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# Performance Improvement of a Domestic Refrigerator Using Pcm

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***Abstract:*** *The project deals with the performance improvement of a refrigerator using PCM (phase change material). The heat release and storage rate of a refrigerator depends upon the characteristics of refrigerant and its properties. The evaporator is covered with help of leak proof aluminum box which has storage capacity or passage for phase change material is fabricated. The HS01/I is an inorganic chemical based PCM having nominal freezing temperature of* $1^{0}$*C. It stores thermal energy as latent heat in its crystalline form. While changing phase this latent heat is released or absorbed, allowing in maintaining the ambient temperature. HS01/I is made of the right mix of various salts, additives and nucleating agents allowing equilibrium between solid and liquid phases to be attained at the melting point. The HS01/I are free flowing in molten state and can be encapsulated in various forms. COP of a domestic refrigerator system is calculated. It is found that the system with PCM is more effective than system without PCM and is increased up to 23 %. The energy stored in the PCM is yielded to the refrigerator during the off cycle and allows several hours cooling without power supply.*

## I.INTRODUCTION

Throughout the history, food preservation has always been one of oldest problems to survive in every culture. In old times before the invention of mechanical refrigeration systems, people keep their food and beverage by some primitive ways, such as by cooling in well preserved caves or in cold water wells, or by drying under the sun or in salt baths or by smoking. Smoking and salting are applied especially to the food which is susceptible to spoilage, such as meat or fish. The milestones in cooling can be summarized as follows: At 1000 B.C., people in China are able to cut and store ice. Around 500 B.C., Chinese and Indian people are able to make ice in cold nights by putting water inside pots and keeping the pot wet. In England, at the beginning of $18^{th}$ century, ice can be collected in winter and put into icehouses to use them in summer. At $19^{th}$ century, portable ice boxes are started to be used. The first artificial refrigeration were proposed and demonstrated by a Scotsman, Dr. William Cullen at mid – 1700s. He created a vacuum using a pump over a container filled by diethyl ether, which caused a sudden boiling and absorbing heat from the surroundings. Dr. William Cullen's demonstration is followed by the works of Oliver Evans, Jacob Perkins and Michael Faraday. At the beginning of 1800s, Michael Faraday liquefied ammonia to create a cooling effect. Oliver Evans designed the first refrigeration machine, which employs a compression cycle similar to the today's modern vapor compression cycle, but that machine is never built. Lately, his design is modified and built by Jacob Perkins and he patented his invention with the title "Apparatus and means for producing ice, and in cooling fluids." By his patent, Jacob Perkins is known as the father of refrigeration. German engineer, Carl von Linden is also a notable inventor in the history of refrigeration. He invented and patented not a refrigeration machine, but an improved method for continuous process of liquefying gases, such as ammonia, sulphur dioxide and methyl chloride for cooling purposes. In 1873, he developed a refrigerator whose working fluid is dimethyl ether. Later, he improved his invention with a more reliable working fluid, ammonia and built a refrigerator based on ammonia in 1876. Later Freon was used as refrigerant but today, R134a is used in refrigeration systems.

## II.LITERATURE SURVEY

The application of PCMs on household refrigerators has showed some benefits in different ways. Since it stores a high amount of heat energy, it can keep the cold energy further and prolongs the compressor off time and reduces the number of on – off cycles. Reducing the number of on – of cycles of compressor is beneficial in terms of efficiency, because the uneven distribution of refrigerant fluid decreases the efficiency of refrigerator at the next start of compressor, until the balance of refrigerant fluid is reestablished. Also, PCMs have an effect of stabilizing the temperatures of refrigerator by reducing the fluctuations caused by on off cycles, which has a dramatic negative effect of frozen foods. The studies about application of PCMs on household refrigerators can broadly be divided in two parts, experimental and numerical. The numerical studies are validated by test data. The type of PCMs in this studies are generally water, or eutectic mixtures of water and salt which have a phase change temperature below 0$^{o}$C, making it suitable for keeping cold energy. In 2005, K. Azzouz et al. investigated the effect of phase change materials applied to the evaporator of a household refrigerator. They developed a simple mathematical model based on conservation equations for the cases with and without PCMs. According to their study, the coefficient of performance and the energy efficiency of this new design increased significantly. The thermal storage of PCMs caused a 10 hours or more continuous operation without electric supply and this reduces the overloading problem to the electrical distribution grid during peak loads.A static type refrigerator without a freezer compartment is considered in this study. The performance of this refrigerator is specified in terms of cooling capacity (500 W.h for 4$^{o}$C and 20$^{o}$C internal and external temperatures respectively), electric consumption, and evaporation and condensation temperatures. The measured global heat transfer coefficient of the walls of refrigerator is 0.34 W/m$^2$K. The types of used PCMs are eutectic salt solutions, whose phase change temperatures are between -6 and 0$^{o}$C. The size of PCM is 0.03 x 0.5 x 0.5 m, having a volume of 0.0075m$^3$. The location of PCM slab in the refrigerator, and the presentation of energy balance of the evaporator and with PCM can be seen in Figure.

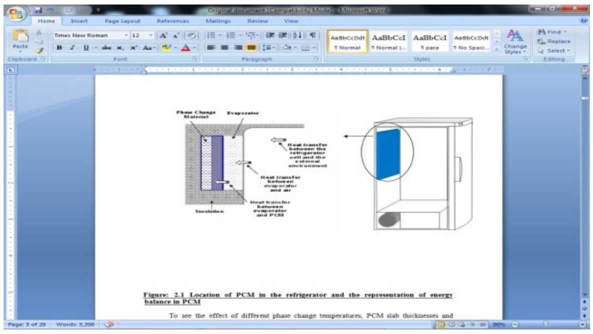

**Fig-1: Location of PCM in the refrigerator and the representation of energy balance in PCM**

To see the effect of different phase change temperatures, PCM slab thicknesses and ambient temperatures, many simulations are carried out. According to the study, the addition of PCM slab significantly increased the coefficient of performance (COP) and the cooling capacity. The heat transfer at the evaporator is increased by %86. The evaporation temperature is increased from -19 to -7$^{o}$C. The decrease of evaporation temperature results a reduction of pressure

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compression ratio, thus a lower power consumption. The COP increased from 1.09 to 1.9. In another study by K. Azzouz et al. (2008), the mathematical model in their previous study is supported by experiments. They used the same refrigerator and PCMs. They validated their model by experimental measurements for the cases with and without PCM. After the model is validated, they did a series of simulations to perform a parametric study with different phase change temperatures from -9 to 0$^o$C, various PCM thicknesses and various thermal load. To describe the effect of PCM slab on the evaporator more clearly by experiments, K. Azzouz et al. conducted another experimental study in 2009. In this study, water and an eutectic mixture having a phase change temperature of -3$^o$C is used for a variety of operating conditions (PCM thickness, ambient temperature and thermal load). This study suggests some options to improve the efficiency of a refrigerator and the option of improving the efficiency of heat exchangers (evaporator and condenser) by using latent heat with PCMs to the evaporator is investigated thoroughly, which is a cheap and effective solution.The experimental device used in previous studies by K. Azzouz remained unchanged in this study, and the PCM slab is also located at the back side of the evaporator. Two setups with different PCM quantities are prepared, having thicknesses of 5 and 10 mm. Temperatures at various locations, such as compressor, condenser, evaporator, PCM slab and refrigerated space are measured with thermocouples. 3 thermocouples are used to measure the refrigerated space temperature. Evaporator and condenser pressures are measured at compressor inlet and outlet with two pressure transducers. The other benefit of employing PCM arises in COP. According to the experiments, the COP increase is between %10 and 30, depending on the thermal load and the type of PCM used. In another study by A.C. Marques et al. analyzed a static type thermal energy storage refrigerator numerically to compare the temperature stability with using different type PCMs. Three scenarios about the location of PCMs are included and the most effective one is evaluated, vertical position at the backside of storage compartment, horizontal position at the top of the compartment, and the combination of these two (vertical and horizontal). In the numerical model, only the half of the refrigerator compartment is included because of the symmetric geometry. At first, the model was validated by using both previous studies and experiments, and then simulations are conducted. According to the simulations, vertical PCM configuration resulted a stratified temperature profile. The airflow is circular and air is nearly stagnant at the center. Horizontal PCM configuration resulted more homogeneous temperature profile, with average temperature lower than previous case. The most homogeneous air temperature profile is observed in the third case, combined vertical and horizontal PCM configuration. The average temperature is lowest.In 2012, Oro et al. conducted an experimental study, aiming to increase the thermal performance of commercial freezers by PCMs usually used in supermarkets, by decreasing the temperature fluctuations inside the freezer, under the cases of electrical failure or frequent door openings. Their main motivation was to increase the lifetime and quality of frozen food, which have to be kept under -18$^o$C. A commercial PCM (Climsel C-18 by Climator) is employed for this purpose, having a melting point of - 18$^o$C. The used freezer is a vertical type static freezer. The evaporator tubes form the base of freezer shelves. It has a double glass door and a thermometer. The PCM is encapsulated into stainless steel plates having a thickness of 10 mm and these plates are placed at the top of evaporator coils of every shelf of freezer. The number of PCM plates is 6. During the normal freezing cycle, a fan at the top of refrigerated space circulates air. Test

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packages (M – packs) are used to simulate the thermal load and thermocouples are placed in the center of some M – packs to measure the temperature fluctuations of M – packs. Experiments are conducted with and without the PCMs and M – packs. Different scenarios are specified for door openings and electrical failure. According to the experiments, the temperature distribution inside the freezer reached highest values without PCM and M – packs in the case of electrical failure as expected, since thermal load is least in this case. The addition of PCM showed a great benefit to the temperature distribution inside the freezer. After a prolonged electrical failure, the use of PCM made the temperatures lower.

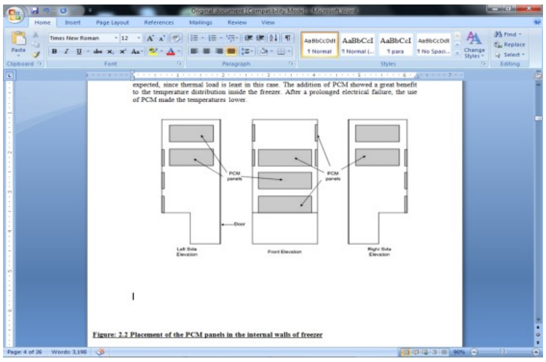

**Fig-2: Placement of the PCM panels in the internal walls of freezer**

## III.EXPERIMENTAL SETUP

A conventional household refrigerator is used in the modified form with PCM box located behind the evaporator cabinet to carry out the necessary experiments. It shows that the details of the location of the PCM box with the evaporator cabinet. The PCM box is made up by aluminum sheet, which is 9.5 cm width, 20 cm height and 26 cm length. The evaporator cabinet box of internal volume 0.0494 m3 with cooling coil is inserted into the empty PCM box .The thickness of the annular space between PCM box and evaporator cabinet is one inch. In the top of the PCM box there is a hole of half inch diameter in which charges the PCM into the box. The experimental set up comprised with a refrigerator, pressure gauge, thermocouple, phase change material box. The followings are the major technical specifications of the refrigerator.

1. Cabinet:-Internal volume= 0.0494 m3
2. Evaporator:

- Mode of heat transfer= Free convection and onduction. -Linear length of coil or tube= 1.5 feet=0.4572 meter
- Internal and external diameter of the tube= 5mm and 6mm respectively. -Material of coil or tube= copper tube.

3. Condenser:

- Mode of heat transfer= Free convection
- Linear length of the coil= 4.1m
- Internal and external diameter of the tube= 3.23 mm and 4.23 mm respectively.
- Material of the tube= steel and wire tube.

4. Compressor: - KULTHORN GDM 225P 1PH 220-240V, 50HZ
5. Expansion device = Capillary tube
6. On/Off control and self-defrost.
7. Refrigerant =R-134a3

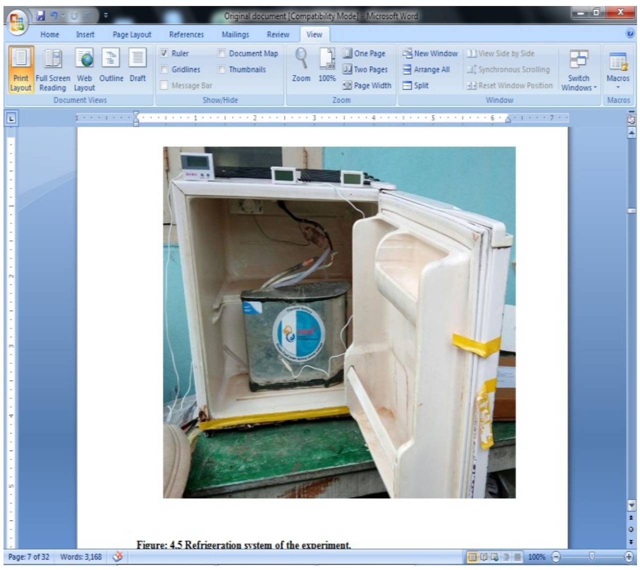

Fig-3: Refrigeration system of the experiment.

**Table: 1 Physical Properties of HCF- 134a refrigerant**

| | |
|---|---|
| Boiling point at 1 atm(101.3kpa or 1.013 bar) | -26.3$^0$C |
| Freezing point | -103.3$^0$C |
| Critical temperature | 101.1$^0$C |
| Critical pressure | 4060kpa |
| | |
| Critical volume | 1.94 x 10$^{-3}$ m$^3$/kg |
| Critical density | 513.3 kg/m$^3$ |
| Density( liquid at 25$^0$C ) | 1206 kg/m$^3$ |
| Density(saturated vapor) at boiling point | 5.25kg/m$^3$ |
| Heat capacity(liquid) at 25$^0$C | 0.339 kcal/kg K |
| Heat capacity at 25$^0$C and 1atm | 0.204kcal/kg K |

**Table: 2 Properties of PCM (HS01I)**

| Property | Value |
|---|---|
| Melting Temp($^0$C) | -1 |
| Freezing Temp($^0$C) | -1 |
| Latent Heat(kJ/kg ) | 390 |
| Liquid Density(kg/m$^3$) | 1010 |
| Solid Density(kg/m$^3$) | 990 |
| Liquid Specific Heat(kJ/kg K) | 3.9 |
| Solid Specific Heat(kJ/kg K) | 2 |
| Liquid Thermal Conductivity | 0.55 |
| Solid Thermal Conductivity | 2.2 |
| Base Material | Inorganic |
| Congruent Melting | Yes |
| Flammability | No |
| Thermal Stability (Cycles) | -2000 |
| Maximum Operating Temperature($^0$C) | 80 |
| Flash Point($^0$C) | NA |

**Table: 3 Uncertainties of Measurement**

| Measured parameters | Measuring device | Uncertainty |
|---|---|---|
| Temperature | Thermocouple | ±2.75% |
| Pressure | Pressure gauge | ±0.01psi |

**Table: 4 Experimental ranges and conditions**

| Type of PCM | Quantity of PCM | Test time(min) | Ambient Temp(0C) | Cabinet setting Temp(0C) |
|---|---|---|---|---|
| Without PCM | ............. | 25 | 31 | -1.1 |
| HSO1 | 2 liters | 264 | 33 | -0.8 |

**Procedure**

1. The domestic refrigerator is selected, working on vapour compression refrigeration system
2. Pressure and temperature gauges are installed at each entry and exit of the components.
3. Flushing of the system is done by pressurized nitrogen gas.
4. R134a refrigerant is charged in to the vapour compression refrigeration system.
5. Leakage tests are done by using soap solution.
6. After starting the test unit, pressure and temperatures are recorded

## IV.DATA COLLECTION AND CALCULATION

The following data have been collected for each test run at the steady state condition of the system.

1. $P_1$= Compressor suction/Evaporator outlet pressure(bar)
2. $P_1$=Evaporator Inlet Pressure(bar)
3. $T_1$= **Compressor suction Temperature (˚C)**
4. $T_2$=**Compressor discharge/condenser Inlet Temperature(˚C)**
5. $T_3$= **Cabinet Temperature(˚C)**
6. t=Time

**Table: 5 Experimental Data without Phase Change Material (PCM)**

| S.No | Evaporator Inlet P1(bar) | Compressor Outlet P2(bar) | Compressor Inlet Temp(T1) | Compressor Outlet Temp(T2) | Cabin Temp(0C) | Time (Min)t |
|---|---|---|---|---|---|---|
| 1 | 0.3 | 13 | 34 | 32 | 22 | 0 |
| 2 | 0.4 | 14 | 34.2 | 40 | 7.8 | 8 |
| 3 | 0.4 | 14 | 35.9 | 52 | 4.1 | 15 |
| 4 | 0.4 | 14 | 32.8 | 40.3 | 1.8 | 20 |
| 5 | 0.4 | 14 | 53 | 53 | 0 | 25 |
| 6 | 0.4 | 14 | 39.6 | 36 | -1.1 | 30 |

**Table: 6 Experimental Data with Phase Change Material (PCM)**

| S.No | Evaporator Inlet P1(bar) | Compressor Outlet P2(bar) | Compressor Inlet Temp(T1) (0C) | Compressor Outlet Temp(T2) (0C) | Cabin Temp (T3)(0C) | Time (Min)t |
|---|---|---|---|---|---|---|
| 1 | 0.3 | 13 | 38 | 44.6 | 28.3 | 0 |
| 2 | 1 | 16 | 41 | 56.6 | 23.3 | 35 |
| 3 | 1 | 16 | 46 | 58 | 18.3 | 72 |
| 4 | 0.8 | 16 | 47.6 | 62.8 | 13.3 | 112 |
| 5 | 2.4 | 2 | 46.6 | 45 | 8.3 | 154 |
| 6 | 0.6 | 14 | 35.2 | 66.6 | 3.3 | 216 |
| 7 | 0.6 | 13 | 40.8 | 59.6 | -0.8 | 264 |

**Table: 7 COP found in each test run without and with Phase Change Material (PCM)**

| S.No | COP found in Vapor compression Refrigerator Without PCM | COP found in Vapor compression Refrigerator With PCM |
|---|---|---|
| 1 | 1.612 | 1.98 |

Below the calculation of COP is given with proper calculation the corresponding enthalpy for desire pressure and temperature found using P-h diagram of refrigerant R-134a.

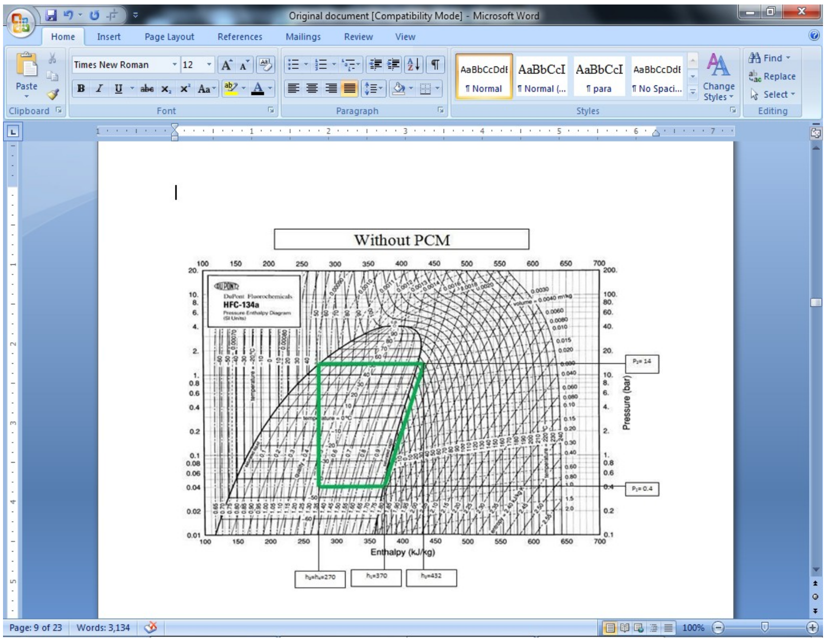


Fig-4: P-h charts (Without PCM)

**With Out PCM**

Evaporator inlet (P1) = 14 bar
Compressor outlet (P2) = 0.4 bar
Enthalpy at compressor inlet
h1= 370 kJ/kg
Enthalpy at compressor outlet
h2 = 432 kJ/kg
Enthalpy at condenser inlet h3 = 270 kJ/kg
Enthalpy at condenser outlet h4 = 270 kJ/kg
COP = (h1-h4) / (h2-h1)
= (370 – 270) / (432 – 370) =50 / 31=1.612

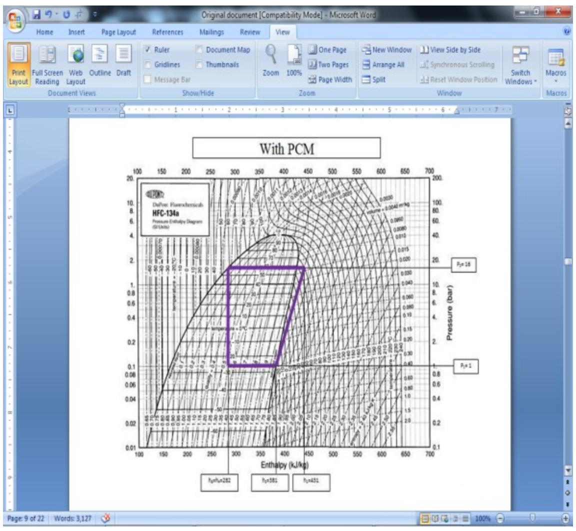


Fig-5: P-h charts (With PCM)

**With PCM**

Evaporator inlet (P1) = 16 bar
Compressor outlet (P2) = 1 bar
Enthalpy at compressor inlet
h1= 381 kJ/kg
Enthalpy at compressor outlet
h2 = 431 kJ/kg
Enthalpy at condenser inlet h3 = 282 kJ/kg
Enthalpy at condenser outlet h4 = 282 kJ/kg
COP = (h1- h4) / (h2 – h1) = (381 – 282) / (431 – 381) =99 / 50=1.980

**Percentage of COP improved for the use of phase change material (PCM)**

= {(1.980 – 1.612) / 1.612} x 100=22.98 %

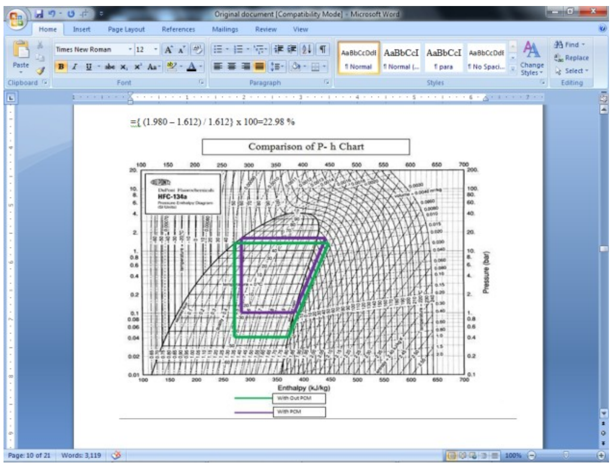


Fig-6: Comparison of P-h chart

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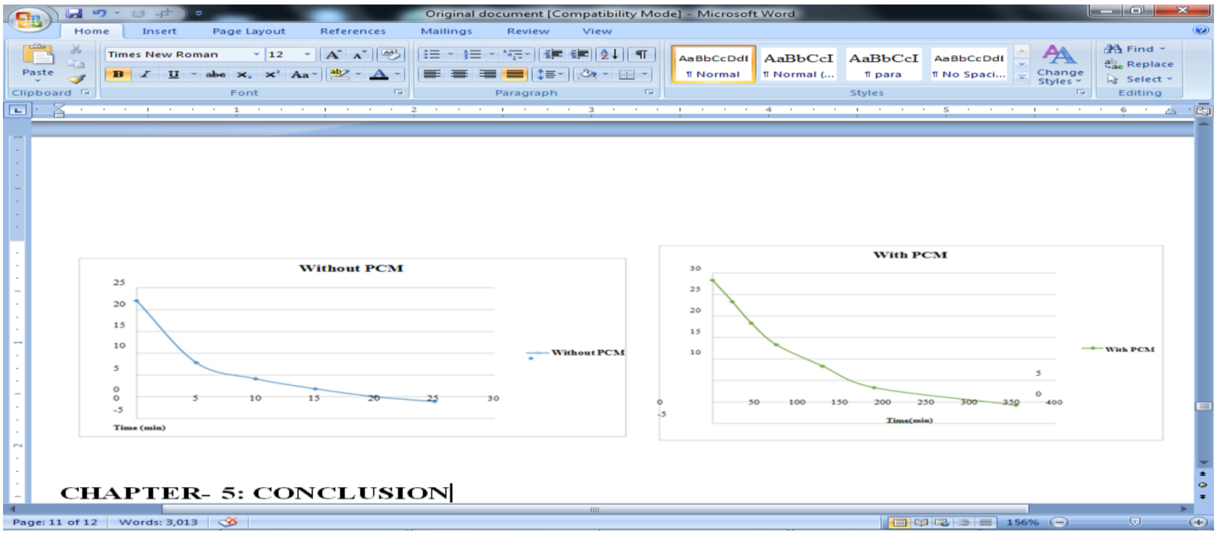


**Without PCM** **with PCM**

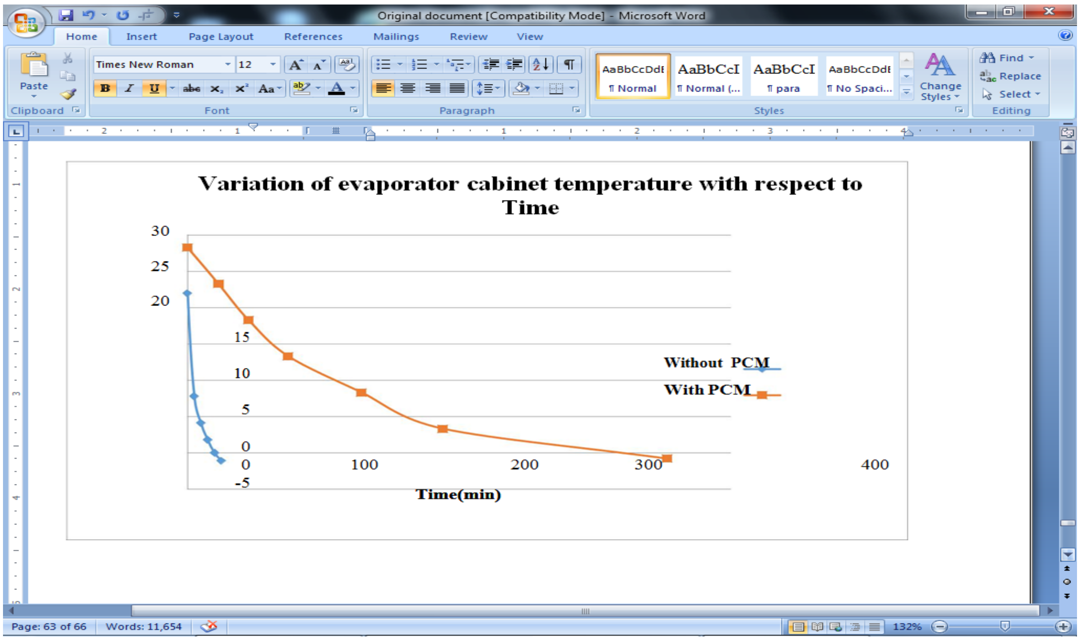


**Fig-7: Variation of evaporator cabinet temperature with respect to Time**

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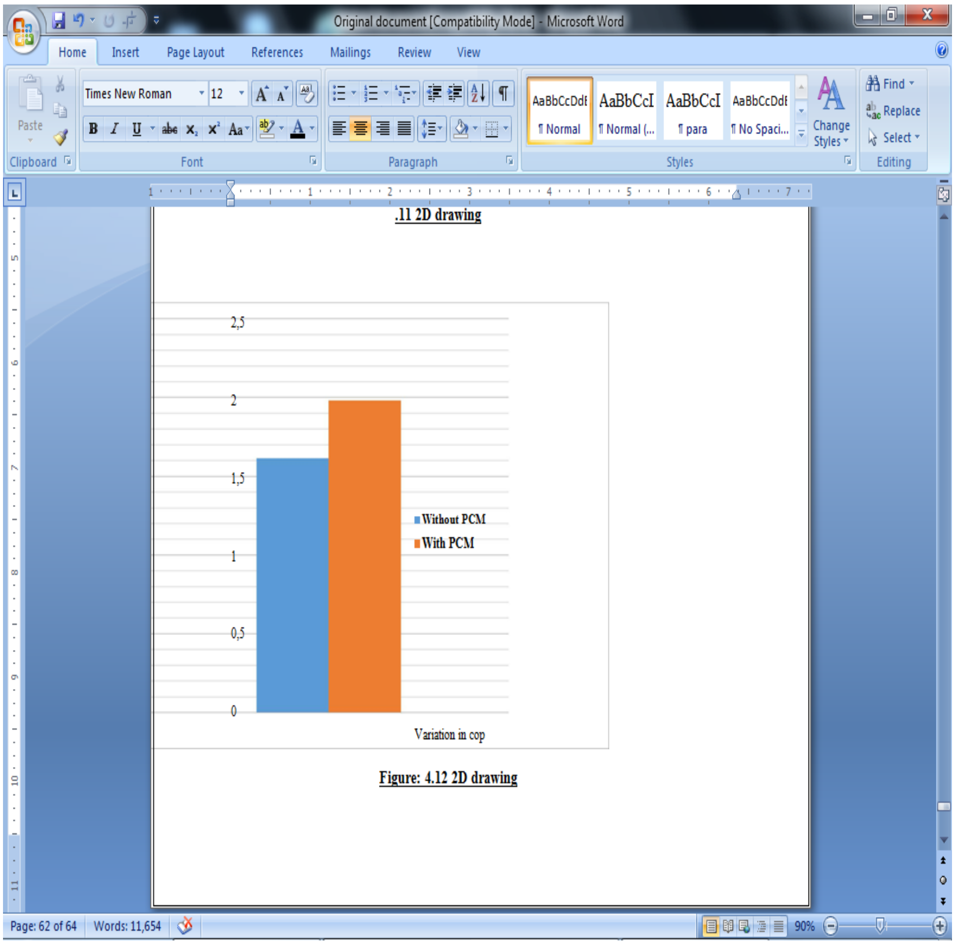


**Fig-8: without PCM and with PCM comparison**

## CONCLUSION

- Use of PCM imposes a great impact on COP improvement.
- Experiment tests have been carried out to investigate the performance improvement of a household refrigerator using phase change materials.
- HS01 is used as PCM and it is found that the 23 % COP improvement has been achieved by the PCM when compared without - PCM in conventional refrigerator.
- After switching on the system the time to reach the temperature inside the evaporator from 28$^0$C to -1$^0$C is noted 6 hours 47 minutes.
- After switching off the system it is observed that 14 hours of cooling is obtained.
- The result shows that PCM could be utilized to limit temperature rises during loss of electrical power. The refrigerator with PCM can be used in remote area.

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