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Experimental Investigation of Graphene coated Al cuboid crammed with PCM`s for Efficient Thermal Energy Storage and Conversion.

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***Abstract**: In this paper, we report on the development of a composite cuboid (20x20x20/A cm^3) which can absorb, store and supply heat consistently for longer periods even the heat source is turned off. The main frame of this composite cuboid is made up of aluminium, whose top surface which faces the heat source is coated with graphene. The hollow space inside the cuboid is filled with paraffin wax pellets for latent heat storage. This cuboid is placed inside an insulated thermocol box whose interior is concealed with reflective aluminium foil. a 100-watt incandescent bulb is used as a heat source. Due to the high thermal conductivity of graphene the thermal conductivity of the aluminium increases, resulting in the high amount of heat absorption. Heat is absorbed by the paraffin wax resulting in the phase change from solid to liquid. This latent heat storage liberates heat uniformly until the phase is altered to its original state. This resulted in a maximum temperature of 105°C in 80 minutes and took 148 min to reach room temperature (24^0c). In contrast, the normal aluminium box without coating and PCM reached a maximum temperature of 77°C in 30 min and a cooling time of 40 min. The results show that the usage of PCM's decreased the rate of cooling and graphene coat increased the heat transfer through the surface.*

Key Words: **Composites, Coating, Graphene, Latent Heat Storage, PCM`s.**

1. INTRODUCTION

Mankind has been highly reliant on fossil fuels which are being used in wide applications ranging from combustion engines to electricity. This unceasing usage of non-renewable resources from several decades led to the diminishing of existing fossil fuels and even led to increase of greenhouse gases. This problem can be solved either by using renewable resources or implementation of efficient energy storage systems. But, most of the renewable energy sources are not consistent round the clock. The intensity of the energy output from these renewable sources can sometimes reach more than requirement experience a sudden drop. Thus, energy storage systems play a crucial role in diminishing the gap between energy supply and energy usage. The heat energy can be stored in several types of materials as sensible heat or latent heat which results either in temperature rise or a change in phase. The energy stored in solid or liquid by raising its temperature is called sensible heat storage and heat storage acquired by a change in phase is called latent heat storage. Latent heat energy storage is efficient due to the reason that its ability to store and maintain heat at constant temperature. Properties like phase transition temperature and high latent heat of transition and good heat transfer need to be considered while selecting a PCM. In general paraffin wax (CH_3-CH_2-CH_3) is used as PCM's. The chain length of the paraffin wax can affect both melting point and latent heat of fission. Moreover, paraffin wax is less expensive, non-corrosive, predictable, safe and reliable.

In most of the developed countries majority of the energy is consumed for conditioning air in the buildings to ensure indoor thermal comfort. This led to a surge in energy consumption and air pollution caused by the greenhouse gas emission. To increase the efficiency and decrease negative effects on the environment, energy storage systems are a great solution. In recent constructions of green buildings, microencapsulated Phase change materials are incorporated within concrete walls. This PCM's in the concrete wall absorbs heat from the sun during the day maintaining the human thermal temperature at 23°c but during cooler nights PCM's releases the stored heat and solidifies. In the same way, this storage module can increase the efficiency of heat exchangers, solar water heater, and food drying machines. Graphene is one of the very few materials with high thermal conductivity which ranges from (4.84 ± 0.44) x 10^3 to (5.30 ± 0.48) x 10^3 W/mK. Single layer graphene has higher thermal conductivity. The number of layers influences its thermal conductivity further, the thermal conductivity decreases from 2800 to 1300 W/mK with an increase in the number of the atomic planes from 2 to 4. Phonons are the reason behind its high thermal conductivity. On the other hand, graphene possesses high elastic properties. When graphene is reinforced with aluminium alloys the resultant metal matrix composites show high thermal conductivity than ordinary aluminium alloys. Moreover, the thermal conductivity of aluminium metal matrix composites increases by 15% at 250°C. These concepts of graphene and PCM's are used in developing our composite cuboid. Graphene coating resulted in an increase in max temperature by 30^o than the normal aluminium sheet. The addition of phase change material made the composite cuboid to store and supply heat for nearly four times the time than the regular metal.

2. EXPERIMENTAL SETUP

The experimental setup can be broadly classified into

A. Aluminium box setup.
B. Heating system.

A. Aluminium box setup: -

Aluminium sheet of 0.1cm thickness is used to make a tray of 20x20x4 cm^3 (1600 cm^3) by using tin smithy which has an opening at the top. This tray rests on a hollow box of dimensions 22x22x12 cm^3 (5808 cm^3) with the help of clamps on its inner edges closing the top side of the hollow box. This results in a decrease in volume of the hollow box from 5808 cm^3 to 3872 cm^3, which is the control volume and its temperature is recorded.

As the size of the cuboid surface is large there is no available equipment for us to coat Graphene. So, the top surface of the cuboid box is coated with a mixture of black enamel paint and graphene powder. To ensure the uniformity, graphene powder is sieved while the paint is wet and the excess is dusted. Half of the empty space inside the cuboid box is filled with wax. Various view of the aluminium box setup is shown in figures 1-4 below.

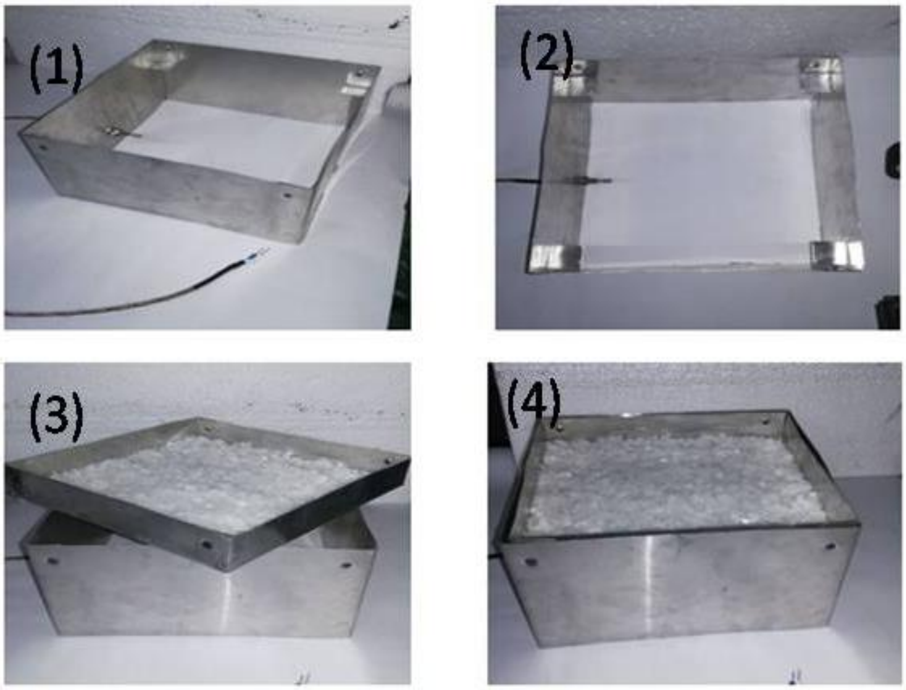

FIG.1-4: shows the box setup with hollow box and tray

B. Heating system: -

Heating system is further classified into

1) Heat Source.
2) Insulation.
3) Temperature measuring devices.

A thermocol box of dimensions 30x34x40 cm^3 (40800 cm^3) is constructed whose interior is insulated with a white drawing chart which acts as an insulator and protects the thermocol from melting. This chart is covered with Aluminium foil to ensure there is no heat loss, most of the heat stays inside the thermocol box. A 100W incandescent tungsten filament bulb is used as a heat source at 220V AC power source and to record the temperature inside the control volume a K-type thermocouple is installed which records the temperature change throughout the process. Various view of the setup is shown in Fig. 5-8 below.

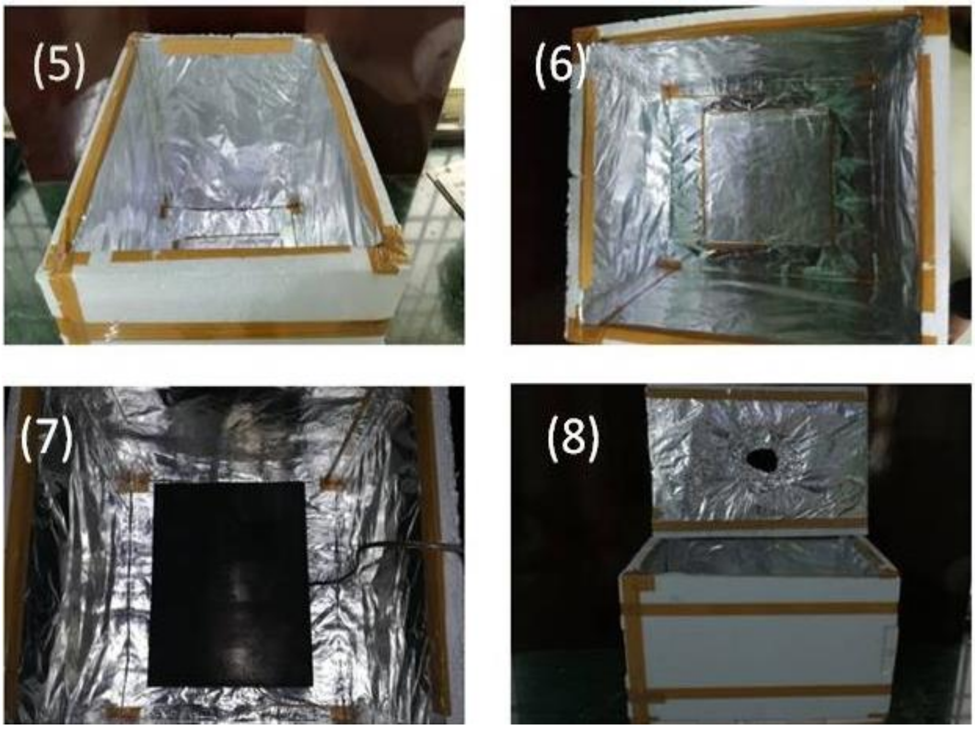

FIG. 5-8 shows the heating system
FIG. 7 shows the graphene-coated lid inside heating system

Temperature representations:

- The temperature inside the control volume: T_1.
- The temperature outside the control volume (Outside the aluminium box and inside the thermocol box): T_2.

3. EXPERIMENT

The aluminium box setup is placed inside the thermocol box and its lid is closed. The initial temperature of the setup is recorded. Though our ultimate result of the setup coated with Graphene and filled with PCM is the main goal, we wanted to do a comparative analysis hence, we experimented with four variations as shown in table 1 below.

Table 1: Experiment Variations

Expt. No.	Box Material	Aluminium box setup	PCM	Graphene + Paint Mixture
1	Aluminium	✓	-	-
2	Aluminium	✓	-	✓
3	Aluminium	✓	✓	-
4	Aluminium	✓	✓	✓

For all the experiments initially, the heat source is turned on and the setup is heated until it reaches a steady maximum temperature and is recorded, Later the source is turned off and the time taken to reach the room temperature is also recorded. Here the temperature inside the control volume i: e T_1 is considered as mainly notable.

4. EXPERIMENTAL RESULTS

Exp. No.1 (Only the Aluminium Box Setup):-

It took nearly 30 minutes to reach a maximum temperature of 77^0c T_1. In just 14 minutes the temperature has raised to 50^0c from 22^0c (room temperature). The rise in temperature is quick till it reached 50^0c, later it took 16 minutes for a 27⁰c rise from 50⁰c to 77⁰c. When the source is turned off, it took 40 minutes to get back to room temperature from saturated temperature.

Exp. No.2 (Top Surface of Cuboid Coated with Graphene Paint Mixture):-

When the top surface is coated with graphene, the maximum temperature reached is around 85⁰c. It took 35 minutes to reach the maximum temperature and the rise in temperature was very quick from 22⁰c to 77⁰c later the time taken for every degree rise is increased. When the source is turned off, it took 55 minutes to reach the room temperature. In general, the temperature inside the control volume of coated setup is 4⁰c-8⁰c more when compared to normal aluminium setup. For instance, if T_2 is 40⁰C thenT_1 (without graphene coat) is 24⁰C and inside the graphene-coated one is 28⁰C (T_1), When T_2 is 60⁰c, the inner temperature is around 30⁰c for noncoated one and is 36⁰c for coated one.

Exp. No.3 (Hollow space filled with PCM without Graphene coat):-

This experiment is subdivided into two parts based on the PCM`s. Half of the hollow space is filled with PCM`s. In the first part, we smashed a household candle and in the second experiment, we used wax pellets from the chemical store. In both the experiments we heated for 40 minutes which resulted in a temperature of 77⁰c raised from 21⁰c (room temperature). But, in the previous experiments, the time taken to reach 77⁰c is around 30 minutes. This is due to the reason that, the heat supplied is absorbed by wax present in the hollow space. Then the heat source is turned off. In the case of candle wax, it took 80 minutes to reach the room temperature. On the other hand, it took nearly 134 minutes to reach room temperature when candle wax is replaced with wax pellets. This may be due to the small size and purity of wax pellets. In both experiments the temperature fall from 77⁰c to 40⁰c is very fast, it took around 1-2 minutes. This is a stunner that even degree temperatures stayed for a long time than the odd temperatures; 36⁰c (2m 8s), 34⁰c (3m 30s), 32⁰c (10m 30s), 30⁰c (23m), 28⁰c (24m) and so-on. In contrast, the odd temperatures; like 39⁰c, 37⁰c, 35⁰c, 33⁰c stayed for lesser than 30s. There are also similarities with the previous experiments like a sharp decrease in temperature from 77⁰c to 40⁰c and 55 minutes for 40⁰c to 30⁰c. Further, the time still increased for the fall of temperature from 30⁰c to 22⁰c.

Exp. No.4(Complete setup): -

In this experiment, the top layer of the cuboid is coated with graphene-paint mixture and graphene powder is sieved over the wet paint surface 3 times to ensure a uniform surface. The half of the hollow space of the cuboid is filled with wax pellets. The total time taken to reach the maximum temperature is 80 minutes and the maximum temperature is 105⁰c. We can observe from the readings below that there is a gradual decrease in time from 24⁰c to 43⁰c, later the time has increased gradually reaching a peak of 9:33 minutes for 69-73 degrees rise. Further, the time followed a similar pattern to that of previous intervals reaching a maximum time of 11:09 minutes for the 100-105 interval. All Intervals and their time patterns are given in table 2 below.

Table 2: Heating and Cooling patterns.

S.no	Heating		Cooling	
	Temperature interval	Time	Temperature interval	Time
1	24-28	2:11	105-101	1:28
2	29-33	1:27	100-96	1:17
3	34-38	1:39	95-91	1:11
4	39-43	1:22	90-86	1:11
5	44-48	2:28	85-81	1:45
6	49-53	2:31	80-76	1:40
7	54-58	3:14	75-71	2:21
8	59-63	6:50	70--65	2:06
9	64-68	7:01	65-61	3:40
10	69-73	9:33	60-56	3:35
11	74-78	5:52	55-51	8:00
12	79-83	5:23	50-46	9:33
13	84-88	4:23	45-41	17:08
14	89-93	6:26	40-36	36:47
15	94-99	9:00	35-31	32:27
16	100-105	11:09	30-24	24:11

5. EXPERIMENT UNDER THE SUN

Though the 100 watts incandescent bulb with a combination of yellow and red light mimics the sunlight spectrum, there are many factors that affect the temperature which includes the humidity, consistency in ambient temperature etc. So, we need to test out the setup in the natural environment to check whether the changes still exist. The experiment is done during August 2017 on an open rooftop in Akkayyapalem, Visakhapatnam, Andhra Pradesh, India. The ambient temperatures are recorded to be fluctuating from 28^0c to 34^0c during the time 10 A.M to 3 P.M. Initially the temperature inside the control volume is nearly the same or matched with the ambient temperature, later as the module got heated up and the temperature inside is raised to a maximum of 36^0c with a difference of 2^0c from the ambient temperature. As time passed the ambient temperature decreased, the temperature in the box remained undisturbed for some time.

6. SEM ANALYSIS OF GRAPHENE COATED SURFACE

The graphene-paint coated aluminium surface is examined under scanning electron microscope and Fig. 9-12 are images at different magnification.

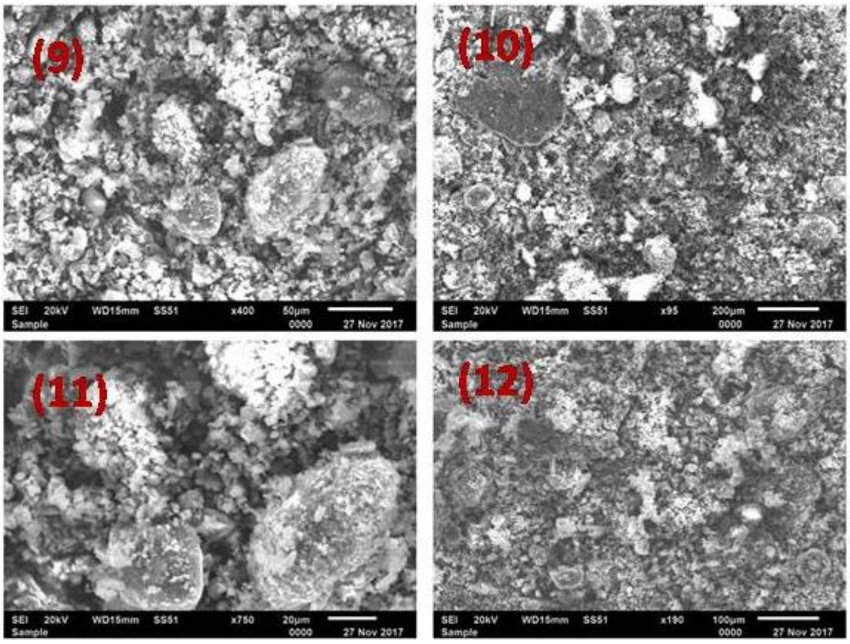

Fig 9-12: SEM Images of Coating at various magnifications

The above Pictures reveals that there are formations of spherical structures (Spherical Morphology) with non uniform grain size. Further, with variations of resolution, we can see the observation that there are lumps deposited in one place and followed by small grain structures i.e. with less agglomeration. As this coating is done with a paintbrush and not with a specific instrument through the surface seems to be uniform, it is not. Here various characteristics come into play that includes the type of brush chosen, the quantity of the Graphene added, Weight: Volume ratio of Graphene: Paint, Number of strokes.

7. OTHER PROPERTIES OF GRAPHENE COATED ALUMINIUM SHEET

Graphene coat on aluminium sheet not only increased the heat transfer but also the electrical properties are altered. When the resistance of the normal aluminium sheet is measured by using Multi meter, it is around 1.1-1.2 ohms. But the resistance is decreased to 0.8 ohms when one side is coated with graphene-paint mixture.

8. CONCLUSION

The aluminium box setup is much efficient in energy storage and conversion and can be used in solar based food drying machines and can be used in other places where there is the inconsistency of heat generation but require a consistent and distributed heat inside a control volume.

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11. BIBLIOGRAPHY

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