International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 15 Issue 06 , June - 2026

Analysis of Waste Heat Storage using Zinc Nano Powder and Paraffin Wax as Heat Storage Matrix

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Abstract - Waste or Unused heat from energy systems like heat engines, heat received from renewable energy sources like solar energy find a common challenge of absorption and storage of heat for latter utilization. As Heat can be stored in the form of sensible heat or Latent heat or both, storage of waste heat in the form of latent heat has more benefits in comparison to sensible heat due to its higher heat storage capacity and reduced convective heat losses to the surroundings. Latent heat storage systems using materials like paraffin wax which have low melting point & high latent heat, suits well for the purpose of heat storage. The limitation of the paraffin is its low thermal conductivity which restricts it from absorbing latent heat in a very quick time, however this inability of paraffin can be overcome by mixing it up with metals in particulate form, since metals are known to have good thermal conductivity. Not all metals may be suitable for this purpose as they should be non-corrosive, chemically non-reactive, have good wettability etc. It is also well-known fact that the surface area of a solid particle is directly proportional to the heat convected, Nano particles offer more surface area to volume ratio hence are ideally suited for quick heat absorption and desorption, hence the combination of paraffin wax along with Nano particles of a metal of high thermal conductivity forms a very good heat storage matrix. In the present study paraffin wax is combined with Zinc nano powder in different proportions and tested as heat storage matrix. For this purpose, an experimental setup consisting of heat exchanger which is a twin cylindrical system having an annular space between them. The annular space is filled with heat storage matrix mentioned above. The system is connected to exhaust of an Internal combustion Engine so that the exhaust gases enter the innermost cylinder and exits while heat exchange takes place between the exhaust gasses and the heat storage matrix. The amount of heat stored, the rate of heating, heating rate, cooling rate etc., the parameters are determined. The result shows that heat storage matrix consisting of 150gms of paraffin wax and 50gms zinc nano particles, the amount of heat stored in the mixture is equal to 73KJ while without adding nano particles it is 43.35KJ an increase of 25% in heat storage capacity with zinc nano particles over without it. It is also observed that the matrix filled with Nano particles rate of rise in temperature increased and reduced time for melting of matrix and increase in heat storge which included Latent heat & sensible heat.

Keywords: Latent Heat, Paraffin wax, zinc nanoparticles Composite phase change materials, waste heat

1. INTRODUCTION -

Energy systems like heat engines have very low thermal efficiency in other words lot of heat generated out of fuel combustion is wasted, which leads to lot of environmental and economical demerits. Hence it becomes necessary to recover the waste heat through a heat sink and utilize the same for any direct or indirect heat applications.

The increasing global demand for energy, coupled with the urgent need to mitigate environmental impacts has led to an intensified focus on developing sustainable and efficient energy conversion technologies. Waste heat recovery and storage represent key strategies in improving energy conversion efficiency and reducing emissions of greenhouse gases. Industrial heat applications, domestic heating

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systems, and transportation systems generate significant amounts of waste heat, which if properly harnessed, can be converted into useful energy, thereby increasing then overall energy utilization. Therefore, the need for means and methods to improve energy utilisations efficiency has become increasingly critical in response to the growing global energy demand and environmental concerns a move towards sustainable development. Waste heat recovery is one such method in this direction. Waste heat, which is the anergy part of the heat supplied from different direct and indirect heat applications often dissipates into the environment, leading to energy loss and inefficiency. Capturing and reusing this waste heat can substantially improve overall energy utilization, reduce greenhouse gas emissions, and decrease reliance on primary energy sources. Thermal energy storage (TES) systems are very much essential in the effective storage of waste heat. These systems store excess thermal energy for later use, helping

to balance energy supply and demand and improve the efficiency of energy systems. TES can be classified into sensible heat storage, latent heat storage, combined sensible-latent heat storage system and thermochemical storage, each with its unique advantages. Latent heat storage systems are more advantageous over others due tom it's characteristics to store the heat without rise in temperature which is helpful in preventing heat losses to the surroundings. Phase change materials (PCMs) are well suited to store latent heat due to their ability to absorb and release significant amounts of latent heat during phase transitions without changing its temperature. Paraffin wax is a commonly used PCM because of its high latent heat capacity, chemical stability, and non-corrosiveness. However, a significant limitation of paraffin wax is its low thermal conductivity, which restricts the rate of heat transfer and impacts the overall efficiency of TES systems. Addressing this limitation is crucial for enhancing the performance of waste heat storage systems. To overcome the thermal conductivity limitations of paraffin wax, recent research has focused on the incorporation of high thermal conductivity nanoparticles into the PCM matrix. Zinc is particularly promising due to their excellent thermal conductivity, mechanical strength, and relatively low cost. By dispersing Zinc nanoparticles within the paraffin wax matrix, it is possible to enhance the thermal properties of the composite material, leading to improved heat transfer rates and overall system performance. This approach aims to create a more efficient and effective TES system for waste heat recovery applications.

This research aims to design, develop, and test a waste heat storage system using a paraffin wax and Zinc Nanoparticles composite Phase changing material(CPCM). The primary objectives are to develop a composite PCM with enhanced thermal conductivity, characterize its thermal properties, design and construct a prototype waste heat storage system, and evaluate its performance under various operational conditions. By improving the thermal conductivity of paraffin wax through the incorporation of Zinc nanoparticles, the study seeks to achieve faster heat transfer, higher energy storage efficiency, and better overall system performance. This advancement in TES technology has significant implications for energy savings, operational cost reductions, and environmental sustainability in various applications.

2. <u>EXPERIMENTAL SET UP</u>

The experimental setup as shown in figures 2.1,2.2 & 2.3 consist of a waste heat storage system filled with heat storage matrix. The heat storage system is a concentric twin cylinder. The exhaust gas from the engine is allowed to pass through the inner cylinder while the annular space between them contains the heat storage matrix. The heat storage system is attached to a 4-stroke diesel engine test rig, with instruments to measure the temperatures, fuel consumption,

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load and speed.

Figure 2.1. heat storage device connected to the Engine exhaust

fig 2.3- experimental setup connected to the Engine exhaust with thermocouple

fig 2.3 4-Stroke diesel Engine setup for experimentation

3. EXPERIMENTAL PROCEDURE

a. Three different samples of Paraffin wax and Zinc Nanopowder were prepared as given below.

i. Sample 1- (150 grams of pure Paraffin wax)

ii. Sample 2-(150 grams of Paraffin wax + 50 grams of Zinc Nano powder)

iii. Sample 3- (150 grams of Paraffin wax + 100 grams of Zinc Nano powder)

Ffifig 3.1 Zinc Nanopowder

fig 3.2 paraffin wax

b. The above-mentioned material is packed in a concentric cylinder as shown in figure 2.1

c. A four-stroke single cylinder Deisel engine fig 2.3) was selected for the purpose of experimentation**.**

d. The engine was made to run at full load for a period of 15 mins to attain steady state.

e. The temperature of PCM matrix was recorded before fitting it to the exhaust pipe. Further the exhaust gas temperature along with rise in temperature of matrix at different time interval was recorded

f. Once the temperature of the matrix reached a constant maximum value the engine was switched off.

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g. The temperature of PCM matrix was recorded at different time intervals during cooling of the matrix until it reached room temperature**.**

h. The recorded values are analyzed to determine the following

- Rate of heating
- Rate of cooling
- Latent heat and Sensible heat stored.

4 CALCULATIONS & EXPERIMENTAL RESULTS

4.1 Heating of PCM using engine exhaust gasses available at an average temperature of 400°C.

Table 4.1 Comparison of temperature Rise in three different samples during heating

Time (Min)	Sample 1 In °C	Sample 2 In °C	Sample 3 In °C
0	26	27	26
2	26	28	26
4	27	40	28
6	29	51	36
8	33	66	49
10	37	80	59
12	44	87	71
14	**49**	**90**	**81**
16	70	92	86
18	70	94	89
20	84	95	91
14	**49**	**90**	**81**

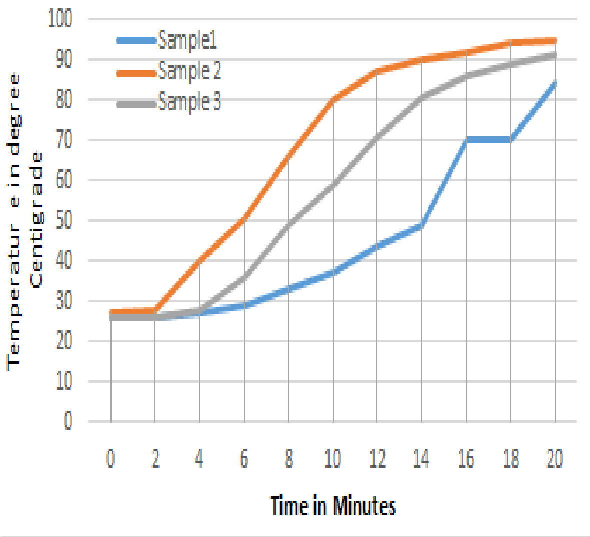

fig 4.1 Comparison of temperature Rise in three different samples during heating by exhaust gasses

4.2 Cooling of PCM at atmospheric conditions of 30°C

Table 4.2 Comparison of temperature drop in three different samples during cooling

Time (Min)	Sample 1 In °C	Sample 2 In °C	Sample 3 In °C
0	95	95	95
20	61	62	62
40	58	59	59
60	56	57	57
80	54	55	56
100	51	53	54
120	48	52	51
140	46	48	47
160	41	43	42
180	39	41	39
200	36	39	36
220	36	34	34

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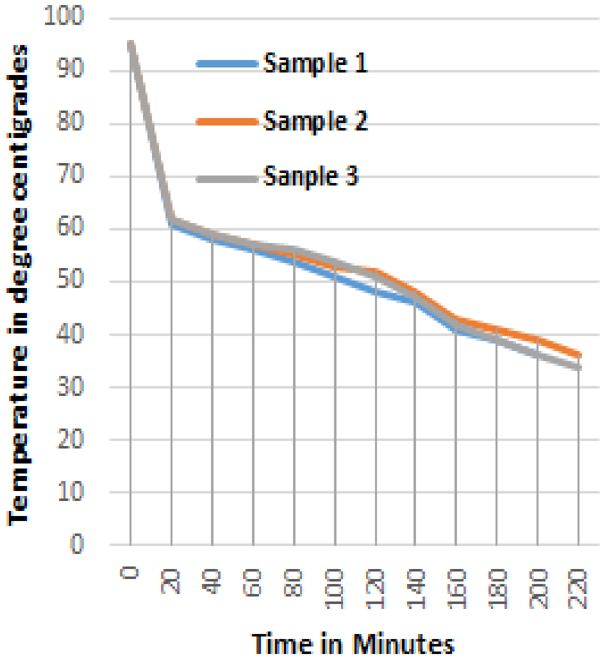

fig 4.2 Comparison of temperature drop in three different samples during cooling in ambient conditions

4.3 Heat stored in heat storage Matrix

The total heat stored is the sum of Sensible heat and Latent heat. Table 4.3 shows the total stored heat.

Table 4.3 total heat storage in three different samples.

Sample no.	Sample 1	Sample 2	Sample 3
Heat storage in KJ	43.36	44.95	46.25

<u>Calculation for heat absorbed/stored</u>

Melting point of Paraffin wax sample=50°C

Specific heat of the materials (Cp) Zinc=0.382kJ/kg-K.

Paraffin wax(Cp solid state)= 2.2kJ/kg-K

Paraffin wax(Cp liquid state)= 2.1kJ/kg-K

Latent heat of Paraffin wax(hfg)=146 kJ/kg

<u>Sample 1: Sample of pure paraffin wax(Qp) mass taken=150 grams</u>

$Qp= m\times(Cp_{solid}\times dT + hfg+ Cp_{liquid})\times dT$

Mass of paraffin wax(m)=150g=0.15Kg

Qp=0.15[2.2× (50-26) +146+2.1 ×(93-50)]

Qp=43.365KJ per 0.15kg of Paraffin wax

<u>Therefore heat that be stored per kg of matrix= 289 KJ/Kg</u>

<u>Sample 2: Sample of 50g of zinc mixed with 150g of paraffin wax.(Qz)</u>

Mass of paraffin wax=150g=0.15Kg

Qp= 0.15 × [2.2× (50-27) +146+2.1 ×(95-50)]

Qp= 43.66 kJ

Qz=0.05×0.382×(95-27)

Qz=1.29 kJ

Qtotal = Qp+Qz =44.95 kJ

Similar calculations are done to determine the heat absorbing capacity in **sample 3** which is a mixture of 150 gms of paraffin wax mixed with 100 gms of zinc refer table 4.3.

RESULTS DISCUSSIONS

The above results highlight the following

- It is possible to increase the rate of heating by mixing Zinc Nano particles. As shown in the table 4.1 it is observed that After about five minutes of heating the rise in temperatures of sample 2 & 3 is significant when compared to sample 1, the reason that may be attributed to increase in heat absorbing capacity of sample 2 & sample 3 is due to the presence of Zinc nano particles, which has better thermal conductivity, thus increasing the overall heat conduction capacity.
- The cooling was done in ambient conditions of 30°C The cooling Pattern shows a prolonged time in all the three samples it is due to presence of paraffin wax which has latent heat, while no variations in cooling pattern is seen between the three samples which only demonstrates the fact that zinc nano particles do not contribute much to the cooling as they don’t possess latent heat part.

CONCLUSIONS

1. The experimental results found that the sample with zinc nano particles(sample 2 & sample 3) and without zinc nano particles (sample 1) when heated using exhaust heat from IC engine

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available at about 400ºC for about 20 minutes, the temperature of the sample 2 was about 95ºC while that of sample 1 was about 70ºC (refer table 4.1), which demonstrates that sample 2 is heated 15ºC more for the same period of heating this extra rise in temperature in sample 2 can be attributed to increase in thermal conductivity of the matrix.

2. The cooling rate is found to be very slow in all the three samples. It took about 3 hours 20 minutes for sample 1 to get back to room temperature while sample 2 & 3 took 20 more minutes to attain room temperature refer (table 4.2), which demonstrates the effect of latent heat from wax. But no difference in cooling rate between the samples helps us to understand that the Nano zinc particles added only contributes during heating of the matrix.
3. Not much variation is seen as for as storage of heat is concerned between the samples as the sensible heat added to the total heat is low because of less mass fraction of zinc nano particles in the matrix. But increase in the zinc mass fraction will help in contributing higher sensible heat storage.

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