Optimisation of Parameters in Thermal Energy Storage System by Enhancing Heat Transfer in Phase Change Material

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Abstract. Phase change material (PCM) is used to store the heat in the form of latent heat and sensible heat. Thermal energy storage by latent heat using PCM was recognized as attractive alternative to sensible heat storage, because large quantity of thermal energy is stored in small volume. In the present experimental analysis, Beeswax is used as PCM and it is enclosed in stainless steel capsules. Beeswax exhibits slow thermal response due to low thermal conductivity value, so an effort is made to dope PCM with copper, aluminium and graphite powders separately to enhance its heat transfer. The capsules are stored in insulated tank and hot water is supplied into it. The experimental design is prepared by considering parameters as Heat transfer fluid inlet temperatures, Flow rate and Number of Capsules. Experiments are conducted based on Taguchi analysis and the responses are recorded. The effect of considered parameters on Thermal Energy Storage (TES) system is studied by analyzing experimental data to find the optimal parameters for designing the effective TES system.

Keywords: Phase change material; Taguchi analysis; Thermal Energy Storage system

1. Introduction
In recent years, studies of phase change material have attracted much attention in view of their application in thermal energy storage system such as Green house heating, Building applications, Automobiles, Cooling of electronic devices, Solar power plants [1]. Thermal energy storage framework is the most popular method utilized for storing and releasing thermal energy in the form of sensible heat and latent heat [2-3]. Thermal energy storage in Latent heat form using phase change material is better method because it gives benefits like reduction in temperature variability and high thermal energy storage density [4-5]. Melting and solidifying phase of a phase change material will absorb and release large amount of heat during its phase change because of its low thermal resistance [6].

Various PCM’s are classified mainly based on compositions (like organic PCM’s and inorganic PCM’s) and melting points (like high temperature PCM’s and low temperature PCM’s). The organic PCM’s are normally preferred to use in Latent heat type thermal energy storage system because they
are chemically stable, biodegradable, non-toxic and non-corrosive in nature [7]. Low Thermal Conductivity of PCM reduced the heat transfer performance of charging and discharging cycle during the phase change [8]. Much effort has been devoted to improve the thermal storage performance of PCM by adding different metal powders [9]. Composite PCM’s exhibits larger thermal conductivity and the charging time were decreased with enhanced heat transfer characteristics [10].

The investigation on the parameters optimization in thermal energy storage system is still limited and much experimental work needs to be done in this direction. This report is concerned with the optimization of parameters in thermal energy storage system by enhancing heat transfer in phase change material with metal powders. In the present study, Beeswax is used as PCM and compared its characteristics of heat transfer by doping with various metal powders such as copper (Cu), aluminium (Al) and graphite (GR). The charging and discharging characteristics of composite PCM were studied. The influencing parameters on charging and discharging times are Heat transfer fluid inlet temperatures, Flow rate and Number of Capsules.

2. Experimental Setup

The fig.2.1 given below depicts the experimental setup. The Beeswax with 62°C melting temperature and 141.49 kJ/kg latent heat of fusion is used as phase change material. The heat transfer characteristics of composite beeswax is studied using stainless steel tank of 10 litres capacity, heat source (electric heater), flow meter, composite PCM filled spherical capsules of 55mm diameter and water storage tank. The tanks are insulated with glass wool. The storage tank is evenly packed with composite PCM filled capsules. The water is taken as both HTF and SHS in this experimental setup.

![Figure 2.1. Experimental setup Line diagram](image)

Flow rate of Heat transfer fluid is measured by using flow meter. By using different tap openings flow rate is changed. The digital thermometers of ± 1°C accuracy are incorporated in TES tank to measure HTF and PCM temperatures. By using electric heat source HTF temperatures in storage tank is maintained constant. The properties of Bees wax is given in the table given below.

| PCM                | Melting point Temperature (°C) | Latent heat of fusion (kJ/kg) | Density, ρ (kg/m³) | Specific heat(J/kg°C) |
|--------------------|--------------------------------|-------------------------------|--------------------|-----------------------|
| Bees Wax \(\text{C}_{15}\text{H}_{31}\text{COOC}_{30}\text{H}_{61}\) | 62                             | 141.49                        | 960                | 745                   | 3400  | 2801 |
The influencing factors on thermal energy storage tank considered are HTF inlet temperature, HTF flow rate and number of PCM capsules. The experimental runs are obtained using Taguchi design in Minitab software. The factors and levels considered to create design are given in the table 2.2

| S.No. | Parameters                                | Levels |
|-------|-------------------------------------------|--------|
| 1     | Heat transfer fluid inlet temperature(°C) | L1 65  |
|       |                                           | L2 70  |
|       |                                           | L3 75  |
| 2     | Flow rate(liter/minute)                   | L1 2   |
|       |                                           | L2 3   |
|       |                                           | L3 4   |
| 3     | Number of capsules(No)                    | L1 30  |
|       |                                           | L2 35  |
|       |                                           | L3 40  |

2.1. Charging Process.
In the charging process the heat energy is stored by circulating HTF continuously into the TES tank. Before starting charging process the PCM filled inside the capsules will be at room temperature of 34°C, which is lower than its melting point temperature. The PCM stores energy in the form of sensible heat until it reaches melting point, after that it stores large energy in the form of latent heat in liquid PCM at constant temperature phase change in small volumes. During this process the PCM and HTF temperatures are with every 2 min interval until they become equilibrium with each other. By this process the effect of given parameters on charging time is studied. Mostly less charging time is preferred for best results.

2.2. Discharging Process.
After charging process, the time taken to release the energy is studied by discharging process. Discharging process can be studied by taking out 2 liters of HTF liquid from TES tank for every 20 minutes and adding same quantity of water at room temperature of 34°C into TES tank. This process is continued until PCM temperature reaches room temperature. By this discharging time and quantity of water used to discharge are recorded for the study. High discharge time is preferred for best results. By separately adding copper, aluminum and graphite powders having different thermo physical properties to beeswax its heat transfer characteristics are studied comparatively.

2.3. Results and discussions.
The responses obtained from experimental runs for charging time(CT) in minutes, discharging time(DT) in minutes and discharge water quantity (QW) in litres for three combinations are detailed below in figure 2.3.1.
From the responses of all combinations beeswax and graphite powder combination with high thermal conductivity gave best results than copper and aluminium combinations. So the responses from graphite beeswax combination experimental runs are analyzed and predicted using Taguchi. The following results are obtained using Taguchi analysis. The obtained results are shown in tables 2.3.1 and 2.3.2. In this study response characteristics like signal to noise ratios and the means were selected to find out which factor is statistically determinant. To determine the relative importance of each factor in the model response characteristic coefficients are used. Relative strength of each factor is indicated by absolute value coefficient. If that absolute value coefficient is large then that factor will have large impact on response characteristics. The average of each response characteristics is shown in the response table for each level of each factor. The relative magnitudes of effects are compared using ranks based on delta statistics which is also given the tables. The difference in highest average to the lowest average in the table gives delta statistics. The predicted main effect plots for means and SN ratios are shown in figures 2.3.2 and 2.3.3.

**Table 2.3.1. Response Table for Means**

| Level | HTF TEMPERATURE(°C) | PCM CAPSULES(No) | FLOW RATE(lit/min) |
|-------|---------------------|------------------|--------------------|
| 1     | 137.8               | **153.6**        | 144.2              |
| 2     | 148.7               | 148.4            | 148.9              |
| 3     | **164.4**           | 148.9            | **157.8**          |

Delta 26.7 5.1 13.6

Rank 1 3 2

Optimal stages 3 1 3

**Table 2.3.2. Response Table for Signal/ Noise Ratios**

Nominal is best (10×Log10(Ybar^2/s^2))

| Level | HTF TEMPERATURE(°C) | PCM CAPSULES(No) | FLOW RATE(lit/min) |
|-------|---------------------|------------------|--------------------|
| 1     | -2.365              | -2.597           | -2.506             |
| 2     | -2.593              | **-2.606**       | -2.561             |
| 3     | **-2.810**          | -2.566           | **-2.701**         |

Delta 0.446 0.040 0.195

Rank 1 3 2

Optimal stages 3 2 3
Figure 2.3.2. Means plot

Figure 2.3.3. SN ratios plot
2.3.1. Regression. A statistical technique used to determine relation between two or more variables. The following equations are obtained from Taguchi method using Minitab software.

Regression equations

\[
\text{GR-CT} = 84.67 - 0.8000 \text{HTF TEMPERATURE} + 0.0667 \text{PCM CAPSULES(No)} - 1.667 \text{FLOW RATE(lit/min)}
\]

\[
\text{GR-DT} = -188.9 + 8.000 \text{HTF TEMPERATURE} - 1.333 \text{PCM CAPSULES(No)} + 20.00 \text{FLOW RATE(lit/min)}
\]

\[
\text{GR-QW} = -16.89 + 0.8000 \text{HTF TEMPERATURE} - 0.1333 \text{PCM CAPSULES(No)} + 2.000 \text{FLOW RATE(lit/min)}
\]

3. Conclusion
From the results following conclusion can be drawn:

- The drawback of low thermal conductivity of beeswax is reduced by doping beeswax with metal powders. The graphite / beeswax composite showed better performance like less charging time and high discharging times when compared with copper and aluminium combinations.
- The effect of inlet temperature of heat transfer fluid at 75\(^\circ\)C and flow rate of 4lit/min is more on charging time and discharging time.
- From the result it is concluded that Taguchi design is able to select the optimum parameters and formulate regression equations to find relation between the variables.

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