# Design and Analysis of Latent Heat Storage System for Hybrid Solar Energy

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## Abstract

This works involves the design and analysis of latent heat storage of hybrid solar energy. In this work, design of the components and their analysis has been carried out as per the calculations. Most of the physical efforts have been reduced by using the electricity, the only thing we have to concern is the matter of production. Conventional methods have been used to produce electricity for most of the present requirements. The fossil fuels are the raw materials that are used to produce electricity in conventional methods. These methods are not only expensive, but they cause significant damage over the environment. When the demand for fossil fuel increases it eventually increases the rise in cost and hazardous emission pollution. Solar is the only source that tends to satisfy both the eco-friendly and efficient. The comparison with the conventional methods shows it is a cheaper electricity generation approach.

**Keywords:** Hybrid solar system, heat exchanger, renewable energy, PCM, power optimization, Paraffin, waste heat recovery system, photovoltaic cell.

## 1. Introduction

Most of the present hybrid solar system demand is to increase the amount of energy generated by solar panels. The one thing that makes this system different from others is the adoption of waste heat recovery system. The waste heat recovery system significantly reduces the heat loss during energy conversion by using the phase change materials (PCM) as a storage medium. **S.M.Shalaby et.al** have experimentally investigated indirect solar drier by using PCM material. After using PCM in this investigation, they have concluded that drying air temperature is much higher than the temperature of ambient air. **Esakkimuthu et.al** investigated PCM Material in thermal storage system for application of solar air heating. They have concluded that the collector efficiency will be higher at high mass flow rate. **Aymen El Khadraoui et.al** have designed and constructed the forced convection type of solar drier by using PCM Material. In this research, they found that drying chamber temperature is higher than the ambient temperature after using solar energy accumulator.

**E.Kavak Akpinar et.al** investigated thin layer drier characteristics of mint leaves with help of solar drier under the open sun condition. In this analysis, He found that energy utilization ratio value and improvement potential of the cabinet will be decreased by increasing the ambient temperature while the cabinet exegetic efficiency will be increased by increasing the ambient temperature. **B.Pitchia Krishnan et.al** experimentally investigated the performance of the solar drier, which is integrated with HSU for crops. **Sakamon Devahastin et.al** investigated on the latent heat storage to conserve the energy during the drying and investigated on its effect of drying kinetics of food products. In this investigation, they found that the charge time decreased by increasing the inlet air velocity and inlet air temperature. **Ahmet Koca et.al** designed and constructed with PCM material to analysis the latent heat storage system. They observed that energy efficiency lower that net energy efficiency and also this research is shown that the energy efficiency of latent heat storage system are very low while using PCM material in this system. **Adnaue Labed et.al** designed and constructed the solar drier to avoid Henna leaves mixture with the ground to keep safely dried sample from insects and scorpions. **Alejandro Reyes et.al** proposed dehydration of mushrooms in solar drier by PCM material. They have concluded that rehydrated mushrooms hardness value will be more than the fresh mushrooms hardness value and by adding the paraffin wax, mass, thermal efficiency will be increased in the accumulator.

## 2. Phase change materials

PCM Materials stores heat energy in the form of latent heat while it transforms from the solid state to liquid state. So, it's also known as latent heat storage material. Our objective is thermal analysis of PCB materials for Improvement in waste heat recovery from the solar panels. In this analysis latent heat storage capacity of different materials are analyzed. The physical and thermal property of the PCM materials, which is used in this research, has given in table.1.

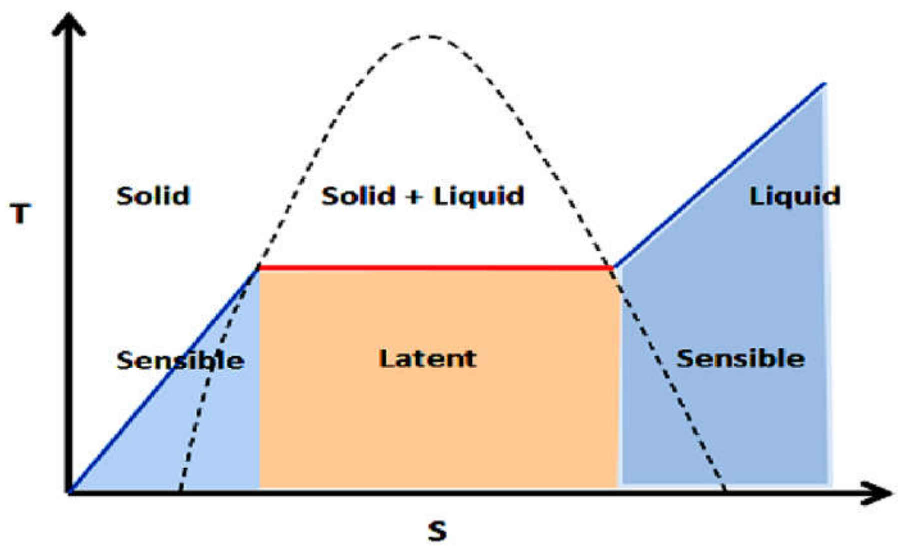


**Figure.1 Temperature-Entropy relationship (TS) diagram of phase change material**

**Table.1 Physical and thermal properties of PCM materials**

| PCM materials | Density ($kg/m^3$) | Thermal conductivity (W/mK) | Specific heat (J/g) | Melting temperature (°C) |
|---|---|---|---|---|
| Paraffin | 780- 870 | 0.24 | 200 | 37 |
| Stearic Acid | 830-940 | 0.35 | 230 | 55 |
| Glycerin | 824-850 | 0.28 | 220 | 38 |

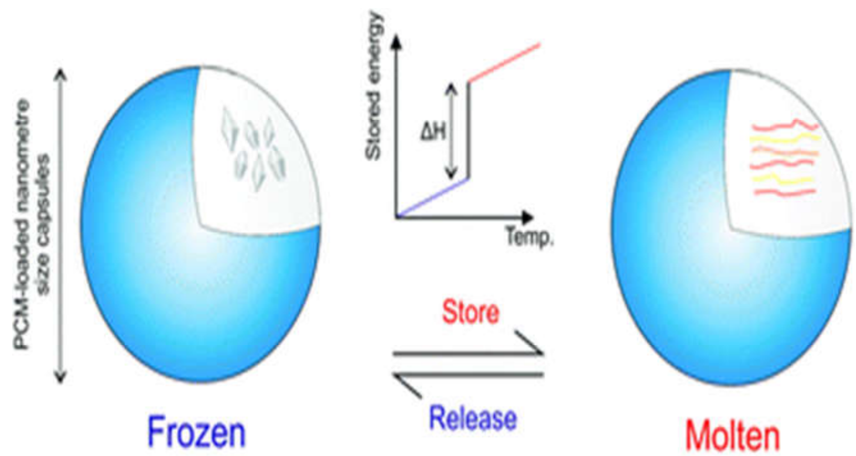


**Figure.2 PCM process illustration**

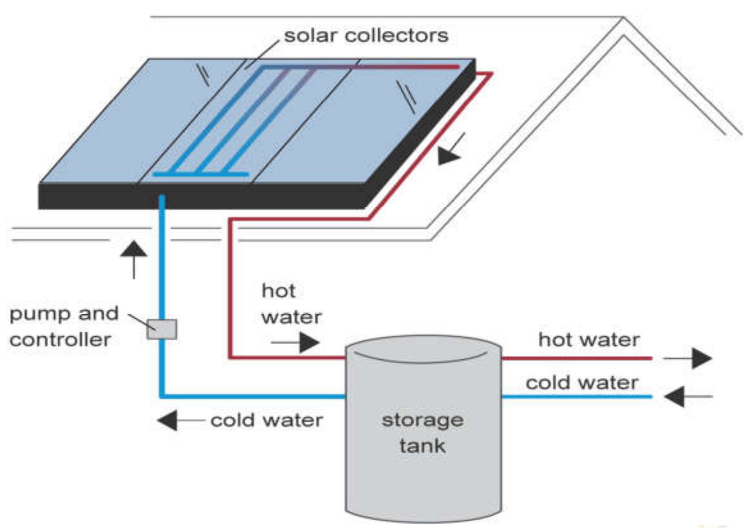


**Figure.3 Power generation process through thermal collector**

## 3. Design of hybrid solar energy system and its components

The combination of photovoltaic system and another power generating energy source makes up the hybrid solar energy system. An additional inverter takes energy from mains, solar PV, optional generators and batteries stabilizes and combines it. The various design details of the parts in this system are given below.

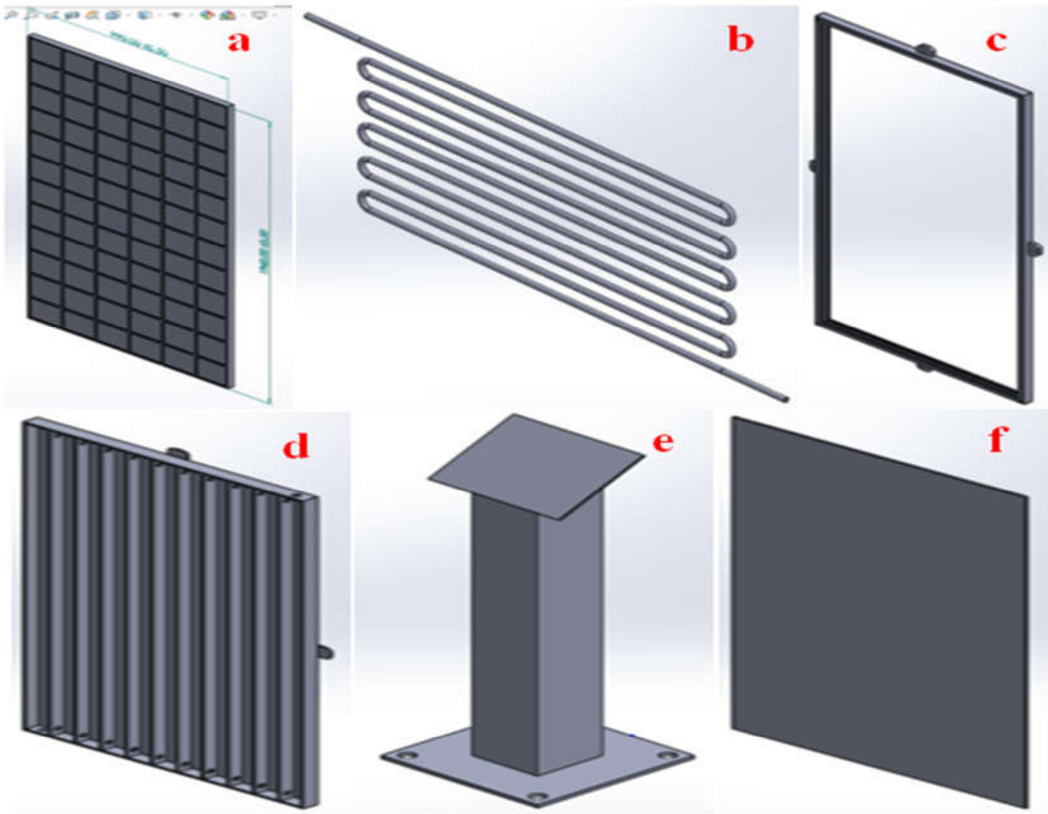


**Figure.4 Comprehensive three dimensional model of (a) solar panel (b) heat exchanger coil (c) holding frame (d) Aluminium panel with fins (e) base (f) aluminum cover plate.**

Three-dimensional model generation of a hybrid solar energy system components have started with the collection of basic dimensions from the physically available solar energy system by reverse engineering concept. The standard specifications of hybrid solar energy system components were measured with the help of standard measuring instruments with tolerances and clearances, in order to get the exact three-dimensional model of the solar energy system components. A commercial modeling software (CREO) is used to create the two dimensional views of the solar energy system components by means of the measured value with proper specifications. Different two-dimensional views are created with the help of the measured dimensions through the modeling software.

Entire two-dimensional views are checked for the conversion of three-dimensional model. The complete three-dimensional model of a hybrid solar energy system components was created with the help of the same modeling software through the two dimensional sketches. Comprehensive three-dimensional model of a hybrid solar energy system components such as solar panel, heat exchanger coil holding frame, Aluminium panel with fins, base and aluminum cover plate, which are modeled by the commercially available software, is shown in figure.4(a) to 4(f) correspondingly. In order to understand the hybrid solar energy system components, the entire three-dimensional model of the hybrid solar energy system components has converted also a wire frame model. Different orientations have applied on the hybrid solar energy system components model to obtain the various configuration views for the better understanding of solar energy system components. The complete assembly and exploded view of a hybrid solar energy systems along with its components are shown in figure.5 (a) and 5 (b) correspondingly. The three dimensional model, that was created by sing the commercially available software is ready for the finite element analysis.

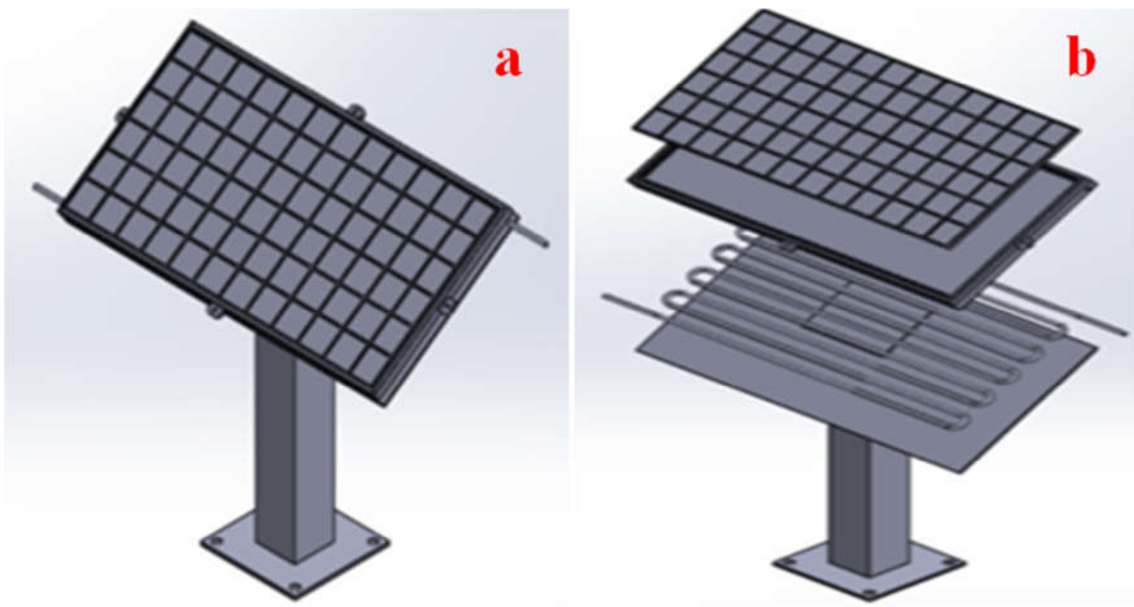


**Figure.5 Hybrid solar energy system (a) complete assembly (b) exploded view**

**4. Finite element analysis on hybrid solar energy system**

The melting and solidification model of ANSYS (Fluent) 18.0 software was used for modeling and simulation of the melting of PCM. ANSYS Fluent uses enthalpy porosity method for modeling the solidification and melting process. In this method, the melting interface is not tracked explicitly. A quantity named as liquid fraction (fraction of cell volume, which is in liquid form) is associated with each cell in the PCM domain. Based on enthalpy balance the liquid fraction is calculated after each iteration.

In this method phase, change interface is shown as a mushy zone in which the value of liquid fraction changes from 0 to 1. Mushy zone is like a pseudo (porous zone) whose porosity decreases from 1 to 0. When the material solidifies, the porosity becomes 0 and the velocity drops to zero in that zone.

**4.1 Assumptions for the analysis of phase change material**

- Smaller rectangular domain of PCM is taken for analysis.
- Melting is transient and assumed to be 2D phenomenon.
- The motion of PCM in liquid state is incompressible, non-Newtonian and turbulent.
- The density, viscosity and thermal conductivity of the PCM vary as piecewise linear.
- Viscous heating and volume expansion is ignored.
- No heat generation within the PCM.

**4.2 Energy equations**

The energy equations solved in ANSYS-Fluent model are:
Where 'H' is the enthalpy, 'ρ' is the density, 'v' is the velocity of fluid and 'S' is the source term. The enthalpy 'H' is calculated as the sum of sensible and latent heat. Where '$H_s$' is the sensible enthalpy at a point at a given instant of time; 'L' is the latent heat. Where '$H_r$' is the reference enthalpy, '$T_r$' is the reference temperature and '$C_p$' is the specific heat at constant pressure of PCM. Where β is the value of liquid fraction and L is the latent heat of PCM. The value of latent heat is zero when material is solid (β=0) and L when material is liquid (β=1).
If, T< T Solidus,
If, T> T liquidus
If, T solidus < T < T liquidus. The melting ad solidification model of PCM in ANSYS. A quantity named as liquid fraction is analyzed using ANSYS. Liquid fraction (ß) value is in between zero to one.
If ß=zero; completely solid.
If ß=one; completely liquid.

**4.3 Model description**

A geometric model of the PCM domain used for simulation is shown in figure.7. The PCM domain is a 2D planer rectangular domain of length 50 mm and height 50mm. Analysis taken for three different materials with two different models.

**4.4 Model – I**

The boundary condition for the PCM domain is as follows: The top, right and bottom sides of the PCM domain are perfectly insulated i.e. $q'' = 0 \ W/m^2$. The left side of the PCM domain is having constant heat flux boundary condition i.e. $q'' = 2500 \ W/m^2$.

**4.5 Model – II**

The boundary condition for the PCM domain is as follows: The top and bottom sides of the PCM domain are perfectly insulated i.e. $q'' = 0 \ W/m^2$.

The left and right side of the PCM domain is having constant temperature condition i.e. 293 K and 323 K respectively. The meshed model shown in figure.6 consists of 9576 nodes and 9375 elements. Convective terms in momentum equations are discretized using second order upwind interpolation scheme. Convective terms in energy equations are discretized using first order upwind interpolation scheme. The coupling between pressure and velocity is done by simple algorithm and presto is adopted for pressure interpolation. The calculations are performed using a default commercial CFD code in ANSYS-Fluent-18.0. Convergence is obtained when the residual of the energy, momentum and continuity equations are reduced to less than $10^{-10}$, $10^{-8}$ and $10^{-5}$ respectively. The time step is set as 0.1s. The number of iterations per time step is set as10. The simulation was performed on 2.4GHz Intel Core i3 processor with 4 GB RAM. Time consumption for the complete liquidification of PCM Materials is analyzed using ANSYS. Increase in time consumption of liquidification is also increase the time of solidification if the solidification time increases. It will improve the efficiency of heat exchanger coils that means recovery of waste heat will be improved. In this finite element analysis through the ANSYS-Fluent-18.0 software, comprehensive three-dimensional model of a PCM domain was undergone the thermal analysis by applying the different analysis parameters.

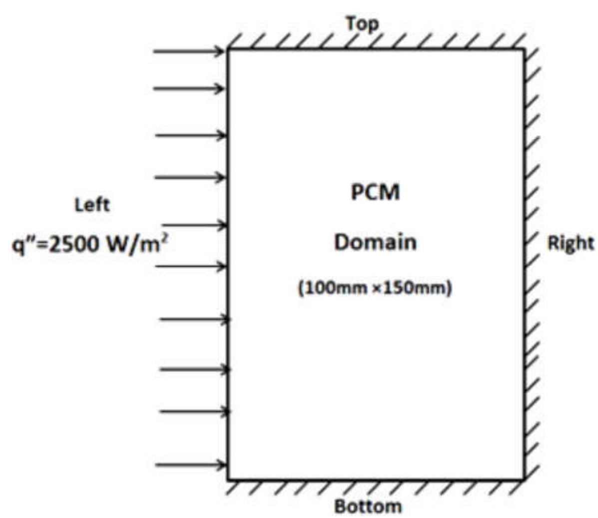


**Figure.6 Illustration of applied boundary conditions for PCM domain in ANSYS Fluent**

Before the thermal analysis on the PCM domain, the complete comprehensive three-dimensional model of the PCM domain has converted as IGES file through the modeling software for the analysis process in ANSYS-Fluent-18.0 software. The converted IGES model of a PCM domain has imported in ANSYS workbench through import module of external geometry file and the imported IGES model of a PCM domain has generated as per the requirements for the ANSYS-Fluent-18.0 software to carry out thermal analysis in the new geometry creation module. In mesh creation module, the entire imported geometry of the PCM domain has selected and the different meshing parameters like, physical preference, type of mesh, number of mesh elements and element size has assigned on the mesh model of the PCM domain.

By using the mesh generation option, the entire PCM domain model has converted as mesh model through the simulation conversion option under the predefined meshing parameters. The exclusive mesh model of PCM domain has demonstrated in figure.7.

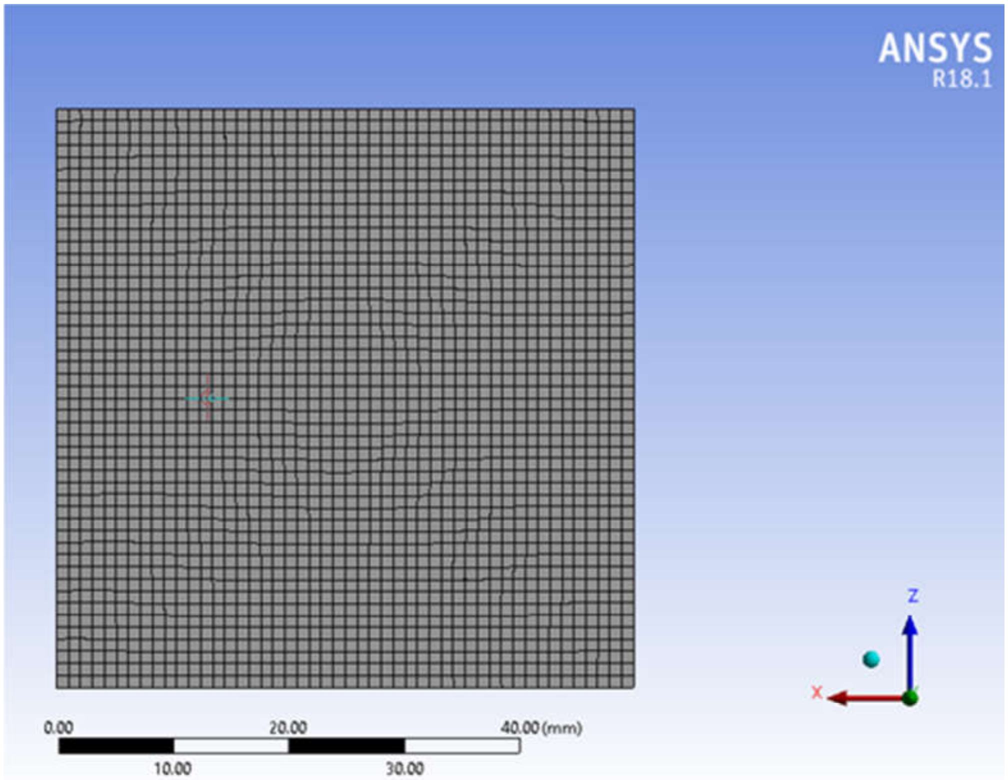


**Figure.7 Finite element model of PCM domain**

By using the solid geometry tree menu, the material for meshed PCM domain model has assigned by means of the new material definition option. The required PCM domain's material properties were feeded into the ANSYS-Fluent-18.0 software by means of the new material menu. After the material properties assignment on the mesh model of PCM domain, new analysis option has selected in the software to fix the support for the PCM domain to apply the thermal load. Thermal analysis option has opted to apply the thermal load on the PCM domain. Finally by using the solve icon option, the entire analysis were computed for the given inputs and for the selected outputs from the ANSYS-Fluent-18.0 software. After the solver command execution process, the required results for the PCM domain has obtained from the software in the form of color counter plots for the specific inputs. In this research, the specific outputs such as the minimum and maximum liquid fraction have obtained through temperature and heat flux analysis in the form of color plots for Paraffin phase change material. The same analysis process has followed for the remaining two phase change materials (Stearic Acid and Glycerin), the corresponding outputs for those materials has obtained, and the analysis results were illustrated and compared with other in results and discussions chapter.

## 5. Results and discussions

A typical finite element analysis has carried out successfully on a hybrid solar energy system with two different methods such as temperature and heat flux analysis by changing the phase change materials like, Paraffin, Stearic Acid and Glycerin materials for the establishment of minimum and maximum liquid fraction exhibited by the hybrid solar energy system under the specific input conditions, which has applied on it theoretically. The following results have obtained from the finite element analysis for the three different phase change materials.

### 5.1 Maximum and minimum liquid mass fraction obtained from temperature analysis for Paraffin PCM domain

Maximum and minimum liquid mass fraction obtained from temperature analysis for Paraffin PCM domain from the ANSYS-Fluent 18.0 software has illustrated in figure.8. From the figure.8, it was observed that the maximum liquid mass fraction of 0.5555 that has exhibited by the Paraffin PCM material. Minimum liquid mass fraction of 0.4445 has established by the Paraffin PCM material.

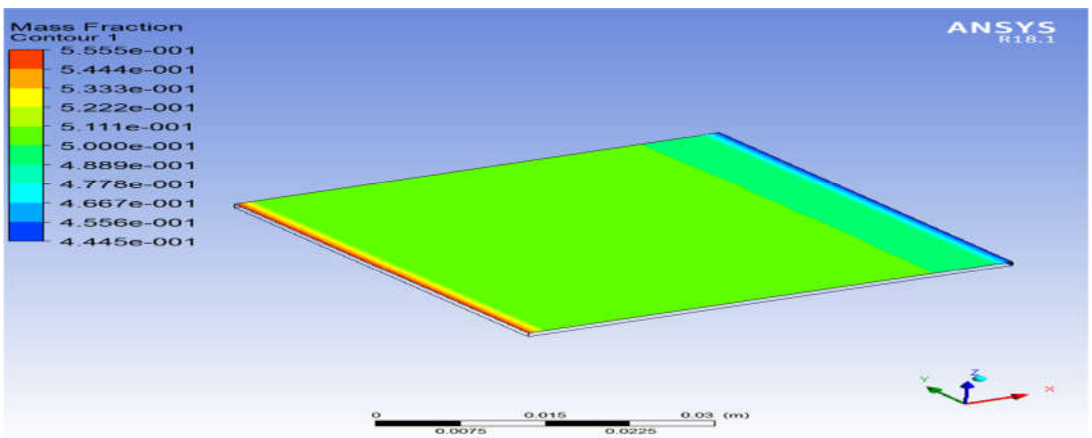


**Figure.8 Liquid mass fraction obtained in Paraffin PCM domain by temperature analysis**

### 5.2 Maximum and minimum liquid mass fraction obtained from temperature analysis for Stearic Acid PCM domain

Maximum and minimum liquid mass fraction obtained from temperature analysis for Stearic Acid PCM domain from the ANSYS-Fluent 18.0 software has illustrated in figure.9. From the figure.9, it was observed that the maximum liquid mass fraction of 0.2166 that has exhibited by the Stearic Acid PCM material. Minimum liquid mass fraction of 0.209 has established by the Stearic Acid PCM material.

### 5.3 Maximum and minimum liquid mass fraction obtained from temperature analysis for Paraffin PCM domain

Maximum and minimum liquid mass fraction obtained from temperature analysis for Paraffin PCM domain from the ANSYS-Fluent 18.0 software has illustrated in figure.10.

From the figure.10, it was observed that the maximum liquid mass fraction of 1.0000 that has exhibited by the Paraffin PCM material. Minimum liquid mass fraction of 0.997 has established by the Paraffin PCM material.

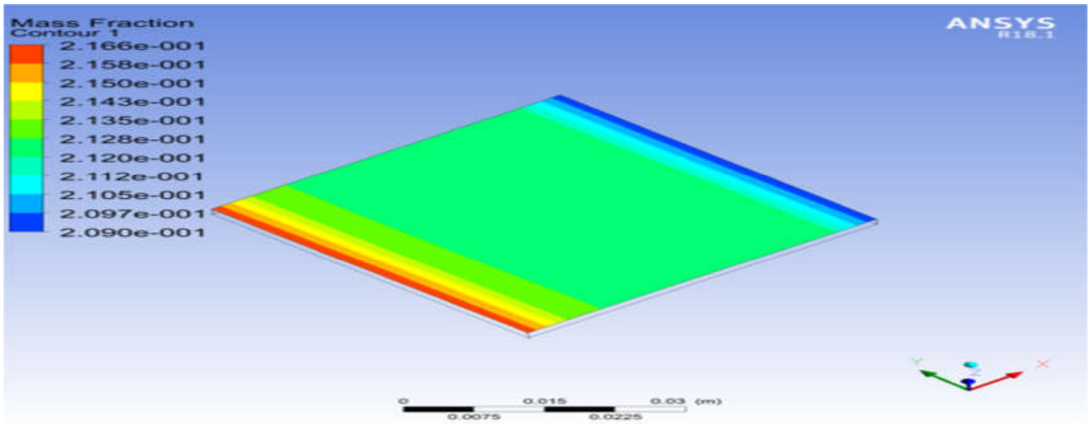


**Figure.9 Liquid mass fraction obtained in Stearic Acid PCM by temperature analysis**

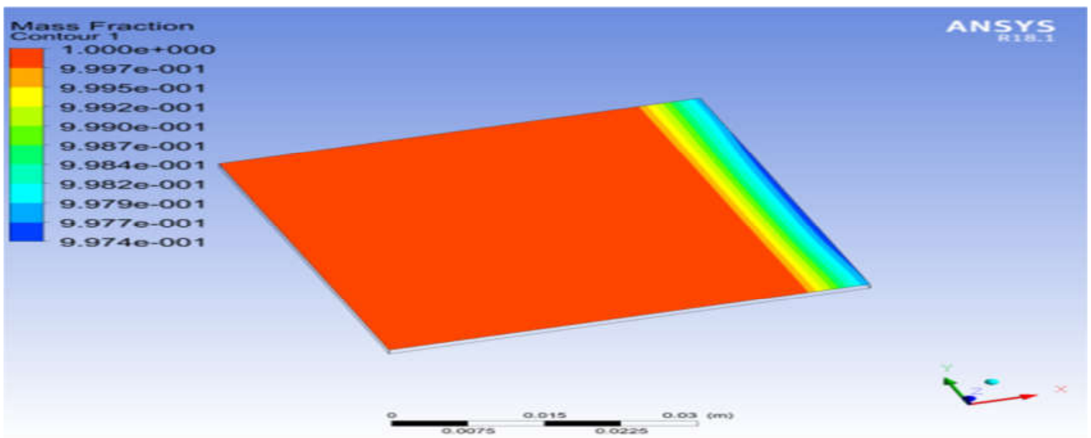


**Figure.10 Liquid mass fraction obtained in Glycerin PCM domain by temperature analysis**

### 5.4 Maximum and minimum liquid mass fraction obtained from heat flux analysis for Paraffin PCM domain

Maximum and minimum liquid mass fraction obtained from temperature analysis for Paraffin PCM domain from the ANSYS-Fluent 18.0 software has illustrated in figure.11. From the figure.11, it was observed that the maximum liquid mass fraction of 0.6767 that has exhibited by the Paraffin PCM material. Minimum liquid mass fraction of 0.5000 has established by the Paraffin PCM material.

### 5.5 Maximum and minimum liquid mass fraction obtained from heat flux analysis for Stearic Acid PCM domain

Maximum and minimum liquid mass fraction obtained from temperature analysis for Stearic Acid PCM domain from the ANSYS-Fluent 18.0 software has illustrated in figure.12. From the figure.12, it was observed that the maximum liquid mass fraction of 0.21980 that has exhibited by the Stearic Acid PCM material. Minimum liquid mass fraction of 0.21280 has established by the Stearic Acid PCM material.

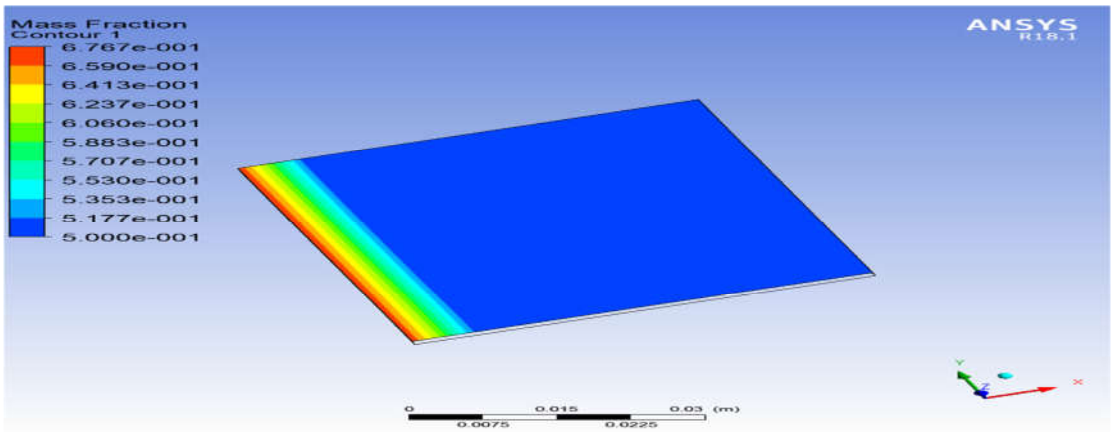


**Figure.11 Liquid mass fraction obtained in Paraffin PCM domain by heat flux analysis**

### 5.6 Maximum and minimum liquid mass fraction obtained from heat flux analysis for Glycerin PCM domain

Maximum and minimum liquid mass fraction obtained from temperature analysis for Glycerin PCM domain from the ANSYS-Fluent 18.0 software has illustrated in figure.13. From the figure.13, it was observed that the maximum liquid mass fraction of 1.0000 that has exhibited by the Glycerin PCM material. Minimum liquid mass fraction of 0.99700 has established by the Glycerin PCM material.

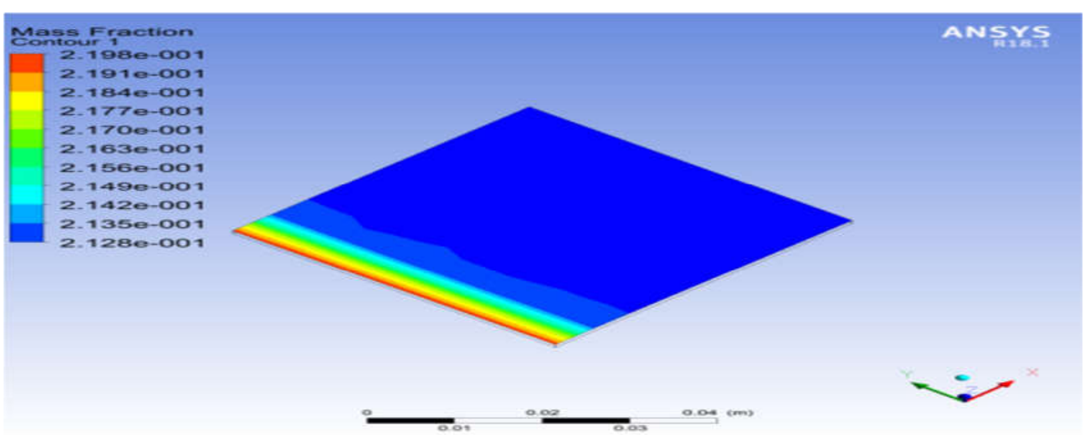


**Figure.12 Liquid mass fraction obtained in Stearic Acid PCM by heat flux analysis**

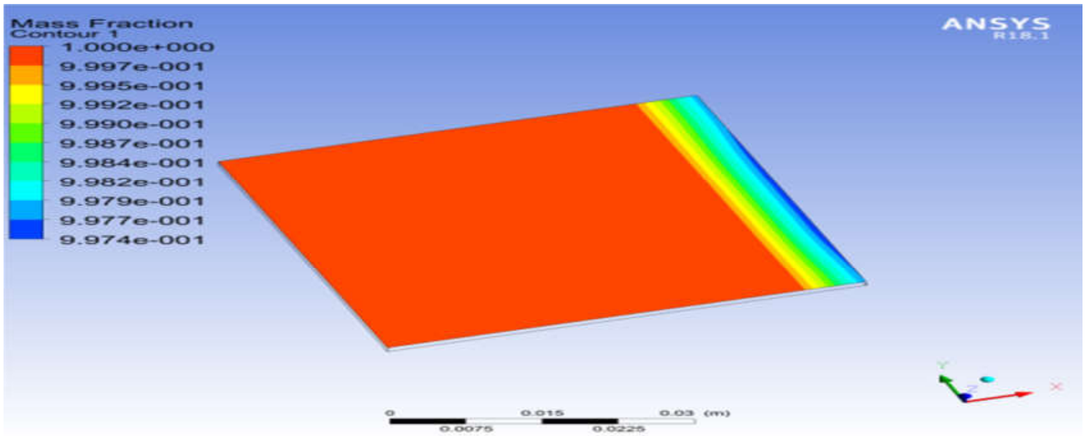


**Figure.13 Liquid mass fraction obtained in Glycerin PCM domain by heat flux analysis**

The variation on maximum liquid mass fraction which was obtained from the numerical analysis by using the temperature analysis method for the three PCM materials were illustrated in figure.14, from this figure.14, it was observed that the maximum liquid mass faction of 0.55550, 0.21660 and 1.00000 were found in the three PCM materials such as Paraffin, Stearic acid and Glycerin correspondingly. Among these three PCM materials, superior liquid mass fraction of 1.00000 was noticed in Glycerin PCM material due to its superior latent heat capacity.

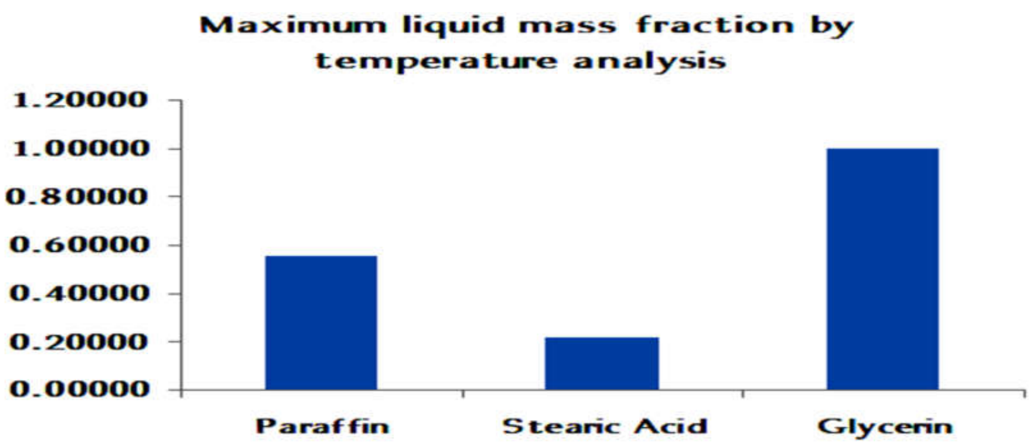


**Figure.14 Variation of maximum liquid mass fraction for all PCM materials in PCM domain by temperature analysis**

The variation on minimum liquid mass fraction which was obtained from the numerical analysis by using the temperature analysis method for the three PCM materials were illustrated in figure.15, from this figure.15, it was observed that the maximum liquid mass faction of 0.44450, 0.20900 and 0.99700 were found in the three PCM materials such as Paraffin, Stearic acid and Glycerin correspondingly.

Among these three PCM materials, superior liquid mass fraction of 0.99700 was noticed in Glycerin PCM material due to its superior latent heat capacity. The variation on maximum liquid mass fraction which was obtained from the numerical analysis by using the heat flux analysis method for the three PCM materials were illustrated in figure.16, from this figure.16, it was observed that the maximum liquid mass faction of 0.67670, 0.21980 and 1.00000 were found in the three PCM materials such as Paraffin, Stearic acid and Glycerin correspondingly. Among these three PCM materials, superior liquid mass fraction of 1.00000 was noticed in Glycerin PCM material due to its superior latent heat capacity.

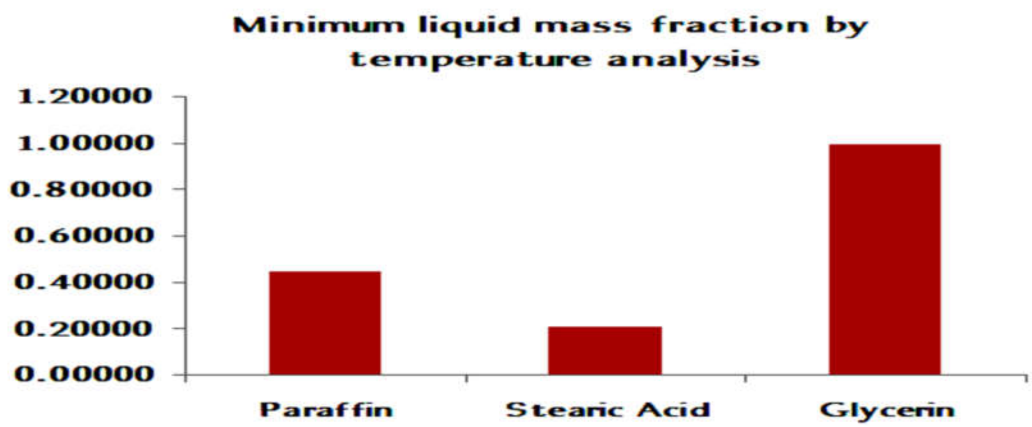


**Figure.15 Variation of minimum liquid mass fraction for all PCM materials in PCM domain by temperature analysis**

The variation on minimum liquid mass fraction which was obtained from the numerical analysis by using the heat flux analysis method for the three PCM materials were illustrated in figure.17, from this figure.17, it was observed that the maximum liquid mass faction of 0.50000, 0.21280 and 0.99700 were found in the three PCM materials such as Paraffin, Stearic acid and Glycerin correspondingly. Among these three PCM materials, superior liquid mass fraction of 0.99700 was noticed in Glycerin PCM material due to its superior latent heat capacity.

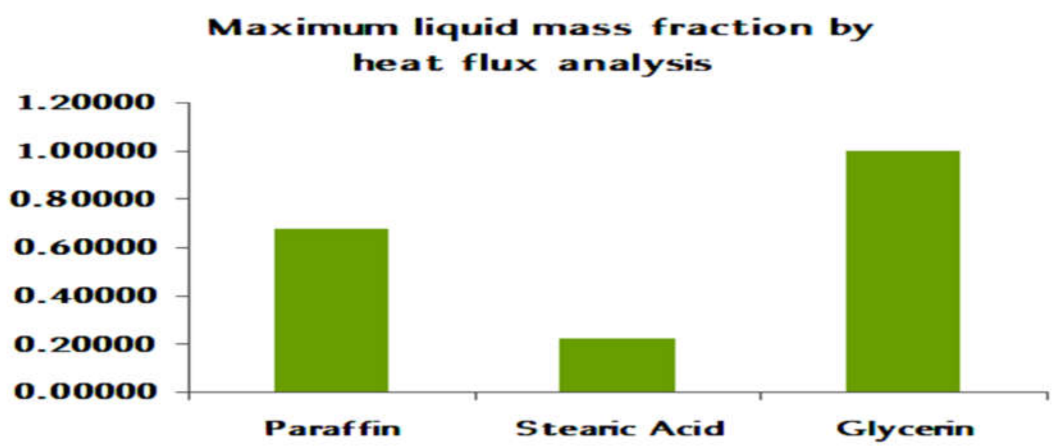


**Figure.16 Variation of maximum liquid mass fraction for all PCM materials in PCM domain by heat flux analysis**

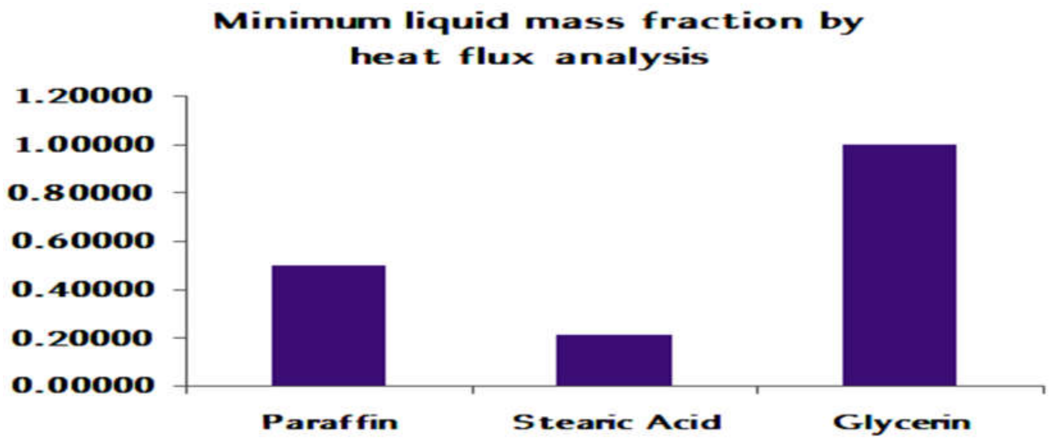


**Figure.17 Variation of minimum liquid mass fraction for all PCM materials in PCM domain by heat flux analysis**

## 6. Conclusions

The following conclusions were made based on the numerical analysis, which has been obtained from the ANSYS-Fluent 18.0 software for the development of effective latent heat storage materials for hybrid solar energy system.

- Latent heat capacity of Glycerin material is highest compared to Stearic acid and Paraffin.
- Latent heat capacities of the PCM materials are directly proportional to the liquid fraction of the PCM materials.
- Glycerin material exhibited the maximum liquid mass fraction than other two PCM materials.
- Waste heat recovery system design with Glycerin as PCM material will be the most effective than other PCM materials.

## References

1. S.M.Shalaby, M.A.Bek, Experimental investigation of a novel indirect solar dryer implementing PCM as energy storage medium, Energy Conversion and Management, 2014, 83, pp.01-08.

2. S.Esakkimuthu, A.H.Hassabou, C.Palaniappan, M.Spinnler, J.Blumenberg, R.Velraj, Experimental investigation on phase change material based thermal storage system for solar air heating applications, Solar Energy, 2013, 88, pp.144-153.

3. Aymen El Khadraoui, Salwa Bouadila, Sami Kooli, Abdelhamid Farhat, Amenallah Guizani, Thermal behavior of indirect solar dryer: Nocturnal usage of solar air collector with PCM, Journal of Cleaner Production, 2017, 148, pp.37-48.

4. E.Kavak Akpinar, Drying of mint leaves in a solar dryer and under open sun: Modelling, performance analyses, Energy Conversion and Management, 2010, 51, pp.2407-2418.

5. B.Pitchia Krishnan, P.Gopi, M.Mathanbabu, S.Eswaran, Experimental investigation of solar drier integrated with HSU for crops, Journal of Advanced Research in Dynamical and Control Systems, 2019, 11 (12), pp.167-173.

6. Sakamon Devahastin, Saovakhon Pitaksuriyarat, Use of latent heat storage to conserve energy during drying and its effect on drying kinetics of a food product, Applied Thermal Engineering, 2006, 26, pp.1705–1713.

7. Ahmet Koca, Hakan.F.Oztop, Tansel Koyun, Yasin Varol, Energy and energy analysis of a latent heat storage system with phase change material for a solar collector, Renewable Energy, 2008, 33, pp.567–574.

8. Adnane Labed, Noureddine Moummi, Kamel Aoues, Adel Benchabane, Solar drying of henna (Lawsonia Inermis) using different models of solar flat plate collectors: An experimental investigation in the region of Biskra (Algeria), Journal of Cleaner Production, 2016, 112, pp.2545-2552.

9. Alejandro Reyes, Andrea Mahn, Francisco Vasquez, Mushrooms dehydration in a hybrid-solar dryer, using a phase change material, Energy Conversion and Management, 2014, 83, pp.241–248.

10. B.Pitchia Krishnan, R.Vijayan, K.Gokulnath, S.Vivek, G.Sathyamoorthy, Experimental analysis of a vapour compression refrigeration system by using nano refrigerant (R290/R600a/$Al_2O_3$), AIP Conference proceedings, 2019.

11. P.Mohanraj, S.Navaneetha Krishnan, T.Naveen Kumar, S.Vijay, Design and thermal analysis of ceramic coated diesel engine piston ($MgZro_3$ & NiCrAl), International Journal of Advanced Science and Engineering Research, 2019, 04 (01), pp.148-156.

12. B.Pitchia Krishnan, Ragland Gazetrin Prabhu, K.Gokulnath, S.Vivek, Enhancement of heat transfer on rotating heat pipe, International Journal of Science Research and Review, 2019, 08 (08), pp.19-24.