Optimization of Process Parameters of PCM Based System for Storing Thermal Energy

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ABSTRACT:-

Current developments in thermal energy storage systems promise to make important contributions to modern technology and have a wide range of applications, including space heating, water heating, waste heat utilization, cooling, and air conditioning. A variety of options are available with thermal energy storage (TES) systems. Phase change materials (PCMs) for TES are materials that provide thermal management at certain phase change temperatures by absorbing and releasing the heat of the medium. Because a lot of thermal energy can be stored in a small amount of space, phase change materials (PCMs) are increasingly used to store heat as latent heat. In the current experimental study, beeswax is used as a phase-change material in a thermal energy storage system to store heat as both sensible and latent heat. Aluminum is doped into beeswax because organic PCMs have poor thermal conductivity. The thermal energy storage system receives heat transfer fluid that is heated continuously from a heat source. A glass round-bottom flask with a phase-change substance inside is used in the thermal energy storage (TES) system. The heat transfer fluid used in the current work is water. While creating the experimental design, parameters like flow rate, heat transfer fluid inlet temperature, and weight of PCM with nanoparticles are taken into account at several levels. Using ***Taguchi analysis*** *as a guide, experiments are run, and results are logged. Analyzing experimental data allows for the study of the impact of the parameters under consideration on the* ***thermal energy storage system****. To determine the ideal HTF inlet temperature, flow rate, and weight of pcm, the data is further examined using* ***Desirability Function Analysis*** *(DFA). The use of only organic materials as PCM and the combination of organic and metallic materials (aluminium powder) are compared*.

KEY WORDS:-*Phase change material, Taguchi analysis, Thermal energy storage, Desirability function analysis.*

1. INTRODUCTION

Phase Change Materials have been employed in thermal energy storage systems because of their high storage density and minimal temperature change from storage to retrieval in a variety of applications. Applications of PCMs can be categorized into various categories, including thermal storage for heating and cooling (of buildings, electronic devices, automotive engines, and spacecraft); applications in the food industry; medicinal; waste heat recovery; cool suits; and cold storages, among others. Solar thermal is one significant application [1].

The storage medium, which can be water, brine, rock, soil, etc., is changed in temperature by sensible TES devices to store energy. Latent TES systems, such as those that store heat by melting beeswax and store cold by using water or ice, use phase transition to store energy[2].

In this study, the working fluid consistency of a pcms, popularly known as a PCM, was tested utilizing a number of different criteria. These elements included the transition length, the temperature range, and the dispersion of the metal interface. The ability to store energy not only helps to correct the imbalance between market forces, but it also increases the efficiency and dependability of generators and is an essential part of energy conservation.[3].

By lowering energy waste and capital costs, it results in the saving of premium fuels and increases the system's cost effectiveness. The capacity of energy in stage change materials (PCM) is a method for using the storage of inert heat, and the released heat is accompanied by changes in the stage of the materials [4].

An aluminium metal matrix with PCM injected, Researchers have experimented with a novel idea to use nanoparticles with the base material in order to enhance the thermal transport capabilities of the base materials due to the quick improvements in nanotechnology. The performance improvement of paraffin wax with nano alumina particles in mass fractions of 1, 2, 3, 4 and 5% in a latent heat storage system has been experimentally investigated in this paper[5].

1.1 Types of TES systems:

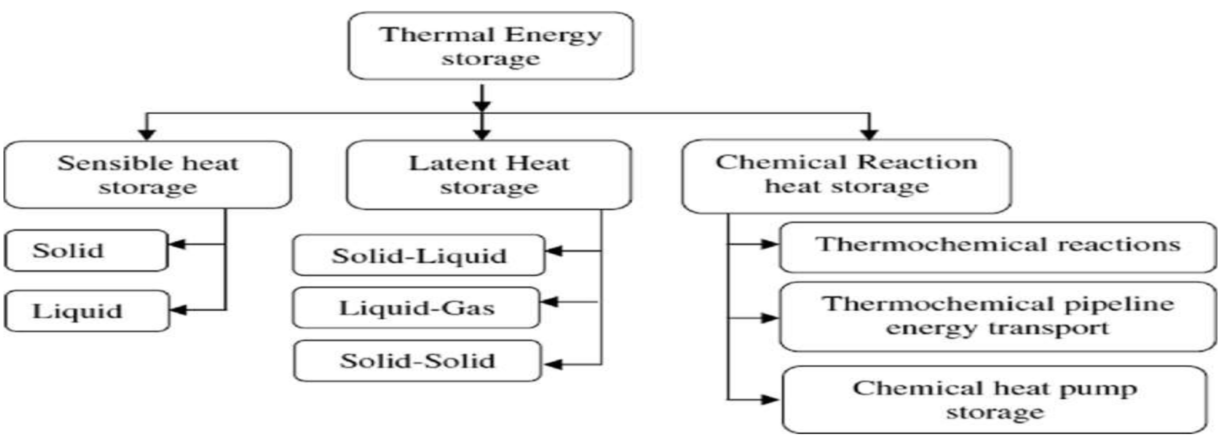


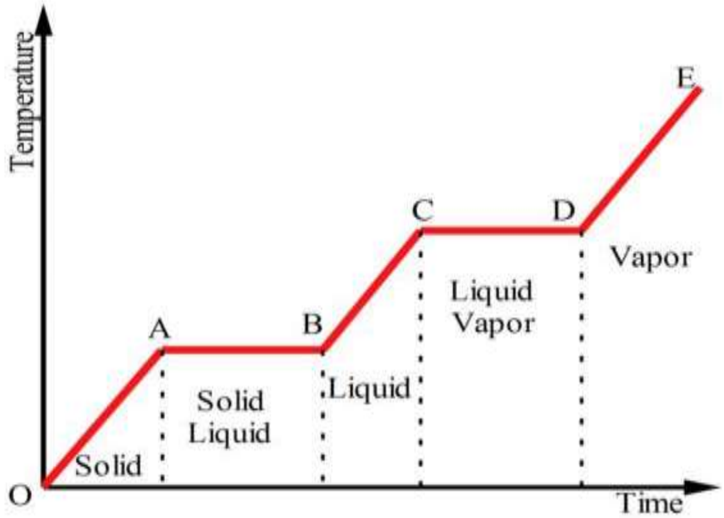
Figure1. A variety of thermal power storage methods

1.1.2 (STES):

All materials have the capacity to store a certain amount of energy as heat. Thermal capacity is a quality that all materials possess. Below a substance's melting point, at which time it is considered to be in its solid state, there are no phase changes that can occur in the substance. A solid will stay solid until it gets to the temperature where it starts to melt.

1.1.3 Accumulation of heat in latent form:

Latent heat is the amount of energy needed to change a substance's existing phase into a new one at a fixed temperature. As a result of its redeployment for hydrogen fuel cells and minimal requirement for temperature changes, latent heat is substantially greater than sensible heat for a given medium and is therefore ideal for the majority of applications.



Graph1: Time-temperature graph for heating a material

1.1.3 Materials with an organic phase transition:

Excellent estimates of heat input, better thermal conductivity, non-flammability, a cheaper price when contrasted with organic and a high water content are only a few of the favorable characteristics of inorganic PCMs, which make them accessible and affordable. Organic PCMs, however, are currently being investigated for this use because of their unsuitable characteristics.

Table1: Melting point and latent heat of fusion: organic salts

Material	Melting point (°C)	Latent heat (kJ/kg)
Bees wax	61.8	177
Formic acid	7.8	247
Caprilic acid	16.3	149
Glycerine	17.9	198.7
Camphinilone	39	205
Camphene	50	238
Hypo phosphoric acid	55	213
Paraffin 34 carbons	75.9	269
Steric acid	69.4	199

1.2 inorganic Phase change materials (PCMs)

a) Salt Hydrates:

Salt hydrates consist of a combination of salt and water that combine in a matrix when the material solidifies. They provide the base for what is deemed as the most important category of PCMs. There are three unique forms and designs of activity seen in melting: congruent melting (when the anhydrous salt is completely soluble in water during hydration), in-congruent melting, and semi-congruent melting (when the liquid and solid the segments are at a state of harmony. during phase transition). The main advantages connected to the usage regarding salt crystals are that they are cheap and easily available, they hold a sharp heat at which ice begins to melt acceptable thermal conductivity and last but not least, their melting enthalpy is high. The main disadvantage is that they often decrease the heat of fusion.

b) Eutectics:

The points of melting for each of these mixtures to include two or much more salts are the lowest that are possible to achieve. During the action of carrying out the crystallisation, a mixture of crystals is produced because the entirety of these salts melts and freezes at the same rate. This only partially separates the constituent elements of the mixture as it continues through the crystallisation process.

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.

Abhat,A[4]., “Low temperature latent heat thermal energy storage: Heat storage materials,” Solar Energy, 30, pp. 313-332, (1983).

R. Meenakshi Reddy et al.[5]- 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.

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.

This study examined the heat transfer capabilities of beeswax and AL nanodispersed PCMs. Combinations of beeswax and aluminium oxide nanoparticles of varying densities were made. The thermal conductivity, sensible heat capacity, and latent heat capacity of the samples were all analysed. This understanding has been important in pinpointing the variables that contribute to the charging and discharging times of water. Considered in the study, with appropriate weights, are the following variables:

Table 2: Influential factors and their magnitudes

S.NO	PARAMETERS	Level -1	Level- 2	Level-3
1	Temperature of incoming heat transfer fluid (ºC)	75	80	85
2	Flow rate(liter/minute)	1.0	1.5	2.0
3	Weight of PCM(gm)	100.5	101.0	102.0

3. EXPERIMENTAL SETUP:

Figures 2 and 3 display a schematic diagram of the experimental setup. The structure comprises of an insulated cylindrical TES tank, a flow meter, and a water storage tank. PCM is kept inside of the flask with the rounded bottom. The tank known as TES in stainless steel has 10 liters of capacity. Insulated with glass wool, storage tank within a storage tank, the PCM weights are packed evenly. The SHS product and High Temperature Fibers in this instance are both water. The rate of flow of HTF is measured using a flow meter with 2% accuracy, and the rate of HTF that is being produced can be altered through a modification of tap opening. Readings taken somewhere at Heat transfer fluid and PCM that are kept inside the PCM are measured by digital thermometers that are integrated into the tank of the TES, and also have a degree of precision of 1(ºC). In order to maintain a steady temperature in the water storage tank, an electric water heater is employed as a source. Table 2 lists the PCM's thermo-physical characteristics.

Table 3: Properties of Beeswax

S.No	Property	*values*
1	Density(kg/m^3)	819.75
2	Melting Point(^{0}C)	65.67
3	Latent Heat(kW/kg)	170.21
4	Specific Heat (kW/kg.K)	0.51
5	Thermal Conductivity(W/mK)	0.25

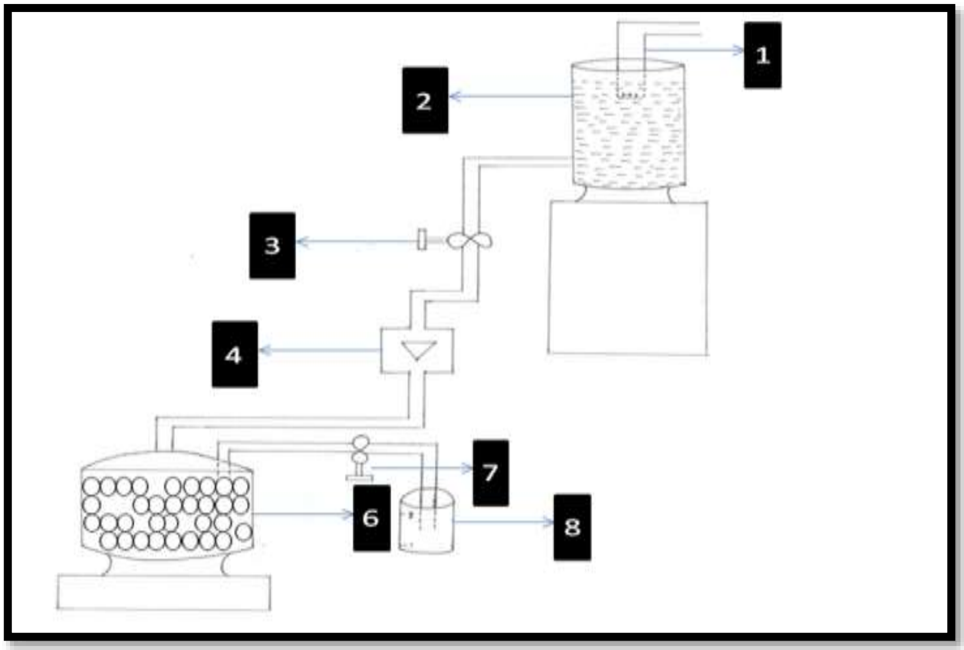


Figure 2: An experimental setup's schematic diagram

1. Powered heater, 2. Uniform temperature bath (water storage tank), 3&7. Flow-regulating valves, 4. Flow gauge, 5.weights of nano with PCM , 6. TES Tank, 8.Outlet tank

Figure 3: Experimental setup

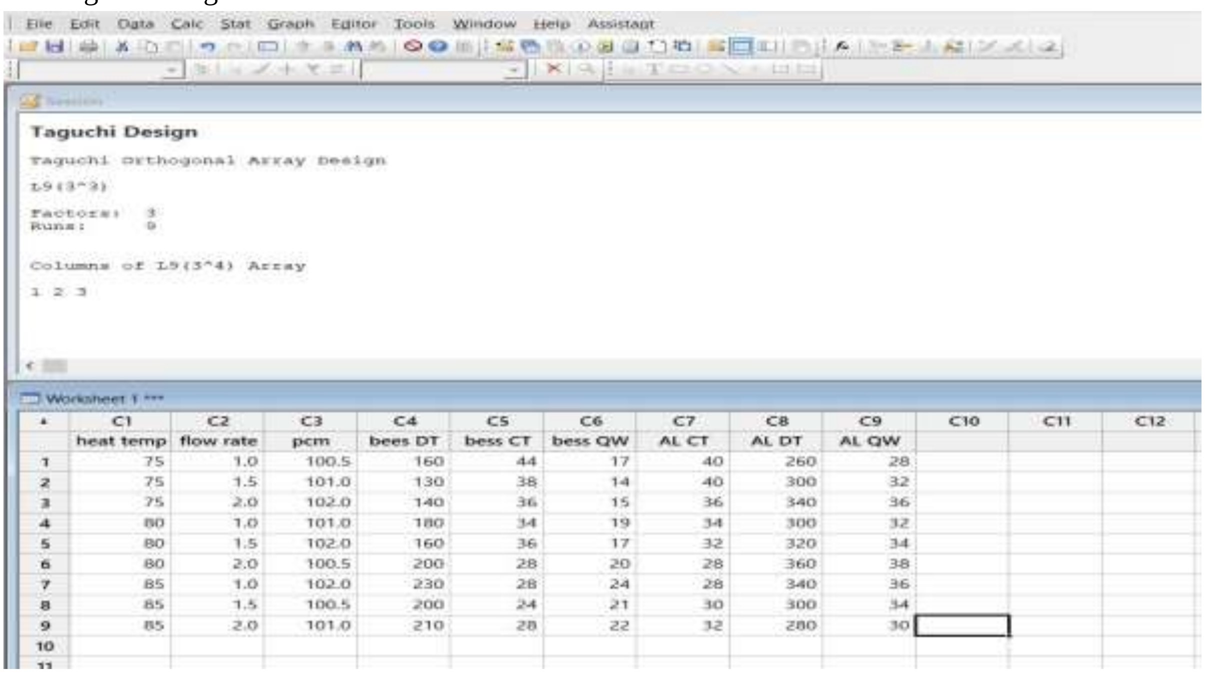
3.1 Charging Process:

Taguchi technique results are included in the trials to determine the procedure for charging**.** As part of this procedure, the HTF inlet temperature (THTF) is maintained constant for a specific flow rate while the TES tank is integrated with a water storage tank with a consistent temperature. The water storage tank's temperature is periodically checked continually. HTF inlet temperature, HTF flow rate, and PCM weight are the main experimental parameters. Temperature, the rate of HTF flow, and various PCM weights different HTF flow rates, HTF inlet temperatures, and PCM weight variations are all tested in these experiments.

The amount of energy stored rises as the charging process goes on until it reaches equilibrium. Two minute intervals are used to record the PCM (TPCM) and HTF (THTF) temperatures in the TES tank. The PCM and Heat transfer values in the TES tank won't be reached until. In balance, the charging procedure is resumed.

3.2 Experimentation:

The Taguchi design from the Minitab software is the foundation for the trials



↓	C1	C2	C3	C4	C5	C6	C7	C8	C9	C10	C11	C12
	heat temp	flow rate	pcm	bees DT	bess CT	bess QW	AL CT	AL DT	AL QW			
1	75	1.0	100.5	160	44	17	40	260	28			
2	75	1.5	101.0	130	38	14	40	300	32			
3	75	2.0	102.0	140	36	15	36	340	36			
4	80	1.0	101.0	180	34	19	34	300	32			
5	80	1.5	102.0	160	36	17	32	320	34			
6	80	2.0	100.5	200	28	20	28	360	38			
7	85	1.0	102.0	230	28	24	28	340	36			
8	85	1.5	100.5	200	24	21	30	300	34			
9	85	2.0	101.0	210	28	22	32	280	30			
10												
11												

Fig 4: Based on Taguchi design, trail runs.

3.3 Discharging Process:

Following the conclusion of the charging process, the phase of discharging will get underway. Experiments with discharging in batches are carried out, and these experiments are reported in this article. During this step of the process, one liter of hot water is emptied out of the thermal energy storage (TES) tank, and an equal amount of cold water heated to 32 degrees Celsius is added to the TES tank in each batch. The temperature of the water that was collected in the bucket during the discharge operation is measured with a digital thermometer to get an average reading of the water's temperature. Readings of the temperature of the water that has been let out of its confines are taken every 20 minutes. Once the water at the outlet reaches 32 degrees Celsius, the batch-by-batch withdrawal of hot water will cease.

During the action of carrying out the discharging waste heat, also known as "heat recovery," the PCM and HTF's varying temperatures are detected and recorded at regular intervals. A comparison is presented between pure beeswax and pure beeswax it is now being mixed with aluminium powder.

4. SAMPLES AND RESULTS:

Taking into account the results of the experiments, Taguchi design runs, the following conclusions are reached.

Table 4: Bees Wax experimental design and response values

Experiment runs	Inlet-temp HTF (T_{HTF}) (^{0}C)	Flow rate(lit/min)	PCM weight (gm)	Charging time(min)	Discharging time(min)	Quantity-of - water discharged(lit)
1	75	1	100.5	44	160	17
2	75	1.5	101.0	38	130	14
3	75	2	102.0	36	140	15
4	80	1.5	100.5	34	180	19
5	80	2	101.0	36	160	17
6	80	1.5	102.0	28	200	20
7	85	2	100.5	28	230	24
8	85	1	101.0	24	200	21
9	80	1.5	102.0	28	210	22

Table 5: Measured Response values for Bees Wax and aluminium Powder, and experimental design

Experimental-runs	Inlet-temp HTF (T_{HTF}) (^{0}C)	Flow rate(lit/min)	PCM weight (gm)	Charging time(min)	Discharging time(min)	Quantity-of - water discharged(lit)
1	75	1	100.5	40	260	28
2	75	1.5	101.0	40	300	32
3	75	2	102.0	36	340	36
4	80	1.5	100.5	34	300	32
5	80	2	101.0	32	320	34
6	80	1.5	102.0	28	360	38
7	85	2	100.5	28	340	36
8	85	1	101.0	30	300	34
9	80	1.5	102.0	32	280	30

4.1 OPTIMIZATION:

Desirability Function Analysis for Optimization-

a) Determine the individual desire index (di) to every response by applying the formula proposed by Derringer and Suich. In most cases, there are three distinct types of desirability functions, each of which is specified by the kind of response characteristic that is being considered. In this scenario, the amount of time spent charging the battery needs to be reduced to the minimum necessary, while the amount of time spent discharging the battery needs to be lengthened. As a result, it is preferable that the amount of time it takes for charging be as short as possible and that the time required for discharging be as long as possible.

$$di(discharging) = y\text{-}y_{min}/y_{max}\text{-}y_{min} \qquad y_{max}=360;\ y_{min}=260$$

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

b) The perfect mix of values for the relevant parameters A greater composite desirability index indicates that the item in question is of higher quality. in order to evaluate the influence of each controllable parameter and determine the optimal setting for each parameter. The following factors should be considered when assigning weight-ages to discharge and charging times:

$$W_c = 0.5$$

$$W_d = 0.5$$

Composite desirability index is calculated as-

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

The observations listed below can be made after the values have been calculated.

Table 5 : Desirability values, both individual and collective

S.No	Discharge time(min)	Charging time(min)	Discharge time (d_i)	Charging time (c_i)	d_G
1	260	40	0.333	0.333	0.333
2	300	40	0.454	0.333	0.393
3	340	36	0.714	0.416	0.565
4	300	34	0.454	0.500	0.477
5	320	32	0.555	0.556	0.555
6	360	28	1.000	1.000	1.000
7	340	28	0.714	1.000	0.857
8	300	30	0.454	0.714	0.584
9	280	32	0.384	0.556	0.470

Table 6: Composite desirability factor impacts

Factors	**L1**	**L2**	**L3**	**Optimum Values**
A (Temperature)	0.4303	**0.6773**	0.6370	A2
B (Flow rate)	0.557	0.5107	**0.6783**	B3
C (PCM weight)	**0.6390**	0.4467	0.2123	C1

5. RESULTS AND CONCLUSION:

- An experimental examination has been tried and tested in the current work to examine melting (i.e. charging) characteristics and determine the impact on thermal Beeswax's performance has improved thanks to the use of alumina (Al_2O_3) nanoparticles as a phase-change material, which increases thermal conductivity**.**
- The thermal characteristics the combination containing nanoparticles of varying amounts of aluminium were investigated while the nanoparticles were in the form of dispersed in nanodispersed PCMs. A quicker rate of heat transmission appears to be the case in phase-change materials that feature nanodispersion. in contrast to pure beeswax, when applied to the processes of charging and discharging simultaneously.
- When compared to other factors, the influence brought on by the bulk flow of heat transfer at 2 liters per minute and heat transfer fluid input temperature at 80ºC is more significant on discharge time. Thus, it can be inferred that larger heat transfer fluid flow rates and intake temperatures are advised.

6. REFERENCES:

[1] Kondakkagari Dharma Reddy, K. D., Venkataramaiah, P., & Lokesh, T. R. (2014). Parametric Study on Phase Change Material Based Thermal Energy Storage System. *Energy and Power Engineering*, *06*(14), 537–549. https://doi.org/10.4236/epe.2014.614047

[2] Kondakkagari Dharma Reddy, R. M, Nallusamy, N., & Reddy, K. H. (2014). The Effect of PCM Capsule Material on the Thermal Energy Storage System Performance. *ISRN Renewable Energy*, *2014*, 1–6. https://doi.org/10.1155/2014/529280

[3] Reddy, S. P. M., Venkataramaiah, P., & Reddy, D. V. V. (2014). Selection of Best Materials and Parametric Optimization of Solar Parabolic Collector Using Fuzzy Logic. *Energy and Power Engineering*, *06*(14), 527–536. https://doi.org/10.4236/epe.2014.614046

[4] Mao, Q., & Li, Y. (2020). Experimental and numerical investigation on enhancing heat transfer performance of a phase change thermal storage tank. *Journal of Energy Storage*, *31*, 101725. https://doi.org/10.1016/j.est.2020.101725

[5] Kanimozhi, B., Ramesh Bapu, B., & Pranesh, V. (2017, August). Thermal energy storage system operating with phase change materials for solar water heating applications: DOE modelling. *Applied Thermal Engineering*, *123*, 614–624. https://doi.org/10.1016/j.applthermaleng.2017.05.122

[6] Prasad Kumar, B., Venkataramaiah, P., & Siddi Ganesh, J. (2019). Optimization Of Process Parameters In Injection Moulding Of A Polymer Composite Product By Using Gra. *Materials Today: Proceedings*, *18*, 4637–4647. https://doi.org/10.1016/j.matpr.2019.07.448

[7] Prasad, M., & kumar Namala, K. (2018). Process Parameters Optimization in Friction Stir Welding by ANOVA. *Materials Today: Proceedings*, *5*(2), 4824–4831. https://doi.org/10.1016/j.matpr.2017.12.057

[8] Agrawal, E., Chopra, R., & Sharma, N. (2021). Treatment of lingual gingival recession on mandibular lateral incisor using minimally invasive full-thickness tunneling technique and subepithelial palatal connective tissue graft. *Journal of Indian Society of Periodontology*, *25*(1), 78. https://doi.org/10.4103/jisp.jisp_91_20

[9] Design, Developing and Construction of an Educational Solar Water Heating System with Phase Change. (2015). *International Journal of Thermal and Environmental Engineering*, *10*(1). https://doi.org/10.5383/ijtee.10.01.007

[10] Cabeza, L., Mehling, H., Hiebler, S., & Ziegler, F. (2002, July). Heat transfer enhancement in water when used as PCM in thermal energy storage. *Applied Thermal Engineering*, *22*(10), 1141–1151. https://doi.org/10.1016/s1359-4311(02)00035-2