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THERMAL ENERGY STORAGE IN WATER HEATER SYSTEM BY PCM

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Abstract :

This study explores the use of Phase Change Materials (PCMs), specifically paraffin wax, for thermal energy storage in water heating systems. Two types of paraffin wax, P-70 and P-72, are investigated for their effectiveness in storing and releasing thermal energy. An experimental setup is designed to compare PCM-based thermal energy storage with conventional systems. Water is heated to a desired temperature and passed through a container surrounded by PCM. The PCM melts, storing thermal energy, which is later released when the water is drained. Temperature measurements show PCM systems offer enhanced thermal stability and efficiency compared to traditional methods. Both P-70 and P-72 paraffin wax demonstrate effective thermal storage, with P-72 slightly outperforming in temperature stabilization. Day-wise readings confirm the consistent performance of P-72 over multiple days. This research highlights paraffin wax PCM as a promising solution for thermal energy storage in water heating, offering benefits such as reduced heat losses, improved energy efficiency, and enhanced system reliability, contributing to sustainable energy management practices.

Keywords:

Phase Change Materials (PCMs), Paraffin wax, Thermal energy storage, P-70, P-72, water heating systems

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1.INTRODUCTION

Various energy storage technologies play essential roles in modern energy systems by enabling the capture and retention of energy for future use, thus balancing supply and demand, integrating renewable sources, and providing backup power during outages. These technologies encompass batteries for portable devices, electric vehicles, and grid-scale applications; compressed air energy storage utilizing underground storage for electricity generation; flywheels storing energy as rotating masses for rapid power delivery; thermal energy storage (TES) methods, such as sensible heat, latent heat, and thermo-chemical storage, applied in heating/cooling systems, solar plants, and industrial processes; and hydrogen storage for transportation and industrial applications. Among these, TES stands out for its diverse applications, including load shifting, improved efficiency, renewable energy integration, demand response, time-of-use optimization, and backup heating in water heating systems. By leveraging TES, these systems can enhance energy consumption optimization, cost reduction, renewable energy utilization, and resilience, aligning with the broader goal of efficient and sustainable energy management. The historical background of thermal energy storage, dating back to ancient civilizations like the Romans and Greeks, underscores its enduring significance in addressing contemporary energy challenges, alongside its diverse range of storage mediums, from water and ice to phase change materials and thermal oil, tailored to specific temperature ranges and scalability requirements.

2. LITERATURE REVIEW

Thomas Hasenohrl[1]:

Hasenohrl's study covers the physical basis of PCM, highlighting applications, benefits, and downsides of using paraffin and salt hydrates. It discusses strategies to address paraffin's low thermal diffusivity and its use in maintaining building temperatures and enhancing water heating system efficiency. The study emphasizes PCM's potential in future energy-efficient applications due to increasing energy conservation needs.

Thirugnanam.C, Marimuthu.P[2]:

Thirugnanam and Marimuthu's study demonstrates PCM's suitability as a storage medium in heat recovery systems for conserving energy lost in various industrial processes. Through trials with different mass flow rates, they highlight PCM's effectiveness in maintaining constant temperature for heat transfer fluid, thereby enhancing system performance.

Mohammed M. Farid, et.al [3]:
Farid et al. highlight the versatility of phase change heat storage, particularly latent heat storage, for various applications due to its higher storage density and minimal temperature differential compared to sensible heat storage. They also discuss ongoing efforts to develop new phase transition materials while reviewing previous research on latent heat storage.

PB Salunkhe, PS Shembekar : This paper investigates how encapsulating phase change materials (PCMs) affects thermal energy storage systems (TESS), examining parameters like size, thickness, material, and geometry. It emphasizes the core-to-coating ratio's importance in determining PCM encapsulation's thermal and structural stability, noting that a higher ratio weakens encapsulation but reduces PCM amount and heat storage capacity. The study also identifies shell material's thermal conductivity as crucial for PCM-HTF heat exchange, with higher conductivity, smaller shell size, and elevated HTF temperature accelerating PCM melting. Conduction and natural convection are found to be dominant during solidification and melting, respectively, while microencapsulated PCM enhances heat transfer, albeit with increased pressure drop and viscosity at higher concentrations.

Rathod, M. K., and Jyotirmay Banerjee : In this work, paraffin wax (melting point: 58–60°C) is used as the phase change material to evaluate the thermal performance of a shell-and-tube latent heat storage unit through experimentation. The material's temperature distribution is tracked throughout time. The impact of the input temperature (75°C to 85°C) and mass flow rate (varying from 1 kg/min to 5 kg/min) of the heat transfer fluid (water) on the heat fraction during the melting and solidification processes is investigated. The results show that shorter total melting durations are produced by higher mass flow rates and intake temperatures. In particular, during the melting process, the entrance temperature has a greater impact on the heat fraction than the mass flow rate.

Goel, Varun : The substantial potential of phase change materials (PCMs) to increase solar thermal systems' efficiency is highlighted in this research. It assesses several PCM-based solar systems in a range of environmental settings, emphasizing that full cycles of charging and discharging are required for the best possible PCM performance. The importance of choosing PCMs according to the thermodynamic properties of certain thermal systems and settings is highlighted by heat transfer evaluations, which result in significant performance improvements. The review makes recommendations for suitable PCMs based on their cost-effectiveness and thermal characteristics for various solar applications. Additionally, it investigates the level of technological preparedness and the levelized cost of storage, suggesting that PCMs are suitable for broad integration in solar thermal applications. All things considered, this review offers insightful information about the thermal dynamics, selection standards, and possible uses of PCMs.

Suraparaju, Subbarama Kousik: Addressing the global water scarcity issue requires immediate action. Utilizing renewable energy sources like solar power is crucial for sustainable development. A single slope solar desalination system with phase change materials for energy storage is designed for converting sea/brackish water into fresh water. The system achieves an average energy efficiency of 26.51%, exergy efficiency of 2.58%, and produces fresh water at a cost of $0.0084 per liter. Additionally, it generates a carbon credit worth $183.5.

Gunawan, Yohanes: This study investigates the integration of phase change materials (PCMs) such as paraffin wax, soy wax, and palm wax in solar air heaters (SAH) to enhance drying of agricultural commodities. PCM containers, repurposed from milk cans, are utilized to support the 3R strategy (Reduce, Reuse, Recycle) amid the Covid-19 pandemic. Tests demonstrate improved SAH performance with all three PCM types, with paraffin achieving the highest energy efficiency (up to 30%) and palm wax yielding the highest exergy efficiency (up to 28.96%) under varying solar irradiation conditions. This approach not only enhances SAH effectiveness but also promotes environmental sustainability through waste reuse.

Brahma, Barkhang : A novel solar air heater (SAH) with integrated phase change material (PCM) was developed at Tezpur University, using MATLAB for design parameters. PCM quantities (acetamide, stearic acid, paraffin wax) were determined based on energy analysis. Experimental results showed close agreement with simulations. SAH with PCM exhibited smoother outlet temperatures during low sunshine periods compared to SAH without PCM. Paraffin wax demonstrated highest heat absorption and efficiency (36.56 kW, 52.83%). SAH with PCM outperformed those without, with efficiency increases ranging from 6.67% to 15.09%. Uncertainty analysis yielded a thermal efficiency range of ±2.02%. This novel PCM-integrated SAH has potential for space heating and solar drying of local agricultural products, warranting further analysis on exergy, economy, and environmental impact.

Moradi, Ramin : In this work, Ramin Moradi uses paraffin underneath the absorber plate to particularly examine the performance of a solar air heater (SAH) integrated with phase change material (PCM) energy storage. The study investigates the effects of several parameters on SAH efficiency, such as air mass flow rate, paraffin quantity, and paraffin thermal conductivity, using a transient two-dimensional laminar model in Ansys Fluent 17. Maximizing the nighttime temperature differential and thermal energy efficiency are the main goals of SAH performance optimization. A 2-cm paraffin layer SAH is used for experimental validation of the numerical model, and the results show good agreement between simulation and experiment.

2. Experimental setup

Experimental setup includes three well-insulated steel tanks: a top tank for heating water up to 90 degrees using an electrical heater, and two bottom tanks filled with paraffin wax in the annular space. The top tank has a capacity of 22 liters, while the inner and outer bottom tanks hold 20 and 17 liters, respectively. When hot water enters the bottom tank, the paraffin wax melts, storing latent heat.

Upon draining the hot water and ading fresh water, the paraffin wax solidifies, releasing latent heat and raising the surrounding water temperature to 52 degrees.

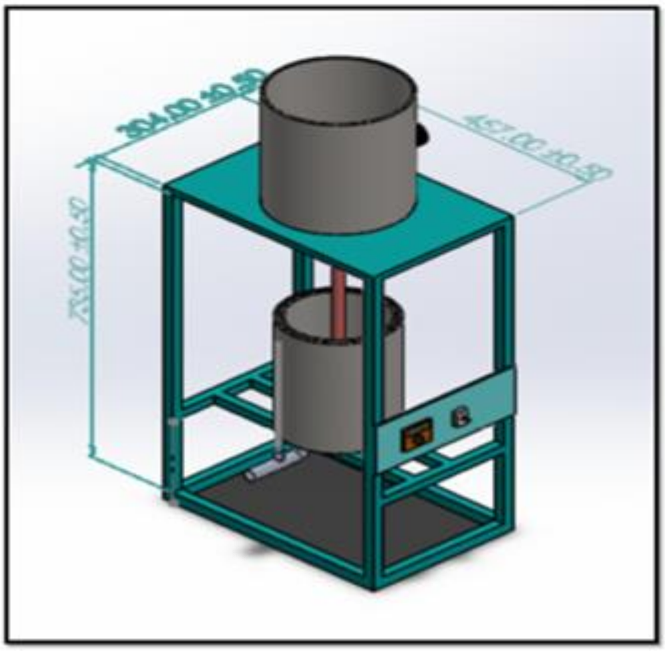


Fig -1: Outline of Experimental Set up and Working

3. Experimentation

The experiment begins by heating cold water in a storage bucket to 70°C using a heater, then maintaining this temperature. The heated water is transferred into a PCM kit, where it is held for 15-20 minutes, causing the paraffin wax within to melt. The outlet valve is then opened, and the hot water, now at approximately 48°C, is drained from the PCM kit. After draining, cold water is reintroduced into the bucket, and its temperature is noted. The process is repeated, with the heated water causing the paraffin wax to solidify and release heat, raising the water temperature to around 49°C before being drained from the PCM kit.

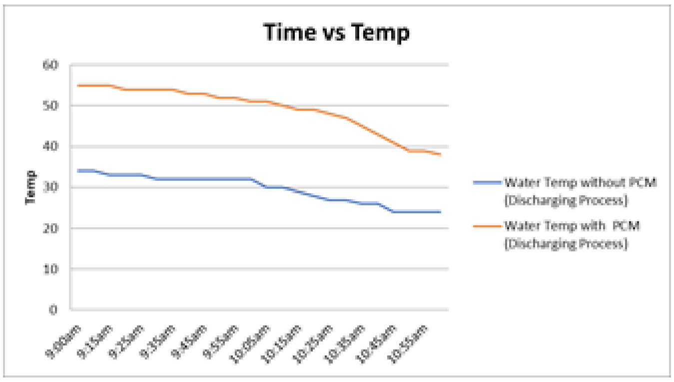
Recorded Readings:
Initial temperature of hot water in the bucket.
Temperature of hot water after removal from the PCM kit.
Initial temperature of cold water in the bucket.
Temperature of water after removal from the PCM kit.

1. Observations and results

In this experiment, PCM is charged during heating, converting solid PCM into liquid and storing energy. During discharge, PCM dissipates heat to surrounding water, changing phase from liquid to solid. P-70 and P-72 paraffin wax are used, compared with a normal setup. Thermocouples and a temperature indicator arrangement are used to take readings every 10 minutes**.**

Time	**Water Temp without PCM (Discharging Process)**	**Water Temp with PCM P-70 (Discharging Process)**
9:00am	34	55
9:10am	34	55
9:15am	33	55
9:20am	33	54
9:25am	33	54
9:30am	32	54
9:35am	32	54
9:40am	32	53
9:45am	32	53
9:50am	32	52
9:55am	32	52
10:00am	32	51
10:05am	30	51
10:10am	30	50
10:15am	29	49
10:20am	28	49
10:25am	27	48
10:30am	27	47
10:35am	26	45
10:40am	26	43
10:45am	24	41
10:50am	24	39
10:55am	24	39

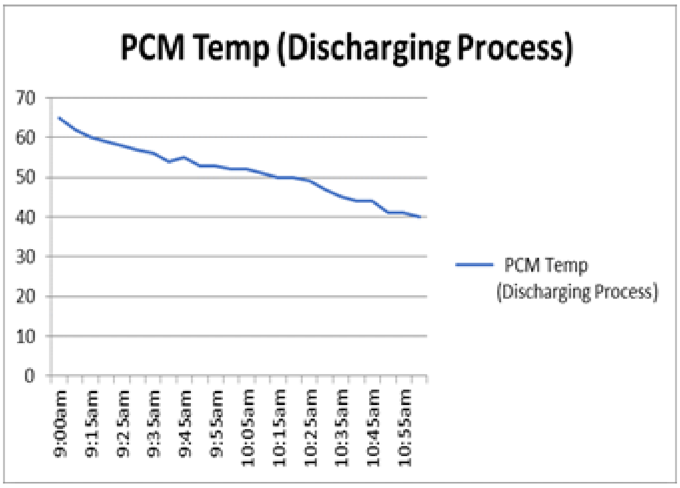
Table 1. Experimentation by P-72 Paraffin Wax



Graph No. 1 Time vs Temp (P-70 Paraffin wax)

Time	**PCM Temp P-70 (Discharging Process)**
9:00am	65
9:10am	62
9:15am	60
9:20am	59
9:25am	58
9:30am	57
9:35am	56
9:40am	54
9:45am	55
9:50am	53
9:55am	53
10:00am	52
10:05am	52
10:10am	51
10:15am	50
10:20am	50
10:25am	49
10:30am	47
10:35am	45
10:40am	44
10:45am	44
10:50am	41
10:55am	41
11:00am	40

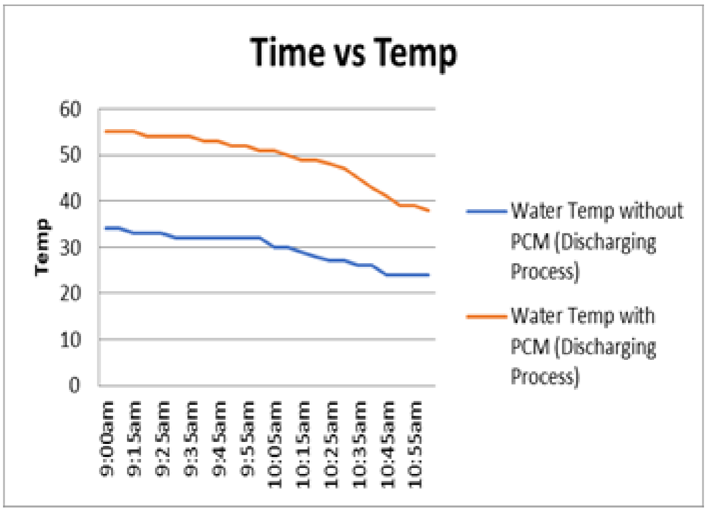
Table 2. Experimentation by P-72 Paraffin Wax



Graph No. 2 Time vs PCM P-70 Temp

Time	Water Temp without PCM (Discharging Process)	Water Temp with PCM P-72 (Discharging Process)
9:00am	35	60
9:10am	34	59
9:15am	34	59
9:20am	34	59
9:25am	33	58
9:30am	33	58
9:35am	33	58
9:40am	33	57
9:45am	32	57
9:50am	32	56
9:55am	31	56
10:00am	31	56
10:05am	31	55
10:10am	31	55
10:15am	31	54
10:20am	30	53
10:25am	30	51
10:30am	29	51
10:35am	29	50
10:40am	29	49
10:45am	28	46
10:50am	26	44
10:55am	26	42

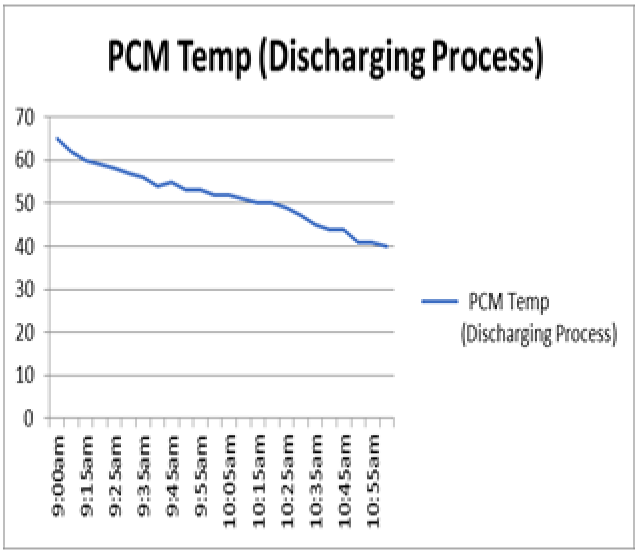
Chart 3 . Experimentation by P-72 Paraffin Wax



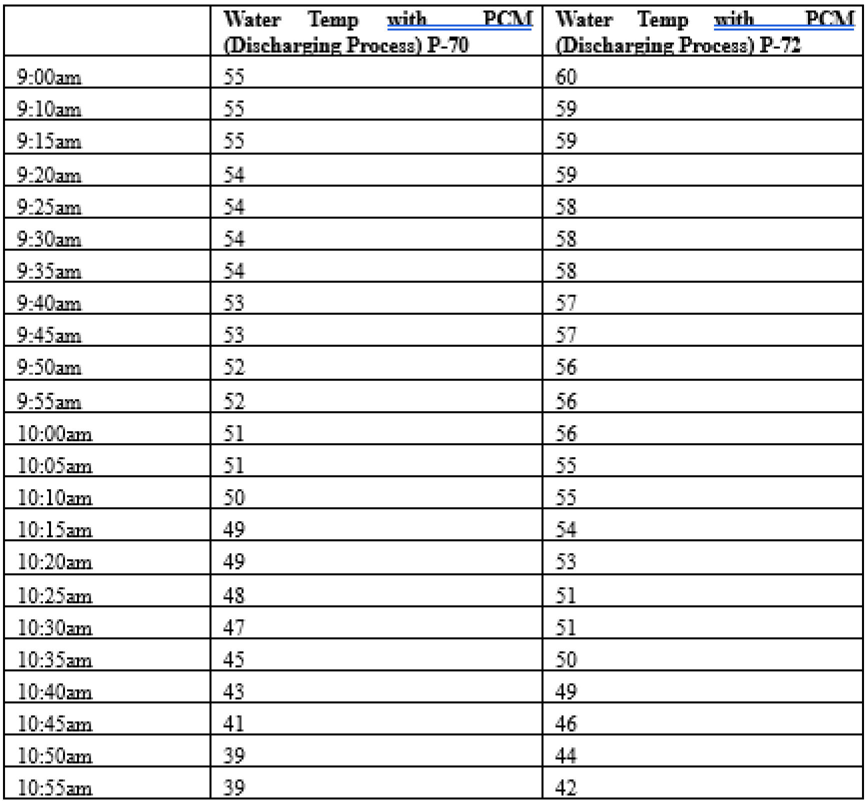
Graph No. 3 Time vs Temp (P-72)

Time	PCM Temp P-72 (Discharging Process)
9:00am	68
9:10am	67
9:15am	66
9:20am	66
9:25am	65
9:30am	65
9:35am	65
9:40am	62
9:45am	62
9:50am	61
9:55am	60
10:00am	60
10:05am	59
10:10am	59
10:15am	58
10:20am	57
10:25am	55
10:30am	54
10:35am	53
10:40am	51
10:45am	50
10:50am	49
10:55am	47
11:00am	45

Chart 4 . Experimentation by P-72 Paraffin Wax

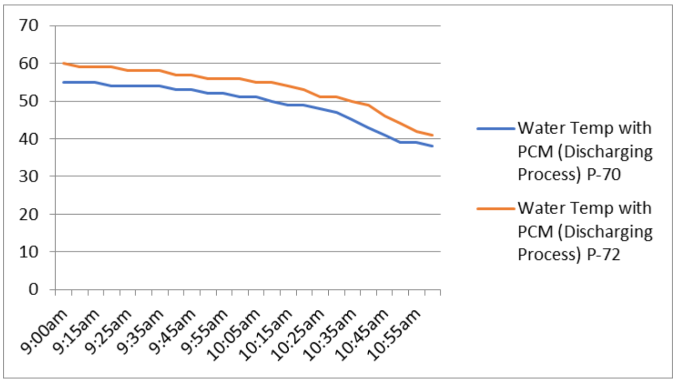


Graph No. 4 Time vs PCM Temp (P-72)



	Water Temp with PCM (Discharging Process) P-70	Water Temp with PCM (Discharging Process) P-72
9:00am	55	60
9:10am	55	59
9:15am	55	59
9:20am	54	59
9:25am	54	58
9:30am	54	58
9:35am	54	58
9:40am	53	57
9:45am	53	57
9:50am	52	56
9:55am	52	56
10:00am	51	56
10:05am	51	55
10:10am	50	55
10:15am	49	54
10:20am	49	53
10:25am	48	51
10:30am	47	51
10:35am	45	50
10:40am	43	49
10:45am	41	46
10:50am	39	44
10:55am	39	42

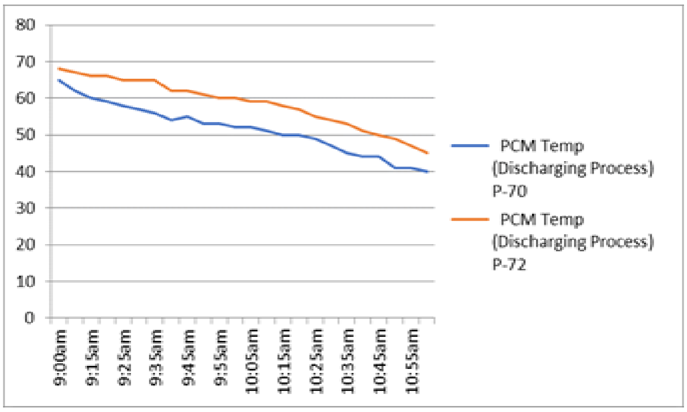
Chart 5 : Comparison between P-70 and P-72 Paraffin Wax



Graph No. 5 Comparison between P-70 and P-72 Paraffin Wax water temp

Time	PCM Temp (Discharging Process) P-70	PCM Temp (Discharging Process) P-72
9:00am	65	68
9:10am	62	67
9:15am	60	66
9:20am	59	66
9:25am	58	65
9:30am	57	65
9:35am	56	65
9:40am	54	62
9:45am	55	62
9:50am	53	61
9:55am	53	60
10:00am	52	60
10:05am	52	59
10:10am	51	59
10:15am	50	58
10:20am	50	57
10:25am	49	55
10:30am	47	54
10:35am	45	53
10:40am	44	51
10:45am	44	50
10:50am	41	49
10:55am	41	47
11:00am	40	45

Table 6 Comparison between P-70 and P-72 Paraffin Wax water temp



Graph No. 6 Comparison between P-70 and P-72 Paraffin Wax temp

Day Wise Reading of P-72 Paraffin wax to know instant stability : In this method P-72 PCM is selected for day wise readings. In that initially water gets heated at 70 to 90 degree and then it is allow in storage tank which is surrounded by PCM. During this time heating temp is noted by temperature indicator and time is noted by stop watch. Then because of hot water in contact PCM get melt and stored energy and after that same water is removed and fresh water is added in lower storage tank without heating it. Then PCM dissipate energy and surrounding water get heated up to 45 to 50 degree within 20 to 30 min without any electricity. During experimentation continuous 3 days readings are taken.

Day-1:

For Hot Water	**Temperature**	**Time for heating**
	70^0C	35 minutes
	Wax Temperature -50^0C	
	Temperature	Holding time
	52^0C	30 minutes

For Cold Water	**Temperature**	**Time for heating**
	24^0C	0
	Temperature	Holding time
	45^0C	30 minutes

Day-2:

For Hot Water	**Temperature**	**Time for heating**
	90^0C	45 minutes
	Wax Temperature -60^0C	
	Temperature	Holding time
	60^0C	30 minutes

For Cold Water	**Temperature**	**Time for heating**
	24^0C	0
	Temperature	Holding time
	49^0C	30 minutes

Day-3:

	Temperature	**Time for heating**
For Hot Water	80^{0}C	47 minutes
	Wax Temperature – 60^{0}C	
	Temperature	Holding time
	60^{0}C	30 minutes

	Temperature	**Time for heating**
For Cold Water	24^{0}C	0
	Temperature	**Holding time**
	47^{0}C	30 minutes

3. CONCLUSIONS

There are various advantages to using paraffin wax in water heating systems as a thermal energy storage medium. With its high latent heat capacity, paraffin wax may both release and absorb a sizable quantity of thermal energy during phase transitions from solid to liquid and vice versa. It is a useful substance for storing and releasing heat because of its characteristic .Paraffin wax, when added to a water heating system, can be utilized to store extra heat in times of low demand or when the main heating source is working harder. When thermal energy is needed, the wax stores it in a latent state by absorbing it from the water or an external heat source. The wax can release the heat when the demand for hot water rises.

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