International Journal Of Engineering Research And Development
e- ISSN: 2278-067X, p-ISSN: 2278-800X, www.ijerd.com
Volume 18, Issue 1 (Jan.-Feb. 2022), PP. 21-31

Waste Heat Recovery from Air Conditioning System using Composite Phase Changing Material

Shivam Vyas[1], Rushikesh Thamke[2], Nikesh Tanwar[3], Dhananjay Waghela[4], S.D. Khetree[5]
[1,2,3,4,5]*Department of Mechanical Engineering,*
Bharati Vidyapeeth College of Engineering, Navi Mumbai, Maharashtra, INDIA
Corresponding Author: shivam.vyas.1807@gmail.com

ABSTRACT:
In the modern world, as people's demand for comfort cooling is increasing, the usage of air conditioners is also increasing nowadays. Air conditioning plays a tremendous role in increasing the Earth's temperature to some extent. An air conditioner is defined as a system that treats air in a defined enclosed area through a refrigeration cycle. In air conditioners, the heat of the indoor air is transferred to the outside air and rejected as waste heat into the environment, which can increase the overall Earth's temperature. Waste heat rejected out from the condenser of an air conditioner, as a by-product remains unutilized in most forms, thereby creating uneasiness among the people passing nearby to it. And in some cases, it can also contribute to an increase in the Earth's temperature. So, to utilize this waste heat for productive purposes, Waste Heat Recovery System can be used, which can increase the efficiency of a system. The main motive for using the Phase Changing Material as the main material for our Waste Heat recovery System is to utilize most of the waste heat from the air conditioner in increasing the temperature of the water. This paper proposes the development of the Waste Heat Recovery System using the Phase Changing Material, mainly Paraffin Wax, mixed with Carbon forming a composite Phase Changing Material. In this case with only PCM, we were able to achieve a 4.3% increase in the COP of the Air Conditioner. As Carbon quantity increases, the increase % in COP of air conditioner increases, and the heat recovered by water also increases.
KEYWORDS: *Waste Heat Recovery; Coefficient of Performance (COP); Phase Change Material; Air Conditioning;*

Date of Submission: 28-03-2022 Date of Acceptance: 19-04-2022

I. INTRODUCTION

Waste heat is the unused heat dissipated or given out to the surrounding environment(in the form of thermal energy) during or after the thermodynamic process. It is dissipated, as a result of a by-product in between, or at end of such a process[20]. As waste heat is low-grade energy, waste heat has lower utility than the original energy source. All such processes give off some waste heat as a fundamental result of the laws of thermodynamics[53]. The sources of waste heat include hot combustion gases discharged into the atmosphere, heated products exiting the industrial process, an air conditioner conditioning the room space and rejecting the heat to the environment, and heat transfer from hot equipment surfaces[59]. Waste heat often dissipates into the atmosphere, or large bodies of water like rivers, lakes, and even the ocean. Since waste heat is a necessary product of heat engines, the efficiencies of power plants are limited, and therefore must burn more fuels to achieve their desired energy output. This increases greenhouse gas emissions and contributes more to global warming.

An air conditioning system has become a staple of the day to day life. Whether in homes, offices, or vehicles, the main purpose of this system is to provide comfort by altering the properties of the air, usually by cooling the air inside. This system is so common that one can experience its effect anywhere we enter. An air conditioner is a system(or device) that is used to cool down a space by removing heat from the space and moving it to some outside area[59]. The cool air can then be moved throughout a building through ventilation[57].

A: Function, principle and working of an air conditioner

The main function of an air conditioner is to change the temperature conditions of a particular environment. Air Conditioner follows the principle of the Vapor Compression Refrigeration system. Generally, there are four main components of an air conditioning system: compressor, condenser coil, expansion valve, and evaporator coil.

The compressor lies at the heart of any air conditioner. The compressor takes in the warm refrigerant vapor and compresses it into a denser form[69]. This process also causes an increase in temperature and pressure, making the refrigerant hotter than before[60]. The pressurized refrigerant is eventually pushed through the condenser coil. After that, the high temperature, high-pressure refrigerant vapor enters the condenser. A condenser fan built into the outdoor cabinet directs ambient air through the condenser coil[69]. This process, which is a constant pressure, changes the refrigerant from a hot, high-pressure vapor into a hot liquid.

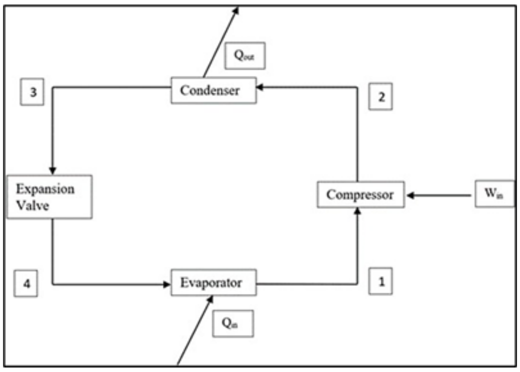

Figure 1: Block diagram of the working of an Air Conditioner

The condenser coil uses the airflow to expel heat from the refrigerant and its job is to release heat from the refrigerant. After then, the refrigerant moves toward the expansion valve. Before the refrigerant passes to the evaporator coils, it must be cooled down[60].This is where the expansion valve (also known as a metering device) comes in, normally a thermostatic expansion valve, operating at constant enthalpy. In this process, the refrigerant passes through the expansion valve, which converts hot refrigerant at high pressure into cool refrigerant at low pressure, thereby reducing its pressure and temperature.

Nomenclature	
C.O.P	Coefficient of Performance
RE	Refrigeration Effect(KJ/kg)
T	Temperature(°C)
TR	Ton of Refrigeration
W	Watt(J/s)
Abbreviations	
PCMs	Phase Change/Changing Materials
PCM	Phase Change/Changing Material
ACs	Air Conditioners
HVAC	Heating, Ventilation & Air Conditioning

Figure 2: General Nomenclature(*The rest abbreviations are given during the calculations part***)**

B: Phase Changing Materials

Phase Change Material is defined as a material that releases/absorbs energy at phase transition temperature to provide useful heat/cooling. These are substances that can absorb or release large amounts of energy, i.e., so-called latent heat when they experience phase transitions among solid, liquid, and gas states. PCM acts like a battery for heat energy because they absorb heat energy as they melt and can be “recharged” by cooling them until they crystallize and give the stored energy back to the environment. Phase change materials (PCMs) are ideal for use in any application where storage and release of thermal energy are desired. They can store and release heat energy thousands of times without a change in thermal properties[73].

PCMs are currently attracting a lot of attention for this application due to the progressive reduction in the cost of renewable electricity, coupled with limited hours of availability, resulting in a misfit between peak demand and availability of supply[72]. There are two principal classes of phase change materials: organic (carbon-containing) materials derived either from petroleum, from plants, or animals; and salt hydrates, which generally either use natural salts from the sea or mineral deposits or are by-products of other processes.

Name	Melting point (°C)	Latent heat (kJ/kg)	Density (kg/m^3)	Thermal conductivity (W/m·K)	Heat capacity (kJ/kg·K)
(Organic)					
n-Octadecane	27.7	243.5	865/785	0.19/0.148	2.14/2.66
Paraffin wax	32	251	830	0.514/0.244	1.96/3.26
RT 55	55	172	880/770	0.2	2
RT 70 HC	69–71	260	880/770	0.2	2
(Inorganic)					
$CaCl_2 \cdot 6H_2O$	29.6	190.8	1562	N/A	N/A
$Ba(OH)_2 \cdot 8H_2O$	78	265–280	2070/1937	1.225/0.653	N/A
E117	117	169	1450	0.7	2.61
$LiNO_3$-$NaNO_3$	195	252	N/A	N/A	N/A
$NaNO_3$	306	172	2261	388.9	N/A

Figure 3: Properties of different Phase Changing Materials

Several factors need to be considered when selecting a phase change material. An ideal PCM will have high heat of fusion, high thermal conductivity, high specific heat and density, long-term reliability during repeated cycling, and dependable freezing behavior. Paraffin waxes are the most common PCM for electronics thermal management because they have a high heat of fusion per unit weight, have a large melting point selection, provide dependable cycling, are non-corrosive, and are chemically inert. Paraffin PCMs also have a low thermal conductivity, so designing sufficient conduction paths is another key design consideration[64].

C: Need of Waste Heat Recovery System

One of the great ironies of climate change is that as the planet warms, the air conditioning technology, which people need nowadays to stay cool, will only make the climate hotter. According to the International Energy Agency, there are about 1.6 billion heating, ventilation, and air conditioning units in the world. By 2050, researchers expect the number of room air conditioners on Earth to quadruple to 4.5 billion, becoming at least as ubiquitous as cell phones are today[50]. By the end of the century, greenhouse gas emissions from air conditioning will account for as much as a 0.5°C rise in global temperatures, according to the World Economic Forum[56].

Air Conditioners(ACs) require lots of electricity to work, which increases a lot during the peak summer season. Air Conditioners extracting more power can reduce their overall Coefficient of Performance (C.O.P) in total. Also, they reject waste heat from the condensers, which contribute to global warming.

So to reduce the amount of waste heat rejected by the condenser of the Air Conditioning System, and to increase its C.O.P, a waste heat recovery system is required. The Waste Heat Recovery System will be in the shape of a container or a wooden box, with Phase Changing Material, filled as per weight in the Aluminum Pipes, where these are stacked, hung inside the box, and placed in front of the condenser, which will try to absorb most of the waste heat from the condenser. So, we are fabricating such a system, which is useful and cost-effective.

II. LITERATURE REVIEW

This section presents the literature review of various authors in the field of the Waste Heat Recovery.

Joseph Stalin et.al[1] devised a methodology where the authors experimented to recover the waste heat rejected by the 1TR air conditioning system. Their main aim was to utilize the waste heat discharged at the outlet for some productive purpose. In their experiment, the heat rejected by the condenser was used for heating the water into the circulating tank, which increases the temperature of the water. Then, the hot water was stored in an insulating tank, which can be used for domestic purposes. They had shown that replacing the water-cooled condenser in AC, helps in recovering the waste heat equivalent to 4 LPG gas Cylinders/ year.

R.B. Lokapure and J.D.Joshi[2] devised a methodology and emphasized energy conservation by using the technique of waste heat by utilizing waste heat from the Window Air-conditioning system and increasing C.O.P simultaneously. The purpose of this experimental apparatus is to develop a multi-utility air conditioning system to produce simultaneously both the air conditioning effect and the generation of hot water, which can be used for domestic purposes. Their experimental setup was set on the Window AC, where they connected the waste heat recovery system, with a designed heat exchanger attached to it. They had set the target of improving the C.O.P of the system up to 20 %, but in this case, they were able to achieve their goal by recovering energy and improving C.O.P up to 13.66% only.

Naser Rezaei et.al[3] devised a unique and innovative methodology of waste heat recovery which can simultaneously reduce the chances of spreading SARS-CoV-2 from heating, ventilation, and air conditioning(HVAC) systems. They have devised a Waste heat recovery system that can reduce the chances of spreading SARS-CoV-2 from hospitals, by using the waste heat to heat the exhaust air. These authors have done their best efforts for controlling the outbreak of SARS-CoV-2 with their proposed heat recovery system. Their system produces exhaust air with a temperature range of 50 °C –80 °C and a relative humidity range of 40%–50%, conditions under which SARS-CoV-2 was observed to disappear.

Xuelai Zhang et.al[4] have devised an experimental investigation on a condensing heat recovery system by using paraffin wax as the PCM(Phase Changing Material), which is designed for daily hot water preparation. They have followed the methodology of doing the experimental analysis of the waste heat recovery system using paraffin wax as PCM. They have designed the waste heat recovery system for the air conditioner with a thermal storage container, thermally insulated with polyurethane, and having paraffin wax as the Phase Changing Material. With their experiments and analysis, they concluded that sensible condensing heat could be recovered effectively by a thermal storage container added and an air conditioning system kept in order with condensing heat recovery.

Zhaolin Gu et.al[16] have developed a heat recovery system using phase change materials (PCMs), which is used to store the rejected (sensible and condensation) heat from the air conditioning system. The thermal properties of the technical grade paraffin wax and the mixtures of paraffin wax with lauric acid(LA) and with liquid paraffin(LA) (paraffin oil) were investigated and discussed by them. Calculations were performed at different condensing temperatures i.e. at temperatures 40, 45, 50, 55, and 60 °C, and according to their analysis, the amount of compressor power input is increased with the condensing temperature increase, whereas the refrigeration capacity and heat recovery capacity are decreased with the increasing condensing temperature. According to their research, analysis, the technical grade paraffin wax and the mixtures with LP and LA are proper PCMs for heat thermal energy storage.

Ramyashree A. P et.al. [23]. worked on a window-type air conditioning system consisting of an air-cooled condenser that was taken for experimentation. Behind the condenser, a rectangular duct is created with a hole at the center which bypasses the hot air. This heating of water is done by extracting the waste heat coming out of the condenser. With this system, they were able to increase the COP of the system by 6% by incorporating a heat exchanger with AC.

Mahbubur Rahman et.al[43] gave a thorough review on Phase Changing Materials, and its classification in detail. According to the authors, they have defined PCMs as the latent heat thermal energy storage materials which use their chemical bonds for the storage and releasing of energy. When these materials reach the temperature at which they melt, they absorb large amount of energy without getting heated. PCMs solidify and releases energy when the surrounding temperature drops. They haves stressed on utilising such type of materials in different types of industries other than solar energy, which can help in doing the energy conservation.

Francis Agyenim et.al[45] describes latent heat thermal energy storage system (LHTESS) where we can effectively charge and discharge latent heat energy from PCM. It is said that most of the phase change problems had been carried out at range of 0 degree Celsius to 60 degree Celsius. Content also describes about PCM containers. In this, rate of heat transfer can be varied according to factors like the geometry of PCM container and parameters of the container for given amount of PCM. Cylindrical PCM containers had been used and tested. It also describes the techniques which can enhance the heat transfer of the PCM and its containers. At last, author had described the classification of heat transfer characteristics.

Elham Ale Hosseini and Seid Mahdi Jafari[46] had discussed about the nanoencapsulation of phase change material (PCM) and their applications in various fields for energy storage and management. According to them, this process also increases the efficiency of PCM. It avoids the leakage of PCM when it is in liquid state. Further the techniques to produce nanoencapsulation of PCM are discuss which includes chemical technique, physico-chemical technique and physico-mechanical techniques. At last the applications are discussed which includes food industry, solar energy storage, heat exchanger, etc.

III. METHODOLOGY, EXPERIMENTAL ANALYSIS AND CALCULATIONS

A:Methodology

The Paraffin Wax was selected as the Phase Change Material for our project. Paraffin is a high-molecular-mass hydrocarbon with a waxy consistency at room temperature. Kinds of paraffin are made of straight-chain hydrocarbons. The melting point of paraffin is directly related to the number of carbon atoms within the material structure with alkanes containing 12-40 C-atoms possessing melting points between 6°C and 80 °C. So, after selecting the wax, we experimented to find out its melting point. We found that the melting point of Paraffin Wax is 39.2°C. And for preparing the composite Phase Changing Material, we have used Carbon in the form of Charcoal Powder. Well, as per Guijun Yang et. al[47], experimental results proved that Carbon can effectively improve the thermal conductivity of PCM, and it is well suited. In our project, we have mixed the Carbon and Wax in a solid-state only to form composite PCM.

Initially, the Aluminum pipes were cleaned so that no foreign particle is present there inside the pipe. Then Paraffin Wax as per the calculations was measured in total, and then we split the total weight of the wax as per the number of pipes in the experimental analysis. We performed the Waste Heat Recovery analysis by using the combined mixture of PCM(Wax) and Carbon in the form of Charcoal Powder. We added the Charcoal powder to the total weight of Wax, and made the batches out of it, as per the proportions like – 0% of Carbon + 100% Wax, 5% of Carbon + 95% of Wax, 10% of Carbon + 90% of Wax, and 15% of Carbon + 85% of Wax proportions. Then, by permanently sealing one end of the hollow Aluminum pipe, we added the mixture to each of the pipes carefully.

After filling them, we stacked all the pipes with rope, sealed the remaining end with the thermocol cork, and then we hanged it vertically in the plywood box chamber, in front of the condenser. Then we attached this box in front of the condenser. We started the air conditioner after attaching it, performing each of the experimental analyses for 30 min, noted down the temperature of the air inside the box at regular intervals. After experimenting for 30 minutes, we opened the door of the box, took out the aluminum pipes stack, and then quickly immersed the whole into the bucket of water. We noted the temperature of the water and its observations in a tabular form..

Sr No.	Material	Thermal Conductivity(W/mK)
1	Aluminum	205
2	Plastic	0.45 – 0.52
3	Wood	0.04 – 0.12
4	Carbon	140
5	Paraffin Wax	0.21

Table 1: Table of Thermal Conductivity of Materials used

Figure 4: Charcoal Powder, and Paraffin Wax

Figure 5: Stacked Aluminum pipes filled with PCM

Figure 6: Condenser of Air Conditioner.

Figure 7: Outside box of the Waste Heat Recovery System

B:Design and Specifications

The Paraffin Wax, used in this experiment has melting point of 39.2°C, which we found out during the experimentation. The other properties of Paraffin Wax, which we have used in our calculations, are mentioned:

Latent Heat of Fusion	190 KJ/kg
Solid Density	930 kg/m^3
Liquid Density	830 kg/m^3
Thermal Conductivity	0.21 W/m °C
Solid Specific Heat	2.1 KJ/kg °C
Liquid Specific Heat	1.98 KJ/kg °C

Table 2: Properties of Phase Changing Material(Paraffin Wax)[74]

Sr No.	Title	Value
Ĩ	Company	Daikin
2	Model Name(Indoor/Outdoor)	ATC50SRV162/RC50SRV162
3	Rated Cooling Capacity	5.2 KW
4	Power Consumption	1600 W
5	COP	3.25
6	Operating Current	7.3A
7	Indoor Unit Dimensions	(298 X 885 X 229)mm^3
8	Outdoor Unit Dimensions	(595 X 845 X 300) mm^3

Table 3: Technical Specifications of Air Conditioner

C: Calculation of Waste Heat rejected by Condenser & the total mass of Phase Changing Material

$$C.O.P = (Desired\ Effect)/(Work\ Done) \quad = (Q_2)/(Q_1 - Q_2) \qquad (1)$$

Where Q_2 = Rated Cooling Capacity ; Q_1 = Waste Heat Rejected from the Condenser

3.25 = (5200)/(Q_1 -5200) → Q_1 = 6800 W

(*Neglecting the losses due to convection and radiation as the wooden box has been placed all around the condenser, and inside the wooden box, Aluminum foil is attached which can reflect most of the amount of heat inside*)

Diameter of the Aluminum Pipe(D) = 1.8cm, Length of the Aluminum Pipe(H) = 52cm
Length of the Cork = 2 cm
Remaining length to be utilized = 52 – 2 = 50cm
Volume of the Pipe $=\frac{\pi}{4} \times D^2 \times H$ (2)
= 127.23 cm^3 = 0.127 dm^3 = 0.127 litre = 127 ml of PCM in Liquid State
Now , Density = $\frac{Mass}{Volume}$ (3)
As Paraffin Wax has two densities, one in the Solid form, and other in the liquid form, so first we will calculate the masses of both PCMs in liquid and solid state and then we will take the average of both masses to get the mass.
Liquid Density = 830 kg/m^3 = 0.83g/cm^3 → $Mass_1$ = 0.83 x 127 = 105.41g.
Solid Density = 930 kg/m^3 = 0.93g/cm^3 → $Mass_2$ = 0.93 x 127 = 118.11g
m = Average of $Mass_1$ and $Mass_2$ = 111.76g
Mass of PCM for 1 pipe = 111.76g
Mass of PCM for 25 pipes = Total Mass for PCM = 111.76 x 25 = 2794g = 2.794kg = 2.79kg

The temperatures inside the wooden box, with composite PCM having different % of Carbon, were noted and these are mentioned in Table no.4.When these pipes with hot PCM are immersed in water, the water temperatures are noted and tabulated in Table no.5 as mentioned, for different PCM proportions. The average temperature from table 4, for further calculation is taken as 62°C as Tf (Final Temperature of Composite PCM)

Sr No.	Time(cumulative) (min)	Temperature (℃) with PCM(0% Carbon)	Temperature (℃) with PCM(5% Carbon)	Temperature (℃) with PCM(10% Carbon)	Temperature (℃) with PCM(15% Carbon)
Ĩ	6	59.3	58.9	59.5	59.9
2	12	62.4	60.4	60.2	61.2
3	18	62.8	61.9	61.9	60.9
4	24	62.9	62.2	62.5	62.5
5	30	62.8	62.5	62.3	62.7
	Average	62.04	61.18	61.28	61.44

Table 4: Temperatures of PCM with different proportions of Carbon in it

Sr No.	Title	$T_{initial}$(°C)	T_{final}(°C)	ΔT(°C)
1	PCM with 0% Carbon	24.5	35.6	11.1
2	PCM with 5% Carbon	24.5	37.7	13.2
3	PCM with 10% Carbon	24.5	39.8	15.3
4	PCM with 15% Carbon	24.5	41.0	16.5

Table 5: Change in Temperature of Water during Experiment

Figure 8: Waste Heat Recovery System

Figure 9: Inside Setup

D:Sample Calculation for general mixture of PCM and Carbon

1. **Heat Recovered by the whole setup of PCM and Pipe**

Heat Absorbed by Composite PCM = $m_1[Cp_s(T_m - T_i) + L_h + Cp_l(T_f - T_m)] + m_2Cp_C(T_f - T_i)$ (8)

Where Cp_s = Specific heat of PCM in Solid State = 2.1KJ/kg °C = 2.1 x 10^3 J/kg °C
Cp_l = Specific heat of PCM in Liquid State = 1.98KJ/kg °C = 1.98 x 10^3 J/kg °C
T_i = Initial Temperature of Composite PCM = 27°C
T_f = Final Temperature of Composite PCM = 62°C(during experiment)
T_m = Melting Temperature of PCM = 39.2°C(during experiment)
L_h = Latent heat of Fusion = 190KJ/kg = 190 x 10^3 J/kg
Cp_c = Specific Heat of Carbon = 0.71KJ/kg°C = 710J/kg°C

5% of the total mass of PCM = 0.05 x 2.794 = 0.1397kg of PCM, this mass will be replaced form the total by 5% of Carbon, and mixed in the total mass
Mass of PCM = m1 = 2.6543kg, Mass of Carbon = m2 = 0.1397kg

Heat Absorbed by Composite PCM = 2.6543[2.1 x 10^3(39.2 – 27) + 190 x 10^3 + 1.98 x 10^3 (62 – 39.2)] + 0.1397 x 710(62 – 27) = 692145.8852 + 3471.545 = 695617.4302J

As this experiment was performed for 30 min. So Heat Absorb Rate = $\frac{695617.4302\,J}{1800 sec}$ = 386.454W

2. **Heat Utilized by Water from the Waste Heat Recovered by the PCM Setup**

Now, after 30 min being exposed in front of the condenser of Air Conditioner, sealed in a wooden box and fixed inside, the whole PCM + Pipe Setup is now dipped into the cylinder bucket having water inside it

Volume of Water Taken = 3 L = 3 x 10^{-3} m^3 → Mass of Water =Density of Water x Volume
= 1000 x 3 x 10^{-3} = 3kg.

Heat utilized by Water from PCM = m_w x Cp_w x ΔT (9)
Where Cp_w = Specific heat of Water = 4.187KJ/kg °C = 4.187 x 10^3 J/kg
ΔT = Temperature difference(taken from table) = 13.2°C

Heat utilized by Water from PCM = 3 x 4.187 x 10^3 x 13.2 = 165805.2J
As this setup was dipped for 10 min. So Heat Absorb Rate = $\frac{165805.2\,J}{600 sec}$ = 276.34W

3. **Calculation of New C.O.P and its comparison with the original C.O.P**

$$C.O.P = \frac{Refrigeration\ Effect + Heat\ Utilized\ by\ Water\ from\ PCM(Waste\ Heat)}{Work\ Done} \quad (10)\ (\text{from [2]})$$

$$C.O.P = \frac{5200+276.34}{1600} = 3.42$$

% Increase in C.O.P = $((3.42 - 3.25)/3.25) \times 100 = 5.23\%$

4. **Waste Heat Recovery %**

$$Waste\ Heat\ lost = \frac{Waste\ Heat\ from\ condenser - Heat\ Utilized\ by\ Water}{Waste\ Heat\ from\ condenser} \times 100 \quad (10)\ (\text{from [2]})$$

$$= \frac{6800 - 276.34}{6800} \times 100 = 95.93\%$$

Waste Heat Recovered = $100\% - 95.93\% = 4.06\%$

IV. RESULTS

Table 6: Results Table

S.No.	Title	New COP	Increase in COP(%)	Heat Recovered by Water(W)	Waste Heat Recovery (%)
1.	PCM with 0% Carbon	3.39	4.3	232.37	3.41
2.	PCM with 5% Carbon	3.42	5.23	276.34	4.06
3.	PCM with 10% Carbon	3.45	6.16	320.31	4.71
4.	PCM with 15% Carbon	3.4658	6.77	345.43	5.08

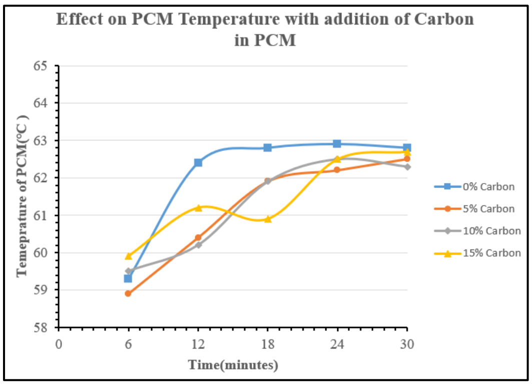

Figure 10: Effect of % Carbon on PCM Temperature

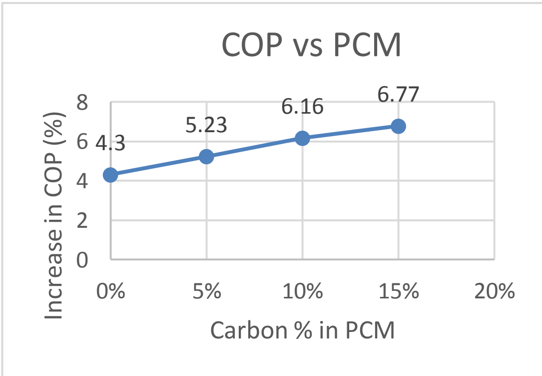

Figure 11:Increase in COP

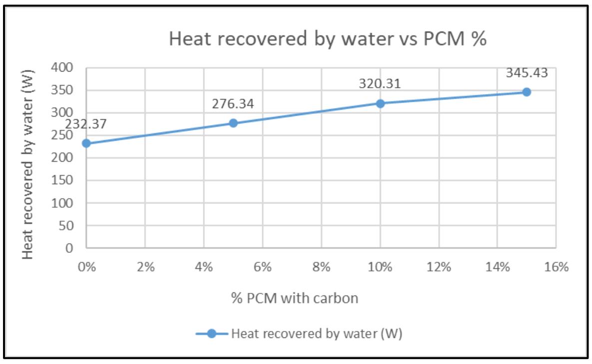

Figure 12: Variation in Heat Recovered by Water

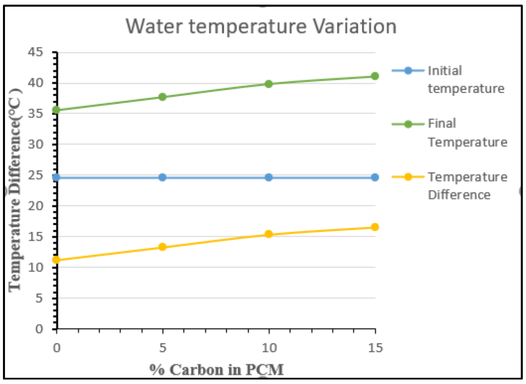

Figure 13: Temperature of Water Variation

V. CONCLUSION

From the above tables and graphs, the conclusions for the 25 tubes of Aluminum with 52 cm length and 1.8 cm diameter are as follows:

1. COP of an air conditioner increases with 4.3% with only PCM, 5.23% with 5% of Carbon, 6.15% with 10% of Carbon 6.77% with 15% of Carbon in the total mass of PCM.
2. With % increase of Carbon in the PCM, the temperature of the composed PCM increased in a fast manner during the experimental analysis.
3. Variation in the temperature of water increased with increase in % of Carbon in PCM

VI. FUTURE SCOPE

The area of Waste Heat Recovery, in general, is necessary for those countries, which are deficient in energy consumption. It is necessary to reach a balance between economically, technically, and environmentally appropriate ways of recovering waste heat not only from Air Conditioners but also from other processes too. In our experimental analysis, we have used PCM with Carbon, only randomly mixed in solid state, which gave us good results. By trying this similar methodology for more than 15% Carbon i.e. with 20% Carbon, 25% Carbon, etc., then the results will be much better. With 25 pipes of 52 cm each and 1.8 cm in diameter, we were able to recover only a small part of heat with this, and also the pipes were first taken out from the box and then dipped into water, so in between this, losses incurred were more. In the future, If along with this setup, a heat exchanger is also attached to it with a continuous flow of water, then it can provide much better results in comparison to our analysis.

Also in the future, the stacks of such pipes can be used which can help in the recovery of more waste heat.

ACKNOWLEDGEMENT

It gives us immense pleasure to express our sincere gratitude towards our guide Prof. S.D.Khetree for her valuable guidance in helping us with all the details related to the project. We are deeply indebted to our respected Principal Dr. S.D.Jadhav and Mechanical Department H.O.D Dr. S.N.Teli, for giving us this valuable opportunity to do this project, and we express our heartily thanks to them for their assistance without which it would have been difficult in finishing the work successfully.

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