absorb and dissipate the heat coming from the outer and inner tube. A thermal energy storage system using triplex tube heat exchanger with internal and external fins is fabricated to investigate heat transfer performance from the use of fins.

3. CONCLUSION

From the calculations of AHP and TOPSIS method, we conclude that material having maximum consistency ratio is selected for required application which is Stearic acid. Also, the material with the highest rank is reliable. Proper selection of Phase Change Material leads to efficient utilization of latent heat thermal energy storage system and the idea of the proposed experimental setup is mentioned in this paper.

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