Scientific Journal of Impact Factor (SJIF): 5.71
e-ISSN (O): 2348-4470
p-ISSN (P): 2348-6406
International Journal of Advance Engineering and Research Development
Volume 5, Issue 09, September -2018

OPTIMIZATION STUDY ON VARIABLE COMPONENTS OF THE THERMAL ENERGY STORAGE SYSTEM

Dr. K. DHARMA REDDY[1], B.HARSHITA[2]

[1] Assistant Professor, Department of Mechanical Engineering, S. V. University, Tirupati-517502
[2]M. Tech (Student), Department of Mechanical Engineering, S. V. University, Tirupati-517502

ABSTRACT:- *A **phase change material** can store large amount of energy in small volumes. This can be employed by using phase change material in small capsules. In the present study, bees wax is used as a phase change material enclosed in stainless steel capsules. These capsules are kept in an insulated tank and hot water is supplied into it. The experimental design is prepared by considering the parameters such as: Inlet temperature of heat transfer fluid, flow rate and number of stainless steel capsules of 55 mm diameter. Experiments are conducted based on **Taguchi analysis** and responses are recorded. The effect of considered parameters on **Thermal Energy Storage** system is studied by analyzing experimental data. The data is also analyzed using **Desirability Function Analysis (DFA)** to obtain the optimal values of inlet temperature of HTF, flow rate and number of capsules. Comparison is made between usage of only organic material as PCM and combination of both organic and metallic materials (copper powder) as PCM.*

KEY WORDS:- *Phase change material, Taguchi analysis, Thermal Energy Storage, Desirability Function Analysis.*

1. INTRODUCTION

Researchers all over the world are in search of new and renewable energy sources to reduce the CO_2 emissions from the combustion of fossil fuels. The developed countries are trying to reduce their dependence on oil imports from other countries by considering renewable sources of energy like solar energy which has an enormous potential for the heating and cooling purposes, producing hot water for domestic and industrial purposes, cooking, warming greenhouses for agricultural crops, etc. As the solar energy, being nonpolluting ,clean and in exhaust able has received wide attention among the scientists and engineers However, solar energy is intermittent, unpredictable, and available only during the day. Hence, its application requires efficient thermal energy storage so that the surplus heat collected during day time may be stored for later usage at night times. Similar situations prevail in industrial heat recovery systems where the waste heat availability and utilization periods do not coincide, leading to the need for energy storage. These among other factors like growing energy costs have necessitated research in the area of thermal energy storage.

1.2 Types of TES systems

1.2.1 Sensible thermal energy storage (STES)

It is known that all substances can store a certain amount of energy in the form of heat. This property exhibited by all materials is called thermal capacity. When a solid is heated, its temperature increases until the melting point is attained, below which, there exists no phase change of the material. The heat responsible for this increase in temperature is called the sensible heat and it is proportional to the difference between the final attained temperature and the initial temperature, the mass of the material, and the heat capacity.

1.3.2. Latent heat storage (LHS)

The heat required to transform a substance from one existing phase to another at constant temperature is called the latent heat. The latent heat is much higher than the sensible heat for a given medium, and it is also suitable for most applications because of its high energy storage density requiring only small temperature variations.

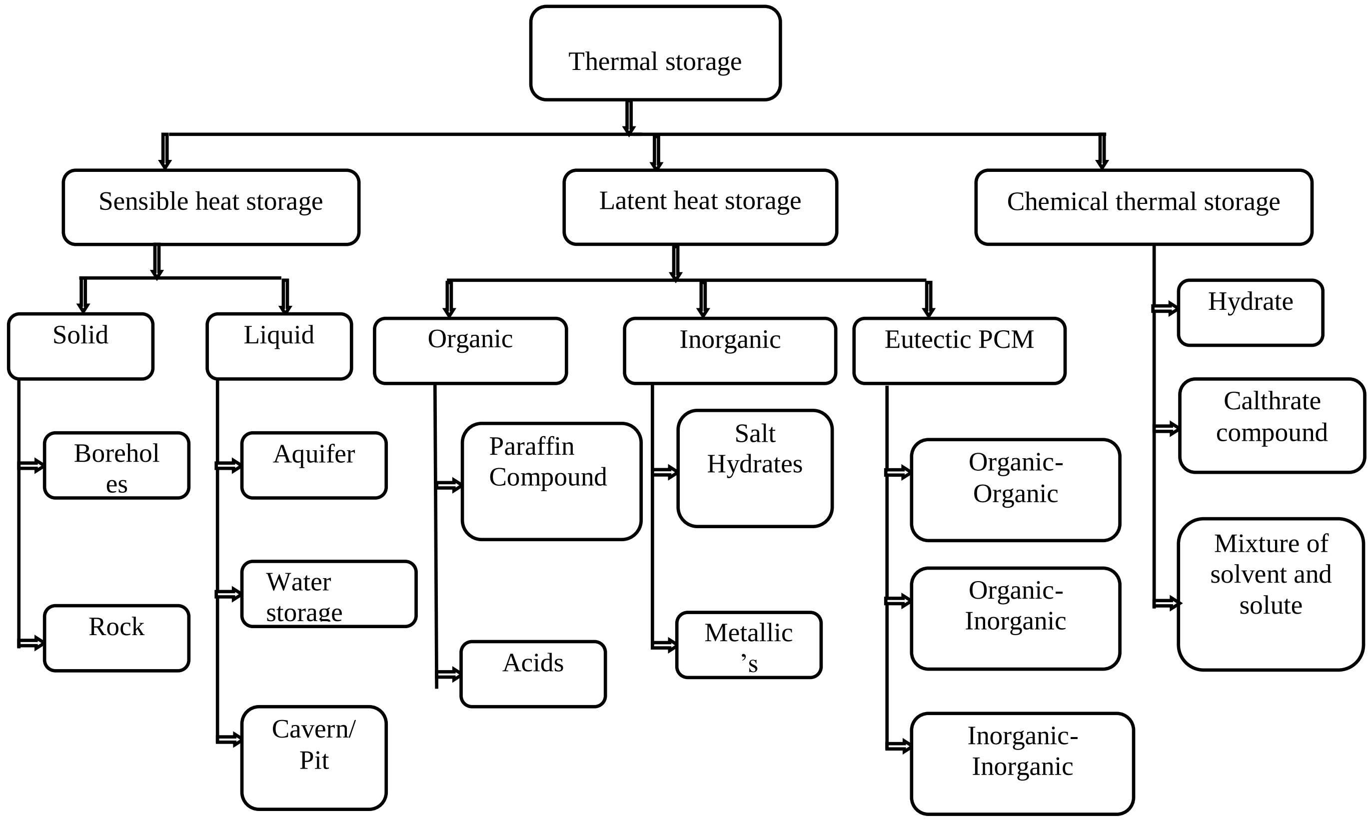

Fig 1 Various types of thermal energy storage techniques

2. LITERATURE REVIEW AND OBJECTIVES

K. Dharmareddy, pathi venkataramaiah and Tupakula Reddy Lokesh[1] et.al used sodium thiosulphatepentahydrate as phase change material to study the performance of combined sensible and latent heat storage system.
K. Dharmareddy, Pathi Venkataramaiah and Poola Praveen kumar[2]- used paraffin wax as a phase change material to study the performance of combined sensible and latent heat storage system. The experimental (Taguchi) design is prepared by considering the parameters: flow rate, heat transfer fluid inlet temperature and PCM capsule shape.
Atul Sharma et al. [3]- made an attempt to investigate and analyze the available thermal energy storage systems incorporating PCMs for use in different applications.
R. Meenakshi Reddy et al.[4]- the thermal energy storage (TES) system using both sensible and latent heat has many advantages like large heat storage capacity in a unit volume and its isothermal behavior exhibited during the charging and discharging processes.
K. Dharma Reddy, Pathi Venkataramaiah and K. Vishnuvardhana[5]- et.al used Sodium acetate trihydrate and Manganese chloride tetrahydrate as PCM to study the performance of sensible heat storage system and used simulated annealing to predict the outcomes.
G. Samba sivareddy, B. Prasad Kumar, P. Venkataramaiah[6]- et.al used optimization of process paramaters in injection moulding of cam bush using DFA and ANOVA.
A. Navaneet Sait, S. Aravindan, A. Noorul Haq[7]-et.al used optimization of machining parameters of GFRP pipes by DFA using Taguchi technique.

The information has been very helpful in finding out the influencing parameters on charging and discharging time of water. The parameters and their levels considered in the study are-

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

Table 1 Influential parameters and their levels

3. EXPERIMENTAL SETUP

A schematic diagram of the experimental set-up is shown in Figures 2 & 3. This consists of an insulated cylindrical TES tank, which contains PCM stored in spherical capsules, flow meter and water storage tank. The stainless steel TES tank has the capacity of 10 liters. The storage tank is insulated with glass wool. The PCM capsules are uniformly packed in the storage tank. Here, water is used as both SHS material and HTF.

A flow meter with an accuracy of ±2% is used to measure the flow rate of HTF and the flow rate of HTF is changed by different tap openings. The TES tank is incorporated with digital thermometers with an accuracy of ± 1 °C are placed in the TES tank to measure the temperatures of HTF and PCM stored inside the capsules. An electric water heater is used a source to maintain the constant temperature in the water storage tank**.** The thermo-physical properties of PCM are given in Table 2.

PCM	Melting Temperature (°C)	Latent heat of fusion (kJ/kg)	Density (kg/m^3)		Specific heat (J/kgK)	
			Solid	Liquid	Solid	Liquid
Bees wax	62	141.49	960	745	3400	2801

Table 2 Thermo Physical Properties of Bees Wax

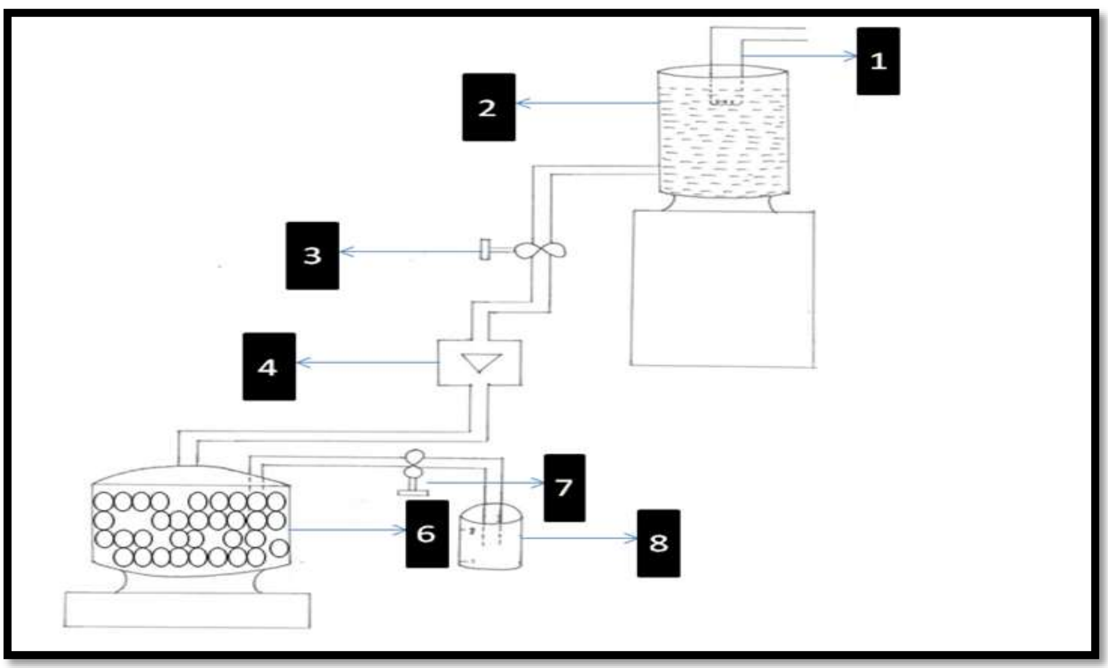

Fig.2 Schematic Diagram of Experimental Setup

1. Electric heater, 2. Constant temperature bath (water storage tank) ,3&7. Flow control valves ,4. Flow meter, 5.PCM capsules, 6. TES Tank, 8.Outlet tank

Fig 3. Experimental setup

3.1. Experimentation

The experiments are carried out on the basis Taguchi design obtained from Minitab software.

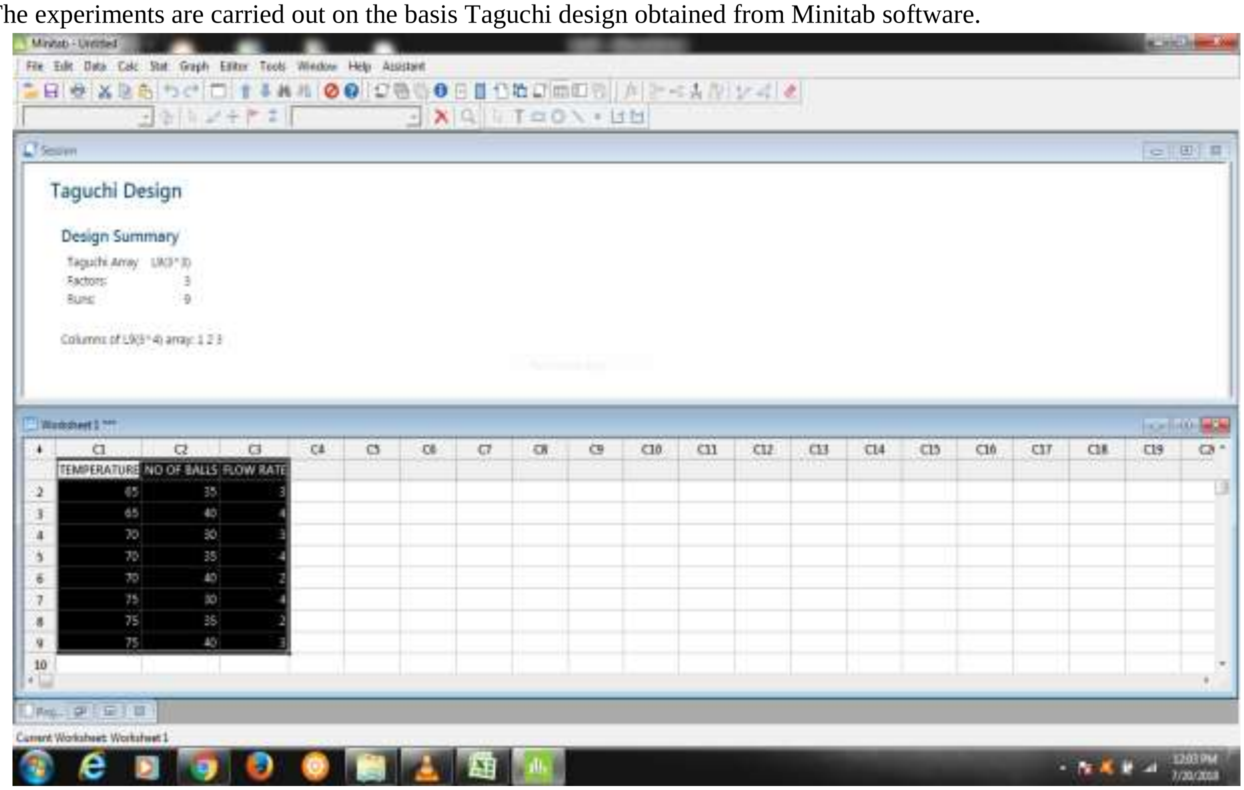

Fig 5. Trail runs based on Taguchi design

3.1.1. Charging Process

The experiments which are obtained by Taguchi method are carried out for charging process. In this process, the TES tank is integrated with constant temperature water storage tank and the HTF inlet temperature (T_{HTF}) is kept at constant temperature for a particular flow rate. The temperature of the water storage tank is continuously monitored from time to time. The key experimental parameters are HTF inlet temperature, flow rate of HTF and number of PCM capsules. Experiments are conducted for different flow rates of HTF, different HTF inlet temperatures and different number of PCM capsule numbers.

As the charging process continues, energy storage increases until it reaches an equilibrium stage. Temperatures of PCM (T_{PCM}) and HTF (T_{HTF}) in the TES tank are recorded at an interval of 2 minutes. The charging process is continued until the temperature of PCM comes in equilibrium with the temperature of HTF in the TES tank.

3.1.2 Discharging Process

After the charging process ends, discharging process initiates. Batch wise discharging experiments are carried out which are detailed below. In this method 2 liters of hot water is discharged from the thermal energy storage (TES) tank and the same quantity of cold water at 30°C is fed into TES tank in each batch. The average temperature of the collected water in the bucket from the discharge process is measured using a digital thermometer. The discharged water is measured for every 20 min to read the temperature. The batch wise withdrawing of hot water is continued till the temperature of the outlet water reaches 30°C.

The variation of HTF and PCM temperature during discharging process (Heat recovery) is measured and noted down. A comparative study is made between bees wax and bees wax with copper powder.

4. TESTS AND RESULTS

The following results are obtained based on the experimental runs from Taguchi design.

Experimental run	HTF inlet temp(T_{HTF})(^oC)	Flow rate(lit/min)	PCM capsules(no.)	Charging time(min)	Discharging time(min)	Quantity of water discharged(lit)
1	65	3	35	40	240	26
2	65	4	40	38	260	28
3	70	3	30	36	280	30
4	70	4	35	34	300	32
5	70	2	40	38	260	28
6	75	4	30	30	360	38
7	75	2	35	32	300	32
8	75	3	40	34	320	34

Table 3 Experimental layout and measured Response values for Bees Wax

Experimental run	HTF inlet temp(T_{HTF})(^oC)	Flow rate(lit/min)	PCM capsules(no.)	Charging time(min)	Discharging time(min)	Quantity of water discharged(lit)
1	65	3	35	38	260	28
2	65	4	40	36	280	30
3	70	3	30	34	300	32
4	70	4	35	32	320	34
5	70	2	40	36	280	30
6	75	4	30	28	380	40
7	75	2	35	30	320	34
8	75	3	40	32	340	36

Table 4. Experimental layout and measured Response values for Bees Wax and copper powder

5. OPTIMIZATION

Optimization using Desirability Function Analysis-

a) Calculate the individual desirability index (d_i) for each response with the help of the formula proposed by Derringer and Suich. There are usually three forms of the desirability functions according to the nature of response characteristic. But, here discharging time must be maximized and charging time must be minimized. Hence, smaller the better for charging and larger the better for discharge time.

$$d_i(\text{discharging}) = y\text{-}y_{min}/y_{max}\text{-}y_{min};\ y_{max}=360;\ y_{min}=240$$

$$d_i(\text{charging}) = y\text{-}y_{max}/y_{min}\text{-}y_{max};\ y_{min}=30;\ y_{max}=40$$

b) Determine the optimum parameter and its level combination. The higher composite desirability index denotes the better product quality. Hence, the parameter effect and the optimum level of each controllable parameter are estimated. Here, the weightages for discharge and charging time are considered as-

$$W_c=0.4$$

$$W_d=0.6$$

Composite desirability index is calculated as-

$$d_g = (d_1^{w1}.d_2^{w2}\ldots.d_n^{wn})^{1/w}$$

After calculating the values, the below observations can be made.

S.No.	Discharge time(min)	Charging time(min)	Discharge time d_i	Charging time d_i	d_G
1	240	40	0.000	0.000	0.000
2	260	38	0.167	0.200	0.1795
3	280	36	0.334	0.400	0.3590
4	300	34	0.500	0.600	0.5378
5	260	38	0.167	0.200	0.1795
6	360	30	1.000	1.000	1.000
7	300	32	0.500	0.800	0.6034
8	320	34	0.667	0.600	0.6394

Table 5. Individual and composite desirability values

	L1	**L2**	**L3**	**Optimum Vlaues**
A (Temperature)	0.08975	0.35877	**0.74760**	A3
B (Flow rate)	0.39145	0.33280	**0.57243**	B3
C (Number of capsules)	**0.6795**	0.3804	0.3238	C1

Table 6. Factor effects of composite desirability

The above mentioned levels and parameters are taken from table 1.

6. RESULTS AND CONCLUSION

From the above observations, the following conclusions can be deduced:

- The effect of mass flow rate of heat transfer fluid at 4 liters per minute and heat transfer fluid inlet temperature at 75ºC is more on discharging time when compared to other. Hence, it is concluded that higher flow rates and higher inlet temperatures of heat transfer fluid are recommended.

- The charging time for lesser number of balls is less. Hence, lesser number of balls with large diameter is recommended.
- The charging time is lesser and discharge time is higher when bees wax is mixed with copper powder than only using bees' wax. Hence, a mixture of organic and metallic materials is recommended.

REFERENCES

1. **Kondakkagari Dharma Reddy, Pathi Venkataramaiah, Tupakula Reddy Lokesh**(2014) Parametric Study on Phase Change Material Based Thermal Energy Storage System. Energy and Power Engineering 537549 http://dx.doi.org/10.4236/epe 2014.614047
2. **Kondakkagari Dharma Reddy, Pathi Venkataramaiah, P. Praveen kumar** A Study on Phase Change Material Based Thermal Energy Storage System Using Fuzzy Logic and Ann International Journal of Applied Engineering Research ISSN 0973 4562 Volume 10, Number 7 (2015) pp. 18089-18103 © Research India Publications http://www.ripublication.com
3. **Gali Chiranjeevi Naidu, K Aruna, K Dharma Reddy, P V Ramaiah** "CFD Simulation for Charging and Discharging Process of Thermal Energy Storage System using Phase Change Material" International journal of Engineering Research Volume No.5 Issue NO.4, pp:332-339.
4. **C. Uma Maheshwari, R. Meenakshi Reddy** "Thermal Analysis of Thermal Energy Storage System with Phase Change Material" International Journal of Engineering Research and Applications (IJERA), Vol. 3, Issue 4, Jul-Aug 2013, pp.617-622.
5. **R. Meenakshi Reddy,N. Nallusamy,and K. HemachandraReddy** "Experimental Studies on Phase Change Material-Based Thermal Energy Storage System for Solar Water Heating Applications" Journal of Fundamentals of Renewable Energy and Applications Vol. 2 (2012), Article ID R120314, 6 pages
6. **Atul Sharma, C. R. Chen** "solar water heating system with phase change materials" International Review of Chemical Engineering (I.RE.CH.E.), Vol. 1, N. 4, July 2009 pp. 297-307.
7. **Mehling, H.Cabeza, L.F.** "Heat and Cold Storage with PCM. An up to date introduction into basics and applications"http:/www.springer.com
8. **G. Samba sivareddy, B. Prasad Kumar, P. Venkataramaiah**- optimization of process paramaters in injection moulding of cam bush using DFA and ANOVA.
9. **A. Navaneet Sait, S. Aravindan, A. Noorul Haq**-optimization of machining parameters of GFRP pipes by DFA using Taguchi technique