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"ANALYSIS OF PCM MATERIAL IN HEAT TRANSFER SYSTEM": RESEARCH

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Abstract

It plays an important role refrigeration system helps to improve the overall performance or we can say it improves the coefficient of performance of the whole system. As we know that lots of refrigerator wide used household appliances and an excellent portion of energy is employed by these systems. With the use of Phase Change Material it becomes an easy task control temperature fluctuation and improvement of system performance is that the main reason of using phase change materials (PCMs) in refrigeration systems. It's a totally different approaches are used to improve the thermal performance/Heat Managements of these systems by integration of PCM. Still a wide range of such study remains untouched in the application of PCM in domestic refrigerators is missing. This paper shows a new possibility to improve the system performance in the field of Domestic refrigeration systems. Moreover, benefits and drawbacks of each kind of storage are presents future possibilities and, the future and potential promising applications of PCMs in domestic refrigerators are mentioned. Its studyto investigate improve the performance improvement provided by a phase change material (PCM) associated with the condenser in a domestic refrigerator. The heat release and storage rate of a refrigerator is depends upon the characteristics of refrigerant and its properties. In this study we also investigated the performance improvement provided by Phase Change material associated with the evaporator in a domestic refrigerator.

Keywords: Phase change material, Domestic refrigeration system, Thermal storage, Condenser.

I. INTRODUCTION

Each material makes its phase change at different temperature. In addition, each material has different value of latent heat and thermal conductivity. The main disadvantage of PCMs is their low thermal conductivity that decreases the heat transfer rate. The most important feature for the selected phase change material is to have its phase change temperature fitted with the application temperature range. Indeed, there is no specific material that is called as an ideal material to be used as a phase change material; each material has its advantages and disadvantages.

In a many ways, this type of property of PCMs can be used, such as thermal energy storage whereby heat or coolness can be stored from one process or period in time, and used at a later date or different location. PCMs are also very useful in providing thermal barriers or insulation.

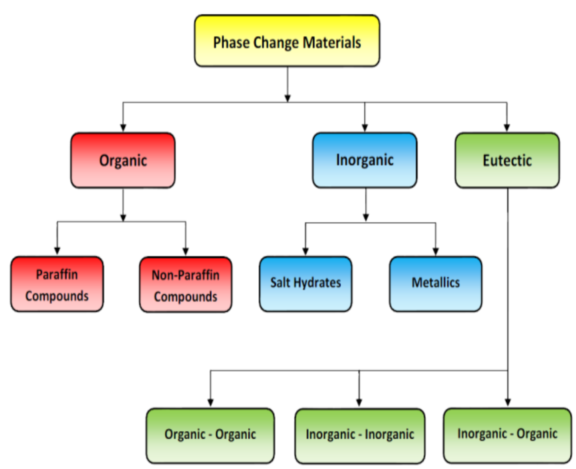

Fig. 1: Phase Change Material –PCMs

A. Organic Phase Change Material:-Organic phase change materials are classified as paraffin's and nonparaffin. Organic PCMs are characterized by their ability to melt and freeze many times without phase segregation and degradation of their latent heat of fusion.

ADVANTAGES

1. Paraffinare available in a large temperature range.

2. Paraffin have no tendencies to super cool.

3. Paraffinare chemically stable.

DISADVANTAGES

1. Low thermal conductivity.

2. High volume change between the solid and liquid phases.

3. Commercial paraffindoes not have sharp exact melting points.

4. Paraffinis flammable.

B. Inorganic Phase Change Materials:-Inorganic phase change materials are classified as salt hydrates and metallic.

ADVANTAGES

1. High latent heat of fusion per unit mass and volume (higher than paraffin).

2. High thermal conductivity (compared with paraffin).

3. Have sharp phase change temperature.

DISADVANTAGES

1. Segregation: segregation is the formation of other hydrates or dehydrated salts that settle and reduce the volume that is available for thermal energy storage.

2. Salt hydrates show super cooling because they are unable to start crystallization at the freezing temperature. This problem can be avoided by using nucleating agents.

3. Salt hydrates cause corrosion in metal containers, whereas metal containers are the common containers used in thermal energy storage systems.

Thermo-Physical Properties:-

a) Phase Change temperature fitted to the application

b) High Latent Heat of fusion

c) Low volume change during the phase change

d) High density

e) High value of specific heat to give additional benefits of sensible heat

Chemical Properties:-

a) Chemical Stability After many cycles of operation

b) No Phase separation or chemical deposition

c) No Degradation after many cycles of operation

d) Nonflammable, non-corrosive and non-toxic

II. LITERATURE:

Shiminget. al. [2018] [1] Confronted with the crises of the growing resource shortages and continued deterioration of the environment, building energy performance improvement using phase change materials has received much attention in recent years, in phase change materials used to optimize building envelope and equipment. This is followed by reporting articles on building equipment optimized with phase change materials to reduce regular energy consumption. Series of air cooling, heating, and ventilation systems coupled with thermal energy storage were comparatively investigated. Finally, the existing gaps in the research works on energy performance improvement with phase change materials were identified, and recommendations offered as authors' viewpoints in 5 aspects. We believe this comprehensive review might provide an overview of the analytical tools for scholars, engineers, developers, and policy designers, and shed new light on the designing and performance optimization for PCMs used in building envelope and equipment.

Ding-QuanNget. al. [2017] [2] A novel phase change material (PCM) microcapsule possessing a thermally conductive but electrically insulated shell is synthesized. The vinylsilane compound is polymerized with the acrylic monomer to first form a copolymer, with the thermally conductive inorganic material subsequently added. Thereafter, the PCM microcapsule with the paraffin core and the thermally conductive but electrically insulated material-containing copolymer as the shell is prepared through mini-suspension polymerization. **YutaoHuoet. at. [2017] [3]**The phase change material (PCM) can be used in thermal energy storage (TES) with large latent heat. However, due to the heat accumulation in the upper region, the solid-liquid phase change process will be slowed down. In this paper, in order to

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enhance the heat transfer of nanoparticle-enhanced PCM (NEPCM) in TES, a separate plate is applied to weaken the heat accumulation. The phase change multiple-relaxation-times lattice Boltzmann (MRT-LB) model is employed to solve the numerical problem and the effects of separate plate location, nanoparticle volume fraction and Rayleigh number are investigated.

A. InésFernándezet. al. [2017] [4] The use of paraffin, salts and salt hydrates as phase change materials (PCMs) have been researched extensively and used in a number of commercial applications. However, metals and metal alloys, which possess a high storage density on a volume basis as well as a substantially higher thermal conductivity, has received much less attention. Although some pure metals and metal alloys present interesting thermal properties to be used as PCMs in thermal storage systems, changes in thermal properties and undesired reactions. Further research is needed before these materials can be used as PCMs in thermal energy storage systems in industry.

LeiShaoet. al. [2016] [5] In this work, we utilize a figure-of-merit (FOM) to compare the performance of various phase-change materials (PCMs) in managing short bursts of high-power heat flux, particularly those associated with microprocessors undergoing bursty operation on a time scale of approximately one second. We numerically investigate the FOM for applications that have realistic boundary conditions and lack analytical solutions.

AzizBabapooret. al. [2016] [6] Phase change materials are widely used in various thermal management applications. Conductive nanoparticles can be added to phase change materials to improve their thermal conductivities. The selection of suitable nanoparticles and weight percent is important from thermal performance point of view. In this study, various nanoparticles (e.g. SiO2 (11 nm, 20 nm), Al2O3, Fe2O3, ZnO). Thermal properties of the synthesized nanocomposites were characterized by differential scanning calorimetric technique. Experimental measurements showed that the presence of nanoparticles can improve thermal conductivity of the nanocomposite.

Pierre Noéet. al. [2016] [7] Chalcogenide phase change materials (PCMs) have outstanding properties, which has led to their successful use for a long time in optical memories (DVDs) and, more recently, in Phase Change Random Access Memories. The latter are the most promising candidate to replace the current FLASH memories. The main feature of PCMs is fast and reversible phase transformations between crystalline and amorphous states with very different transport and optical properties. Controlling their crystallization, however, is a challengeand hence control the stability of the amorphous phase in PCMs.

Marco Casiniet. al. [2016] [8] This chapter focuses on the importance of the heat capacity of the building envelope for energy efficiency and indoor thermal comfort, presenting the most innovative smart materials for latent heat storage in new and existing buildings. An overview of phase-change materials is provided, explaining their classification, technical specifications, encapsulation methods, functional models, and application inside or outside the building, even combined with advanced insulating materials. Lastly, there is an in-depth look at future prospects and developments.

KingaPielichowskaet. al. [2014] [9] Phase change materials (PCMs) used for the storage of thermal energy as sensible and latent heat are an important class of modern materials which substantially contribute to the efficient use and conservation of waste heat and solar energy. Many different groups of materials have been investigated during the technical evolution of PCMs, including inorganic systems (salt and salt hydrates), organic compounds such as paraffins or fatty acids and polymeric materials, e.g. poly(ethylene glycol).

Yanping Yuan et. al. [2014] [10] Fatty acids as phase change materials have attracted much attention for their various applications in building energy efficiency, solar heating systems and air-conditioning systems. After summarizing the basic characteristics of fatty acids, eutectic mixtures of fatty acids and fatty acid esters, as well as the preparation and characteristics of fatty acid composites as phase change materials (PCMs). It also points out the future research direction of fatty acids as PCMs as a solution of the insufficiency and flaws of current researches.

Joseph Stalin et. al. [2014] [11] Energy is an important phenomenon in today's hectic world. A lot of researchers are doing research in this field due to its wide importance and also due to the scarcity of sources of energy in modern world, which in turn needs new inventions and discoveries to satisfy the demands of this scientific world. Reducing the wastage and utilizing the energy completely depicts

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the overall efficiency of any system. In today's modern world, air conditioning plays a major role due to the rapid increase in the earth's temperature and therefore, people long for comfort cooling. Nowadays, a lot of energy is wasted in the form of heat which eventually reduces the overall efficiency of any system. Therefore a system should be designed which shows a maximum efficiency by reducing its wastage to a very minimal amount. By using the industrial waste heat from industries and solar heat, an air conditioning system is designed in such a way that the input given to it is used completely without any wastage and the system uses Vapour Absorption System for conditioning of air.

Weihuan Zhao et. al. [2013] [12] Solar energy is receiving a lot of attention recently since it is a clean, renewable, and sustainable energy. Solar energy is used for space heating, power generation and other applications. A major limitation however is that it is available for only about 2000 h a year in many places. Using encapsulated phase change materials is potentially a better way to store thermal energy with the associated reversible heat transfer Diffusion and phase change computations are reported here in the form of temperature profiles of the phase changing and encapsulated materials for spherical capsules.

Min Li [2013] [13] Nano-graphite (NG)/paraffin composites were prepared as composite phase change materials. NG has the function of improving the thermal conductivity of the composite. The microstructure and thermal properties of the materials were examined with environmental scanning electron microscopy and differential scanning calorimetry. The results indicated that the NG layers were randomly dispersed in the paraffin, and the thermal conductivity increased.

Yuefeng Li et. al. [2013] [14] An analytical temperature model and an enthalpy difference function, based on lumped parameter method and assumption of rectangular effective specific heat, are presented in this study, which can measure the enthalpy change of inorganic salt high temperature. It can be seen that with this method it is possible to obtain both melting point and heat of fusion in a simple way which will be of great help in selecting heat storage material in solar-energy and industrial waste heat utilization and in the subsequent design of a thermal energy storage system.

X. H. Yang et. al. [2011] [15] This study reports on an analytical estimation of the effective thermal conductivity of phase change materials (PCMs) and its dependence upon temperature. During the phase change process, two distinctive phases (solid to liquid) co-exist and the effective thermal conductivity of the PCM varies significantly with temperature. To analytically estimate the variation, the classical Series model assuming one-dimensional (1D) heat conduction normal to the solid–liquid interface was employed. For model validation, experimental measurements with paraffin were conducted covering a wide range of temperature (including the phase change temperature.

Yifen QIU et. al. [2011] [16] To investigate thermal protection effects of heat sinking vest with phase-change material (PCM), human thermoregulation model is introduced, and a thermal mathematical model of heat transfer with phase change has been developed with the enthalpy method. The uniform energy equation is constructed for the whole domain, and the equation is implicitly discreted by control volume and finite difference method. Then the enthalpy in each node is solved by using chasing method to calculate the tridiagonal equations, and the inner surface temperature of PCM could be obtained. According to the human thermoregulation model of heat sinking vest, the dynamic temperature distribution and sweat of the body are solved.

Omar Sanusiet. al. [2011] [17] Phase change materials (PCMs) are known to be excellent candidates for thermal energy storage in transient applications. However, enhancement of the thermal conductivity of a paraffin-based PCM is required for effective performance, particularly during solidification where diffusion is the dominant heat transfer mode. This research indicates that GNF impregnation into phase change materials is an effective method for the enhancement of the thermal energy storage and the solidification of paraffin-based phase change materials.

Bogdan M. Diaconuet. al. [2010] [18] A new microencapsulated phase change material slurry based on microencapsulated Rubitherm RT6 at high concentration. Some heat storage properties and heat transfer characteristics have been experimentally investigated in order to assess its suitability for the integration into a low temperature heat storage system for solar air conditioning applications. An experimental set-up was built in order to quantify the natural convection heat transfer occurring from a vertical helically coiled tube

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immersed in the phase change material slurry. It was found that the values of the heat transfer coefficient for the phase change material slurry were higher than for water, under identical temperature conditions inside the phase change interval.

C.Murisetet. al. [2010] [19] A PCM dephaser and storage module based on a melting/freezing model was built and implemented into the Dymola-Modelica software. This software offers thermal libraries with standard components as tubes, pumps, heat exchangers, etc. Main simulation results of interest include the phase shift (delay time) caused by cylinders filled with a PCM and positioned in the storage/dephasing device. Furthermore, an entire Minergie house was modeled by a rather simple (economic in terms of CPU time), but still very effective thermal model.

Guobing Zhou et. al. [2010] [20] Thermal characteristics of shape-stabilized phase change material (SSPCM) wallboard with sinusoidal temperature wave on the outer surface were investigated numerically and compared with traditional building materials such as brick, foam concrete and expanded polystyrene (EPS). One-dimensional enthalpy equation under convective boundary conditions was solved using fully implicit finite-difference scheme. Phase transition keeping time of inner surface and decrement factor were applied to analyze the effects of PCM thermo physical properties (melting temperature, heat of fusion, phase transition zone and thermal conductivity), inner surface convective heat transfer coefficient and thickness of SSPCM wallboard.

L. Xia et. al. [2010] [21] Expanded graphite (EG)/paraffin composite phase change materials (PCMs), with mass fraction of EG varying and characterized. Polarizing optical microscope investigation showed that compact EG networks formed gradually with increase in the mass fraction of EG. These networks provided thermal conduction paths which enhanced the thermal conductivity of the composite PCMs, e.g., an addition of 10 wt.% EG resulting in a more than 10-fold increase in the thermal conductivity compared to that of pure paraffin. Thermal characterization of the composite PCMs with a differential scanning calorimeter (DSC) revealed the effect of the porous EG on the phase change behavior of paraffin. The shifts in the phase change temperatures were observed. The DSC investigation also showed an anomaly in the latent heat of the paraffin in the composite PCMs in that it first increased and then decreased with increase in the EG fraction.

III. METHODOLOGY

STEPS OF WORKING METHOD: After setting the solver various PCM material were created for the analysis. The properties of the materials are discussed below.

Table 1: Properties of the materials

Material	Density[kg m^{-3}]	Specific Heat [J kg^{-1} K^{-1}]	Thermal conductivity [W m^{-2} K^{-1}]	Viscosity[kg/m-s]
Paraffin Wax	900	2140	0.15	0.000686
Ethylene Glycol	1111.4	2415	0.252	0.0157
Lauric Acid	1004	2141	0.147	0.0073
R134a	0.1304	2140	0.0212	0.000271

STEPS OF ANSYS ANALYSIS: The different analysis steps involved in ANSYS are mentioned below.

1. Preprocessor
2. Building the Model
3. Define Materials
4. Generate Element Mesh
5. Solution Processor
6. Obtain Solution
7. Postprocessor
8. Boundary Condition

CASE-I:

CFD Analysis of Condenser coil without PCM:

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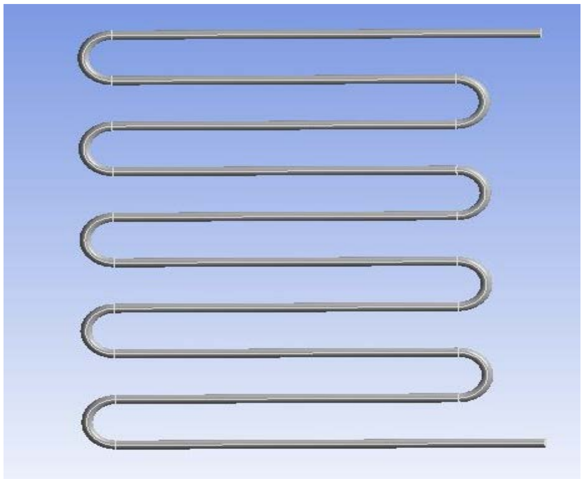

Fig. 3: Condenser Coil without PCM

Meshing of condenser coil without PCM material:

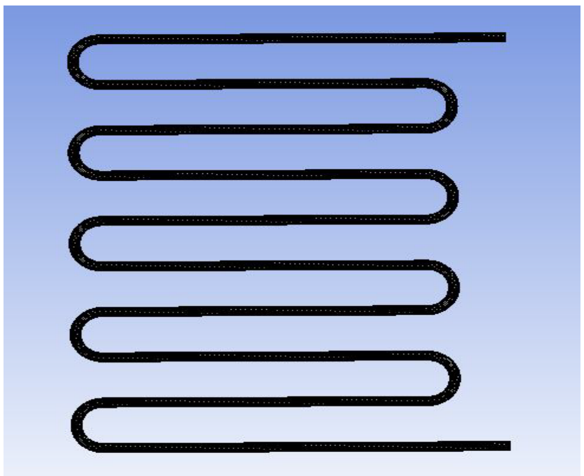

Fig. 4: Meshing: Total No. of Nodes: 285056& total No. elements: 204318

CASE-II:

CFD analysis of condenser coil with various PCM materials:

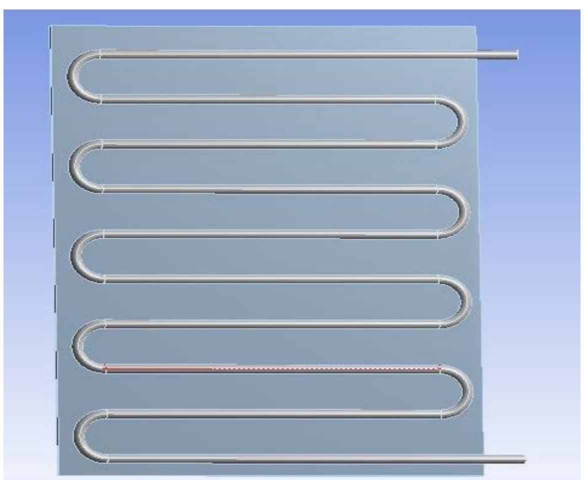

Fig. 5: Condenser Coil with PCM

Meshing of condenser coil with PCM material

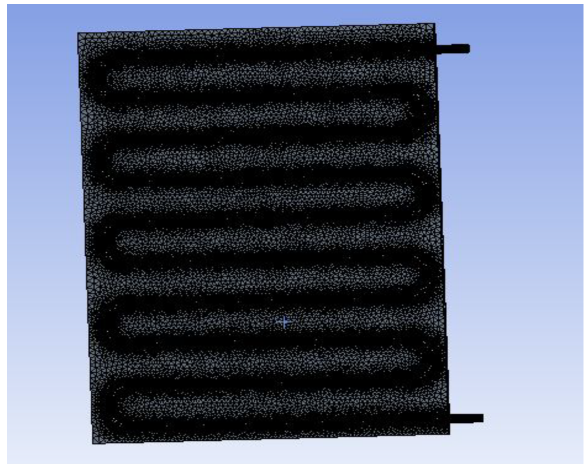

Fig. 6: Meshing: Total No. of Nodes: 285056& Total No. elements: 204318

CASE-III:

CFD ANALYSIS OF EVAPORATOR:

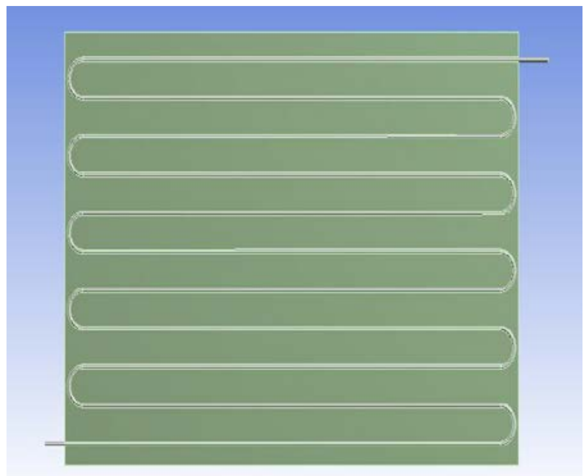

Fig. 7: Evaporator Geometry with Fluid Domain of Air

Meshing of the Evaporator Geometry:

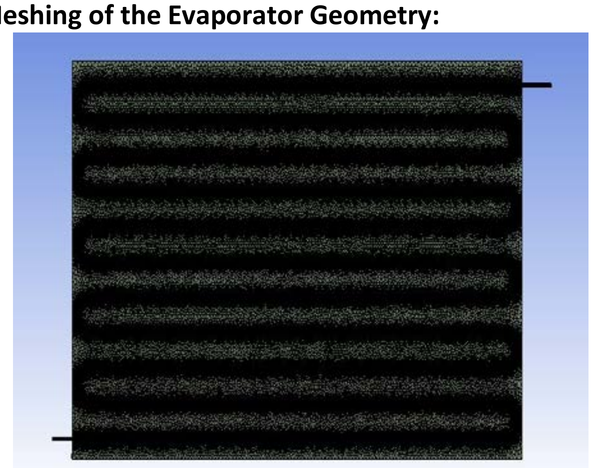

Fig. 8: Generated Mesh of the Coil, The total Node: 3065491& Total No. of Elements: 7409415

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CASE-IV:

CFD ANALYSIS OF EVAPORATOR WITH VARIOUS PCM MATERIALS:

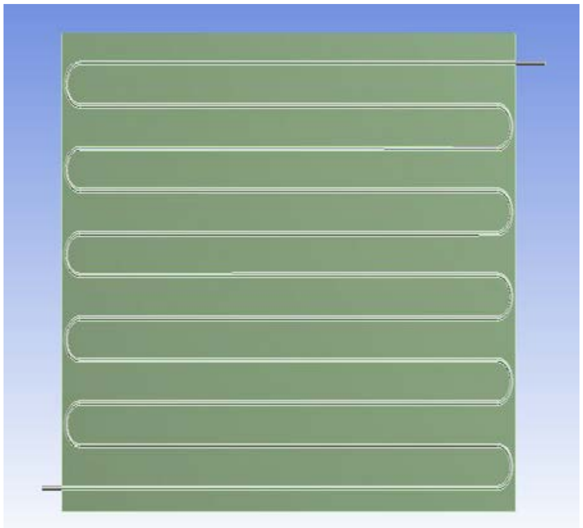

Fig. 9: Evaporator Geometry with Phase Change Material

Meshing of the Evaporator Geometry with Phase Change Material:

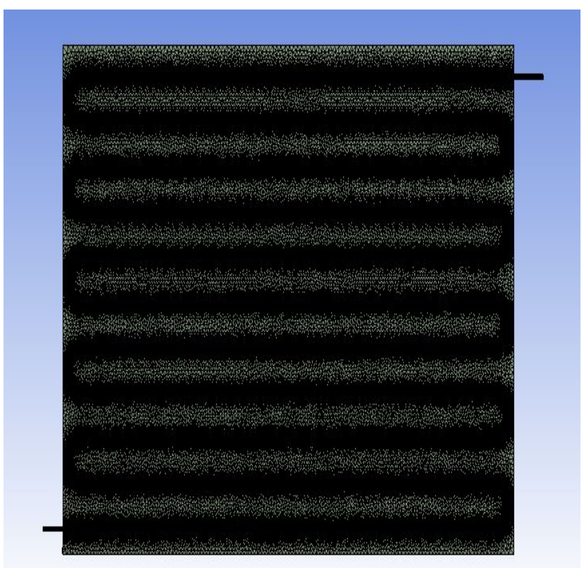

Fig. 10: Generated Mesh of the Coil with various PCM material

IV. RESULTS:

CASE-I:

Contours for Condenser coil without PCM Only Simulation:

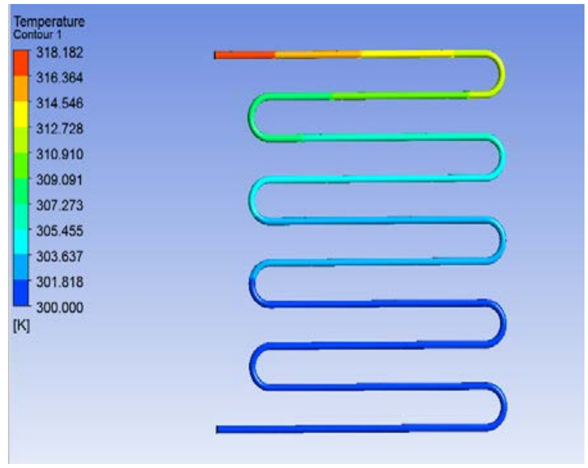

Fig. 11: Temperature Contour for Condenser coil without PC

As can be seen in fig above the temperature of the coil drops 318k at inlet to 300k at outlet.

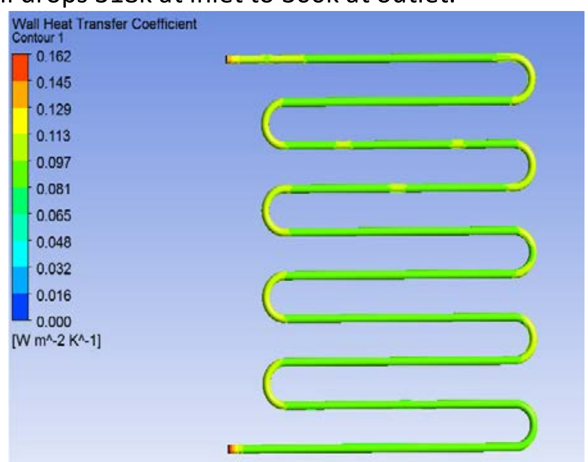

Fig. 12: Heat Transfer Coefficient for Condenser coil without PC

The heat transfer coefficient for the condenser coil as shown above ranges from 0W/m2k to O.162 W/m2k.

CASE-II:

A. Contours for Coil with Paraffin Wax As A PCM Material:

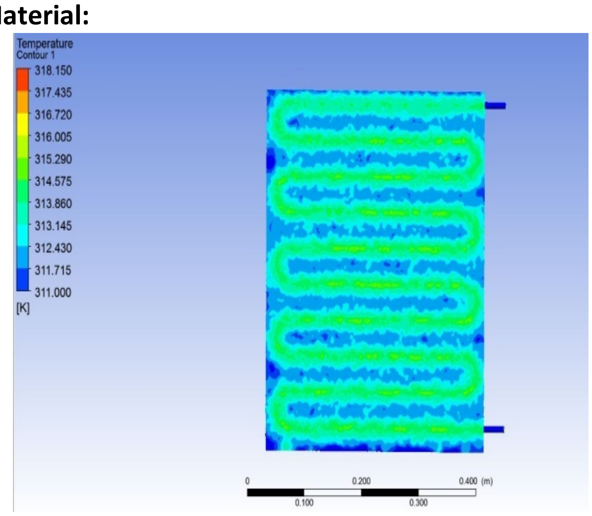

Fig. 13: Temperature Contour of PCM Material

It can be seen in the fig above that temperature of the PCM panel ranges from 311k to 318k, while in the fig below we can see the temperature range of the coil which is 299k to 320k.

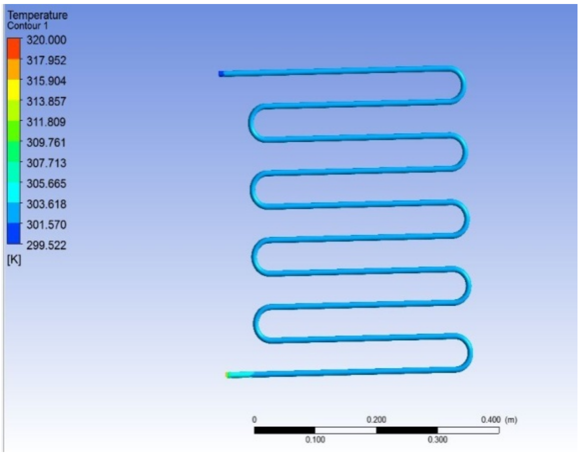

Fig. 14: Temperature Contour of Coil with PCM Material

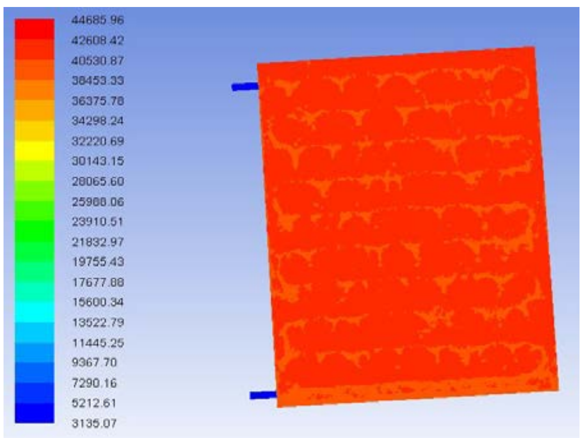

Fig. 15: Enthalpy Contour of PCM Material

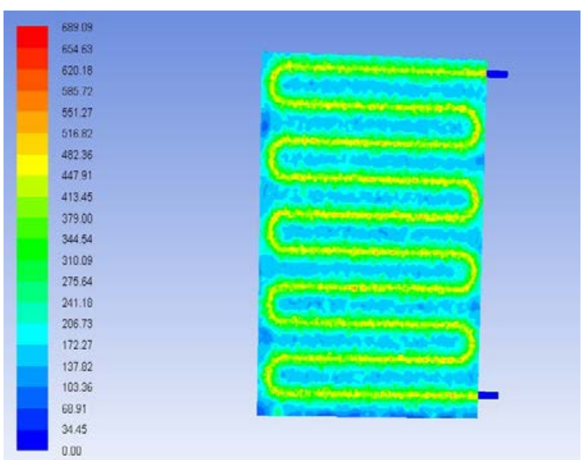

Fig. 16: Heat Transfer Coefficient of PCM Material

Heat transfer coefficient obtained for PCM panel with condenser coil ranges from 0W/m2k to 689W/m2k as shown in the Fig above.

B. Contours for Coil with Ethylene Glycol As A PCM Material:

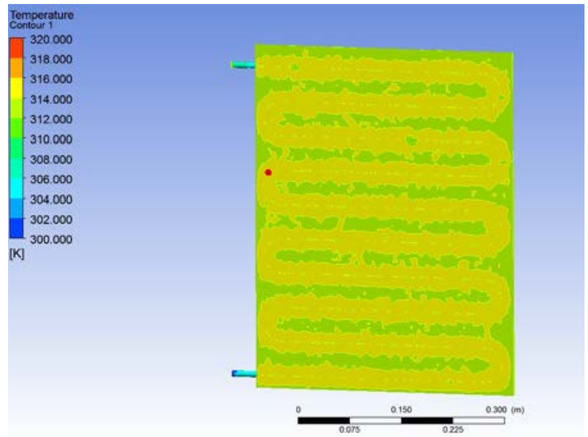

Fig. 17: Temperature Contour of PCM Material

It can be seen in the fig above that temperature of the PCM panel ranges from 300k to 320k, while in the fig below we can see the temperature range of the coil which is 300k to 320k.

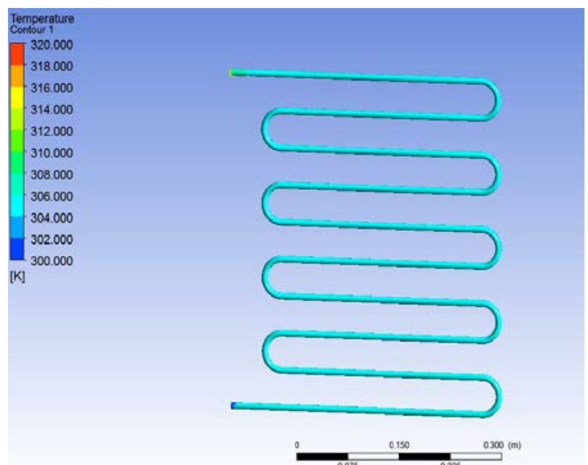

Fig. 18: Temperature Contour of Coil with PCM Material

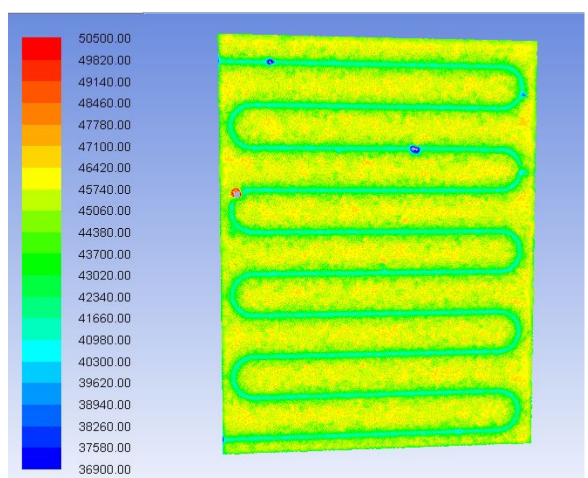

Fig. 19: Enthalpy Contour of PCM Material

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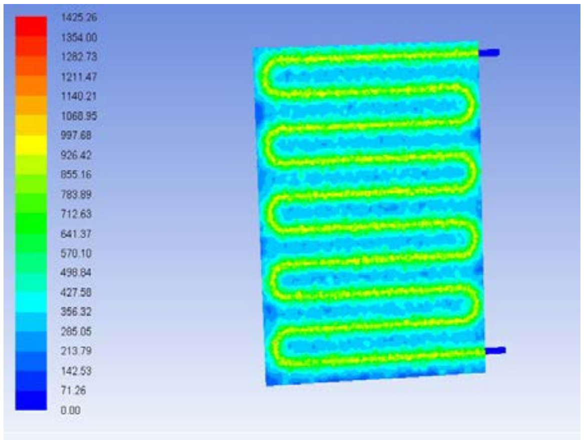

Fig. 20: Heat Transfer Coefficient of PCM Material

Heat transfer coefficient obtained for PCM panel with condenser coil ranges from 0W/m2k to 1425W/m2k as shown in the Fig above.

C. Contours for Coil With Lauric Acid As A PCM Material:

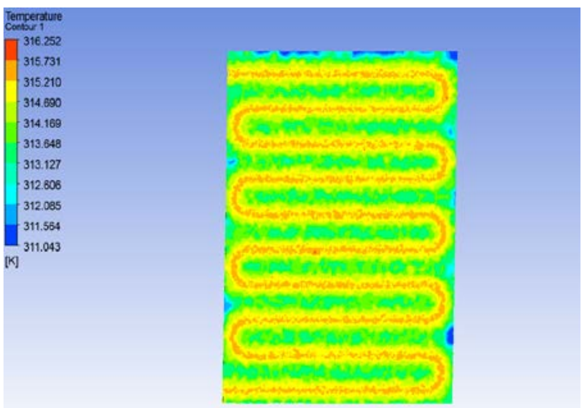

Fig. 21: Temperature Contour of PCM Material

It can be seen in the fig above that temperature of the PCM panel ranges from 311k to 316k, while in the fig below we can see the temperature range of the coil which is 299k to 320k.

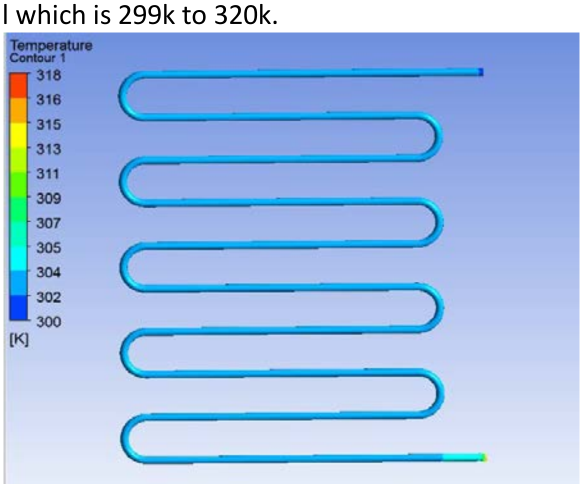

Fig. 22: Temperature Contour of Coil with PCM Material

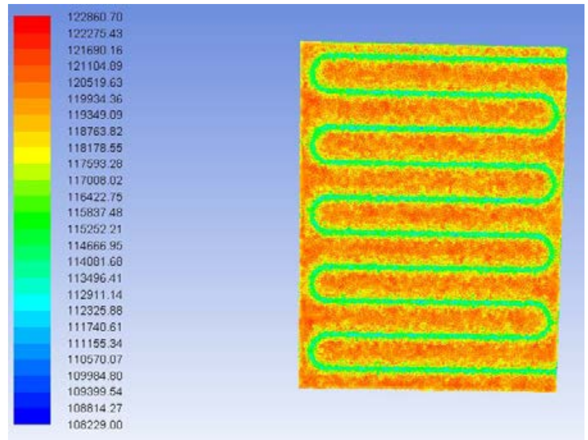

Fig. 23: Enthalpy Contour of PCM Material

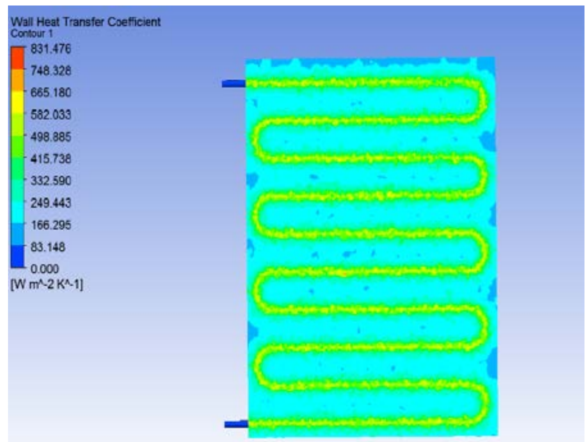

Fig. 24: Heat Transfer Coefficient of PCM Material

Heat transfer coefficient obtained for PCM panel with condenser coil ranges from 0W/m2k to 831W/m2k as shown in the Fig above.

CASE-III:

CFD ANALYSIS OF THE EVAPORATOR COIL

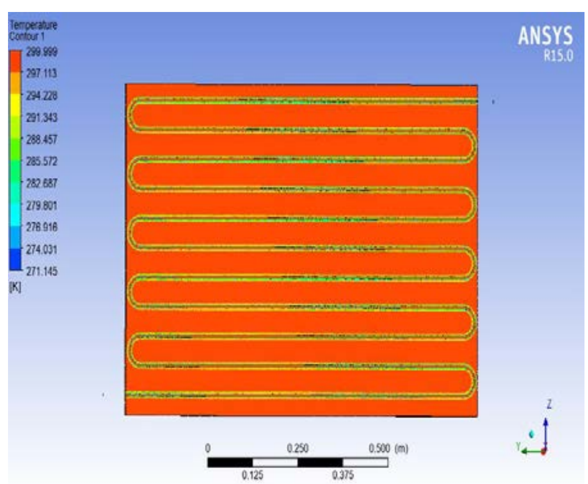

Fig. 25: Temperature Contour OF the coil and Air domain

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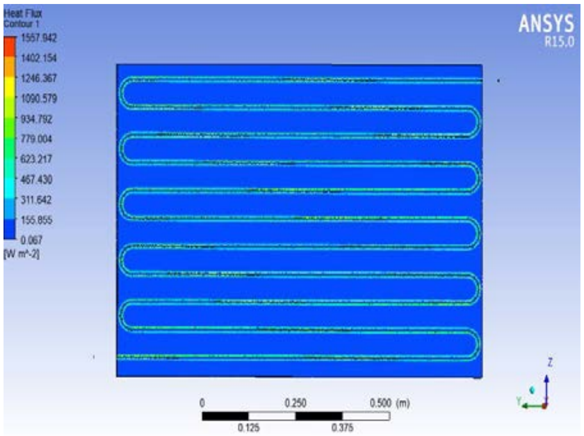

Fig. 26: Heat Flux of the Evaporator Coil and Air Domain

The heat flux obtained from the evaporator coil and air domain is shown in fig 26, from the images we can conclude that most of air domain retains 0w/m2 heat flux while some region retains 1557 W/m2 of heat flux.

CASE-IV:

A. CFD ANALYSIS OF THE EVAPORATOR COIL WITH PARAFFIN WAX:

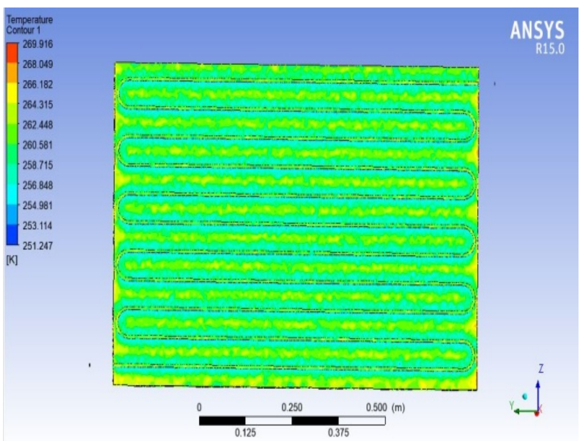

Fig. 27: Temperature Contour OF the coil and Paraffin Wax

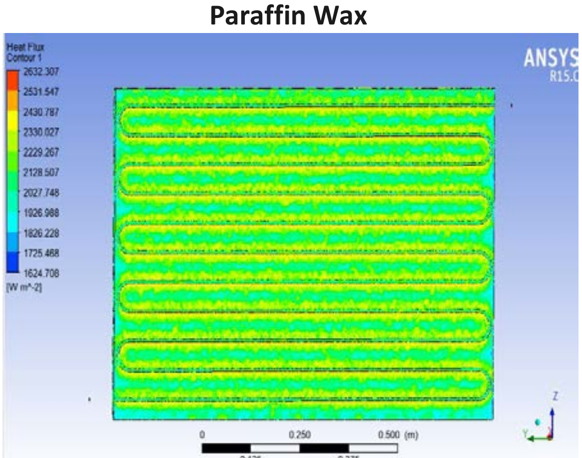

Fig. 28: Heat Flux of the Evaporator Coil and Paraffin Wax

The results obtained from the CFD analysis of evaporator coil with paraffin wax as a thermal energy storage medium is shown above. Fig 27 here shows the variation in temperature of the paraffin wax. It can be seen the temperature of the PCM panel varies from 251k to 270K. Fig 28 here shows the amount of heat flux stored by the paraffin wax. It can be seen the amount of heat flux retained in the PCM panel ranges from 1624 W/m2 to 2632 W/m2.

B. CFD ANALYSIS OF THE EVAPORATOR COIL WITH ETHYLENE GLYCOL:

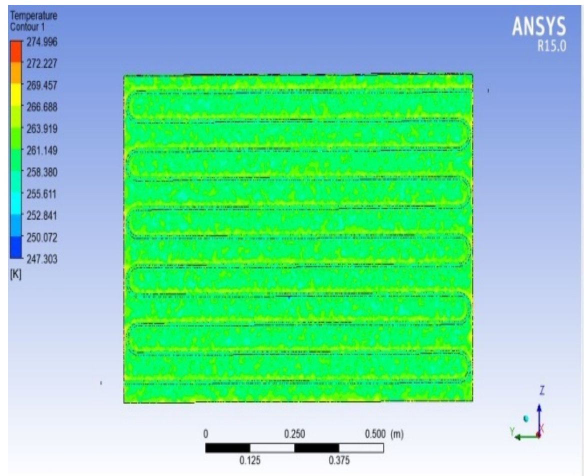

Fig. 29: Temperature Contour OF the coil and Ethylene Glycol

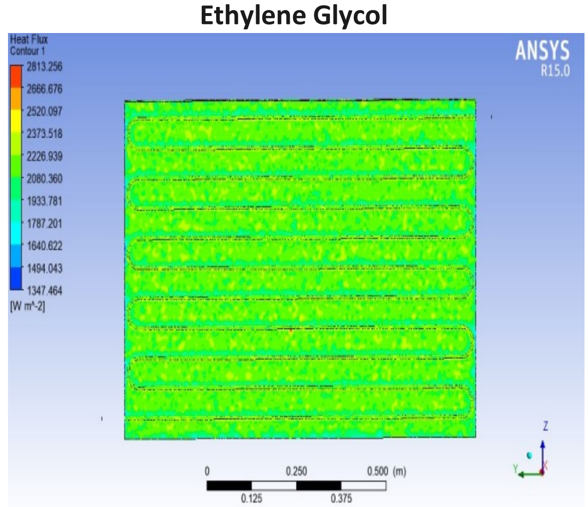

Fig. 30: Heat Flux of the Evaporator Coil and Ethylene Glycol

The results obtained from the CFD analysis of evaporator coil with Ethylene Glycol as a thermal energy storage medium is shown above. Fig 29 here shows the variation in temperature of the Ethylene Glycol. It can be seen the temperature of the PCM panel varies from 248k to 275K. Fig 30 here shows the amount of heat flux stored by the Ethylene Glycol. It can be seen the amount of heat flux

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retained in the PCM panel ranges from 1348 W/m2 to 2813W/m2.

C. CFD ANALYSIS OF THE EVAPORATOR COIL WITH LAURIC ACID:

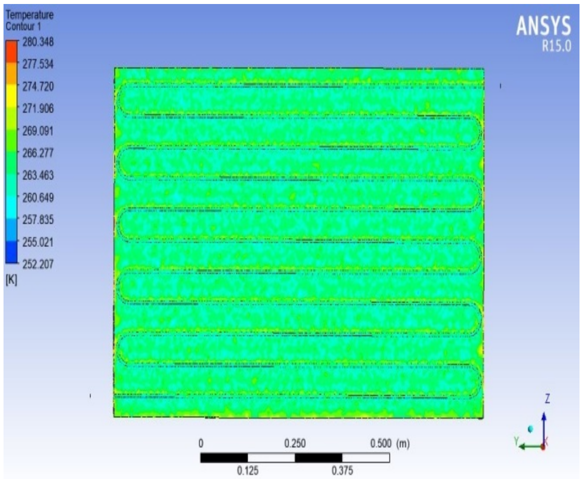

Fig. 31: Temperature Contour OF the coil and Lauric Acid

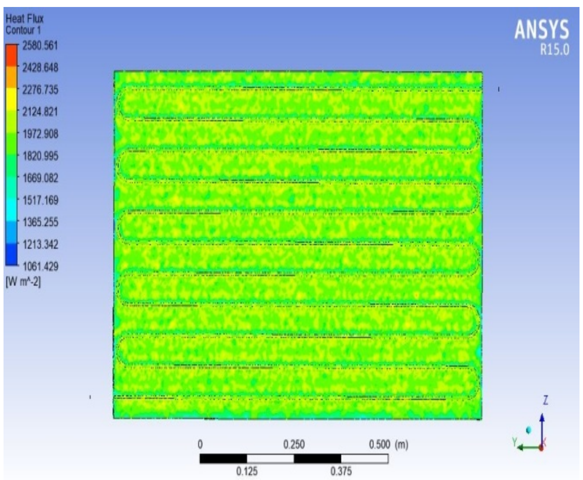

Fig. 32: Heat Flux of the Evaporator Coil and Lauric Acid

The results obtained from the CFD analysis of evaporator coil with Lauric Acid as a thermal energy storage medium is shown above. Fig 31 here shows the variation in temperature of the Lauric Acid. It can be seen the temperature of the PCM panel varies from 252k to 280K Fig 32 here shows the amount of heat flux stored by the Ethylene Glycol. It can be seen the amount of heat flux retained in the PCM panel ranges from 1061 W/m2 to 2580W/m2.

V. CONCLUSION:

In this thesis the thermal characteristics of condenser of a refrigerator is analyzed and compared with and without PCM material. From the results mentioned in the previous chapter following conclusion can be drawn:

1. The heat transfer coefficient and heat transfer rates for the condenser was much lower than those of the Condenser with PCM.
2. The condenser with Ethylene Glycol as the PCM material showed the best results for compared to other two PCM material i.e. Paraffin wax and Lauric acid.
3. However due to poisonous nature of ethylene glycol proper safety measures should be considered while using it.
4. On the other hand the results of Lauric acid were second best and due to its non-poisonous nature it can easily be used for domestic application.
5. On the other hand for the evaporator coil heat Flux obtained for Evaporator with ethylene glycol as a PCM showed best results followed by paraffin wax and then lauric Acid.
6. Temperature profile obtained for the Evaporator with PCM showed Better Results than Evaporator Without PCM.
7. Based on the results and considering safety issues it is recommended to use lauric acid as a PCM material with condenser coil to increase the efficiency of the refrigerator and decrease power consumption.
8. For Evaporator Coil After Ethylene Glycol, Paraffin Wax is the second Best material to be considered for use as Thermal Energy Storage device.

VI. SCOPE OF THE WORK:

1. The results provided in this work can be experimentally verified.
2. Study can be done with compressor off and on condition simultaneously.

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