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Transient Analysis on Effect of Inclination Angles in the Performance of Finned PCM Heat Sink Integrated Photovoltaic Panels

Jayasree Sushma Ramathota[1], K. Srinivasa Prasad[2]
[1, 2]Mechanical Engineering Department, Jawaharlal Nehru Technological University- University College of Engineering Vizianagaram

Abstract: In this paper, the performance of the Phase change material in a heat sink integrated with a Photovoltaic Panel is explored by providing both internal and external fins to the sink. The performance characteristics of PCM can be evaluated with different inclinations (25^0,30^0, and 35^0) of Photovoltaic Panels. RT 42 is used as PCM material in the heat sink. AUTO CAD 18.0 is used to design the PV back panels integrated with PCM heat sinks (PV-PCM) and Ansys Fluent 19.0 for transient analysis with the constant wall temperature of 343^0K on the top of the PCM heat sink and calculated the temperature distribution, heat enhancement and melting time for increasing the efficiency of PV panels. The results showed a significant improvement in melting time, and temperature distribution in PV panels, if the fins are provided as of three in number and inclination of 25^0 for the panel.

Keywords: Phase Change Material (PCM), heat sink, Melting time, liquid fraction and Fins

I. INTRODUCTION

Renewable energy becoming an important aspect in development of several applications, one of its applications is Photovoltaic panels. The uses of these panels are most significant due to its advantages of fewer emissions. To increase the efficiency of PV Panels, several techniques are in research concern. One of them is the use of Phase Change Material (PCM) in PV cells. As PCM is latent heat storage material, it is useful in many areas like electronic applications [1], textiles, automobiles, heat management by waste materials LED Lights, and many more. PCMs have the property of reversible conversion i.e., absorbing heat when it is heated (Charging Process) and release of heat when the heat is removed (discharging process). Due to this property, it is used in many thermal storage systems. PCMs are mainly categorized in three forms namely Organic, Inorganic, and eutectic salts. Among all, the choice of Organic PCMs is preferred over Inorganic PCMs, as they don’t react and rust with PCM capsulated material [2]. Therefore, leakage issues with Organic based PCMs are very rare. Organic PCMs also exhibit a very low degree of sub cooling compared to Inorganic PCMs. Paraffin is commonly used Organic PCM due to its desirable properties, although its thermal conductivity is relatively low and can be expensive compared to other inorganic PCMs.

The factors that affect the efficiency of Photovoltaic panels are solar incident on the cell, the material of semiconductor in use i and the operating temperature of PV cell which is majorly controlled by effective cooling of panels by water or forced air but it causes issues like corrosion. So, the passive cooling technique of using PCM in PV panels is a prominent technique. The various methods have been implementing in northern countries [3]. The use of nanomaterials[4] in the PCM for much more effective heat absorbing from PV cells was experimented, A new method of providing fins for discharging heat from PCM is experimentally proved [5]. The fins that are internally assigned to the PCM sink to increase the heat transfer from PV cell [6]. The use of salt eutectics as PCM is experimentally done and seen an increase in thermal conductivity of PCM and melting time [7] the recent study has seen that the inclination angle of PV cell also affects the efficiency of the panel [8]. Several experiments in both indoor and outdoor of the buildings at different climatic conditions and concluded that PCM effects are predominant on PV temperature in hot climates [9]. Their study in UAE at desert conditions used RT42 as PCM saw a decrease of heat transfer by 7% with a temperature of 3.5^0c during day time and the indoor conditions of decreased peak temperature in the interior of the building by two hours and the power output increase by 5.5% [10].

The experiments in Italy at Palermo [11] during the summer season of June for two days and observed difference in an effective heat transfer, if there is no direct thermal contact between the back surface of the PV-Panel and PCM. The results with a finite-difference model for PV-Panel integrated with plastic pouches of capsulated PCM at the back surface of the PV Panel [12] are calculated numerically [13]. Commercially RT 27(Tm =27 °C) encapsulated in plastic pouches and placed at the back of PV Panel with the help of wire mesh is conducted experimentally in tropical climates of Malaysia for the first time in the present duration and

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they showed the decrease of 10% in the operating temperature of PV-Panel at the typical sunny day having a peak temperature for 4 to 6 consecutive hours and show the drop of temperature to ambient by PV Panel experimentally [14]. Thermal PV/PCM models are developed have received wide interest so far, yet these require further modification, which could include heat loss to the environment from PV panel surfaces by natural convection effects within the melted PCM, fusion and solidification of the PCM, the effect of the PV panel's inclination angle on the heat loss mechanisms. In the present thermal model, these improvements have been considered to study the thermal response of a PV module coupled with PCM under constant temperature with internal and external fins that are attached to the back of the Photovoltaic panel and the PCM heat sink back surfaces along with 25^0,30^0 and 35^0 inclination angles. This is accomplished by investigating the heat losses from the PV module's surface to the environment along with the mass, momentum and energy transfer in the PCM.

A. Nomenclature

PV Systems	Photovoltaic systems
PCM	Phase Change Material
AUTO CAD	Commercial Computer Aided Design
ANSYS 19.0	ANSYS stands for Analysis System. Finite element analysis software developed by ANSYS Inc, United States of America (USA)
PV-PCM	Photovoltaic Panel integrated with Phase Change Material container
DEG	Degrees of inclination
T_W	Constant Wall Temperature
2 D	Two Dimensional
3D	Three Dimensional
CFD	Computational Fluid Dynamics
T_m	Melting Temperature(K)
T_i	Initial Temperature(K)
u_i	Initial velocity (m/s^2)
2 fins PV-PCM	Photovoltaic panel integrated with Phase Change Material having 2 fins both internally and externally
3 fins PV-PCM	Photovoltaic panel integrated with Phase Change Material having 3 fins both internally and externally
Greek letters	
P	Density (kg/m^2)
M	Dynamic viscosity (kg/ms)
Ө	An Inclination angle of the heat sink

II. SIMULATION MODEL AND BOUNDARY CONDITIONS

Modeling of the PV cells integrated with PCM heat sinks with (2 and 3) external and internal fins (PV-PCM) along with three inclinations(25^0,$30^0$and 35^0) is done by Auto Cad 18.0 with the dimensions of 0.12m ×0.05m (height ×width) for heat sink and PV cell back panel with 0.12m× 0.01m (height × width) with an equal ratio of 1:1.The distance between the fins is about 0.029m for 3 fins PCM rectangular container. The physical model of PV-PCM model is given in fig 1. The properties of panel is given in table 1 and the commercial PCM of RT 42 is used for current study and its properties are given in table 2

Table 1

PROPERTIES OF ALUMINIUM	
Density(Kg/m^3)	2719
Thermal Conductivity(W/m-K)	202.4
Specific heat(J/kg-K)	871

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A. Boundary Conditions

1) Initial conditions

At t=0, $T(0) = T_i = 300K$,

2) Input temperature at PV cell:

$$T(t)_{\substack{x = 60\text{ mm} \\ y = 0\text{-}120}} = T_w = 343\text{ K}$$

3) Adiabatic boundary conditions are given at the PCM container walls and the heater surfaces:

At the top wall of the PCM container

$$-k\,(\partial T/\partial y)_{\substack{x = 0\text{-}60\text{ mm} \\ y = 120\text{mm}}} = 0$$

At the bottom wall of PCM container

$$-k\,(\partial T/\partial y)_{\substack{x = 0\text{-}60\text{mm} \\ y = 0\text{mm}}} = 0$$

The value of the heat transfer coefficient is generally 5-10W/m^2 K is applied to the back surface of the PCM panel and also for the extended fins. The convection from the PCM heat sink back surface will lose heat to the outside and reduces the chances of heat built up in the container.

Table 2

THERMAL AND PHYSICAL PROPERTIES OF PCM(RT 42)		
PROPERTY	*RT42*	*UNITS*
DYNAMIC VISCOSITY, μ	*0.0235*	*Kg/ms*
DENSITY OF SOLID, ρ	*880*	*Kg/m^3*
HEAT CAPACITY C_P	*2000*	*J/Kg K*
DENSITY OF LIQUID, ρ	*760*	*Kg/m^3*
THERMAL CONDUCTIVITY, K	*0.2*	*W/m K*
MELTING TEMPERATURE, t_l	*311*	*K*
LATENT HEAT, l_h	*165*	*KJ/Kg*
SOLIDUS TEMPERTURE ,t_s	*315*	*K*
THERMALEXPANSION COEFFICIENT, β	*0.0001*	*K^{-1}*

The assumptions considered in numerical analysis are

a) Unsteady, laminar, two-dimensional fluid flow is to be assumed
b) Liquid PCM as a Newtonian fluid.
c) The thermo-physical properties of PCM are constant.
d) The volume of PCM changing in phase change transition is ignored.
e) Radiation Effects are neglected.

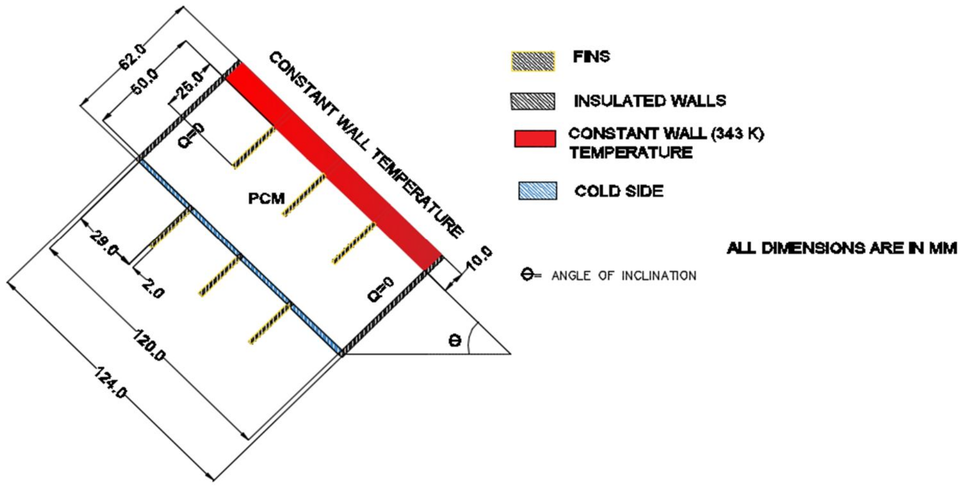

Fig 1: Simulation model of PV-PCM heat sink

Governing equations for Simulation work
The physical governing equations considered are:
Continuity equation,
$(\partial\rho/\partial t)+ \nabla(\rho \, . \, \vec{u}) = 0$
Momentum equation,
$\partial/\partial t\,(\rho\vec{u}) + \nabla.\,(\rho\,\vec{u}\,\vec{u}) = \mu\,\nabla^2\vec{u} - \nabla p + \rho\vec{g} + \vec{S}$
Energy equation,
$\partial/\partial t\,(\rho H) + \nabla\,.\,(\rho\vec{v}\,H) = \nabla\,.\,(k\nabla T) + S$
Where H = enthalpy
ρ = density
$\vec{v}$ = fluid velocity
S = source term

III.COMPUTATIONAL PROCEDURE

The model of a 2D geometrical model of Photovoltaic- Phase Change Material based Heat sink (PV-PCM) is designed in Auto CAD 18.1.The 2 fins PV-PCM heat sink is designed with the distance of fins 41mm, and 71mm from the 62mm horizontal line as given in fig 2. The 3 fins PV-PCM heat sink is designed but the distance of fins is 31mm, 61mm, and 91mm from the 62mm horizontal line is represented in fig 3. The 2 and 3 fins PV-PCM heat sink with an inclination of 25, 30^0, and 35^0 are created.

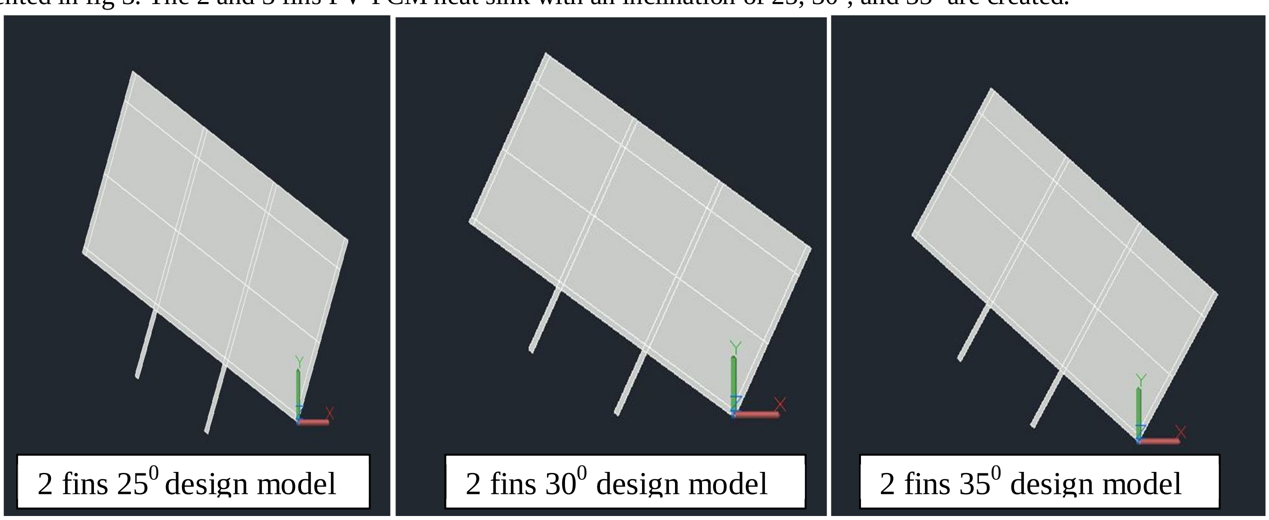

Fig 2: Design of 2 fins PV-PCM systems at different inclinations of 25^0,30^0 and 35^0

Ansys 19.0 is used for transient conditions and governing equations associated with PV-PCM analysis. SIMPLEC (Semi- Implicit Method for Pressure Linked Equation Consistent) Algorithm is used as pressure-velocity coupling under-relaxation factor to 1.0 and PRESTO (Pressure staggering option) is adopted for pressure correction equation. The second-order upwind scheme is used for momentum and energy equations discretization with under relaxation factors of 0.3, 1, 1, 0.2 and 1 for pressure, density, body forces, momentum, and energy. The residuals for continuity, momentum and energy equations are less than 10^{-4}, 10^{-5}, 10^{-5}, and 10^{-6}. Initialize the temperature of 300 ^{0}K in all zones by standard initialization with the time step size of 0.2 s and a constant temperature of 343^{0}K at the back surface of PV panel The values of time, temperature, liquid fraction, and heat transfer enhancement are analyzed. The variation in the melting of PCM from initial state to complete melting is seen in fig 5, 6, 7, 8 and 9 at different inclinations of 25^0,30^0 and 35^0 with different number of fins (2, and 3 fins).

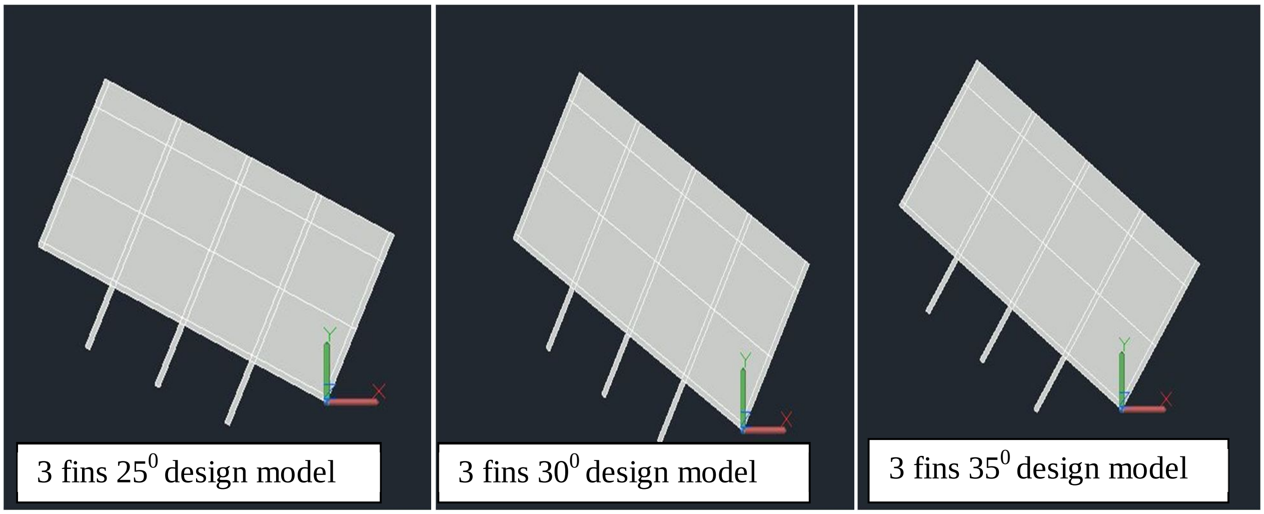

Fig 3: Design of 3 fins PV-PCM systems at different inclinations of 25^0,30^0 and 35^0

IV. RESULTS AND DISCUSSIONS

A. *Effect of Inclination angle on the operating Temperature of PV-PCM Heat Sink*

The PV-PCM tilt angle affects the melting time of the PCM attached at its back due to the convective heat transfer inside the PCM. The developed thermal model is solved for three different angle of inclination from vertical i.e. 25^0, 30^0 and 35^0. Fig10 represents the effect of tilt angle on variation of PV panel operating temperature to the melting time. From table 3, it is observed that 2 fins with inclinations of 35^0 has taken 655 minutes for complete temperature distribution as it is better than the 2 fins 25^0 and 2 fins 30^0 inclined PCM containers. For 3 fins, it is seen that for inclinations of 25^0 it is taken770 minutes for complete temperature distribution which is better than 30 ^{0} and 35^0 as represented in table 4.As the tilt angle of PV/PCM system increases the melting time PCM increases, which reduces the convective heat transfer inside the PCM cavity. The natural convection heat transfer losses of air to the environment over the panel decreases along with the PV tilt angle. Overall the PV panel operating temperature decreases with reduction in PV panel tilt angle.

TIME(MIN)	2 FINS 25 DEG TEMPERATURE	2 FINS 30 DEG TEMPERATURE	2 FINS 35 DEG TEMPERATURE
0	300	300	300
50	317.56	318.13	316.86
100	320.89	322.8	319.58
150	322.79	324.65	321.96
200	324.89	326.55	323.96
250	326.99	328.45	325.96
300	329.09	330.35	327.96
350	331.19	332.25	329.96
400	333.29	334.15	331.96
450	335.39	336.05	333.96

480	336.65	337.19	335.16
500	337.49	337.95	335.96
520	338.33	338.71	336.76
550	339.59	339.85	337.96
580	340.85	340.99	339.16
600	341.69	341.75	339.96
635	342.79	342.987	341.65
645	342.98		342.25
655			342.95

Table 3. Temperature of PCM at three inclinations of 2-fins PV-PCM based heat sink to time

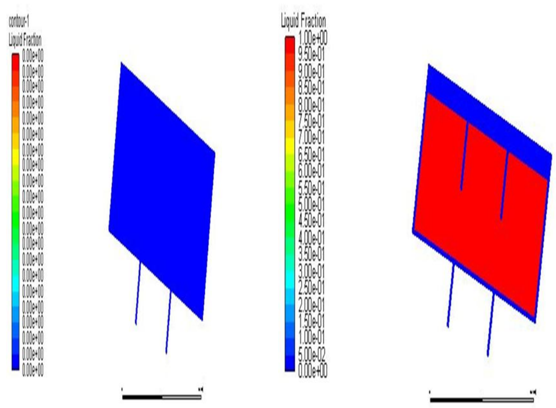

Fig 4. 2 fins 25^0 model complete melting at 645 min

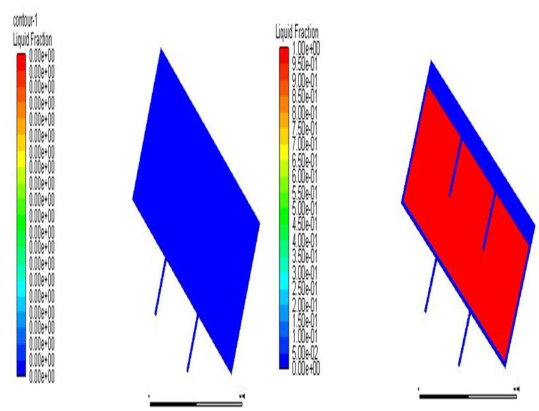

Fig 5. 2 fins 30^0 model complete melting at 635

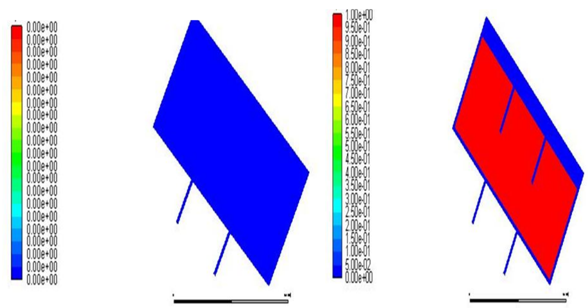

Fig 6. 2 fins 35^0 model complete melting at 635 mins

TIME(MIN)	3 FINS 25 DEG TEMPERATURE	3 FINS 30 DEG TEMPERATURE	3 FINS 35 DEG TEMPERATURE
0	300	300	300
50	318.79	319.22	320.39
100	320.6508	321.51	324.45
150	322.2842	322.62	326.2567
200	323.9175	323.62	328.0567
250	325.5508	324.62	329.8567
300	327.1842	325.85	331.6567
350	328.8175	327.85	333.4567
450	332.0842	331.85	337.0567

450	332.0842	331.85	337.0567
500	333.7175	333.85	338.8567
520	334.3708	334.65	339.5767
550	335.3508	335.85	340.6567
590	336.6575	337.45	342.0967
600	336.9842	337.85	342.6894
605	337.1475	338.05	342.8956
650	338.6175	339.85	
700	340.2508	341.85	
720	340.9042	342.65	
770	342.8902		

Table 4. Temperature of PCM at three inclinations of 3 fins PV-PCM based heat sink to time

The comparison of the temperature distribution in 2 and 3 fins PV-PCM heat sink at the different inclinations of 25^0, 30^0, and 35^0 is represented graphically. From figure 10 , it is clearly shown that, the PV panel operating temperature tends to close to the PCM operating temperature , due to the higher convective heat loss from finned back surface of PCM results in increased heat transfer to the surroundings from PV/PCM. The lower ambient temperatures lead to enhanced heat losses from PV panel front and PCM container back surface by natural convection.

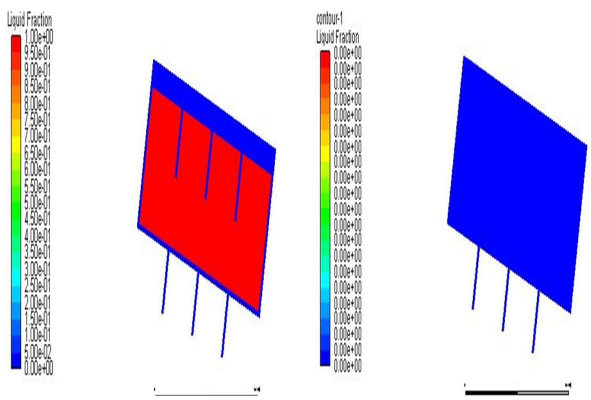

Fig 7. 3 fins 25^0 model complete melting at 770 mins

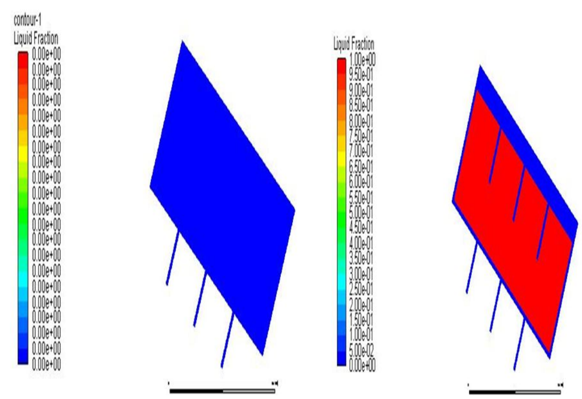

Fig 8. 3 fins 30^0 model complete melting at 720 mins

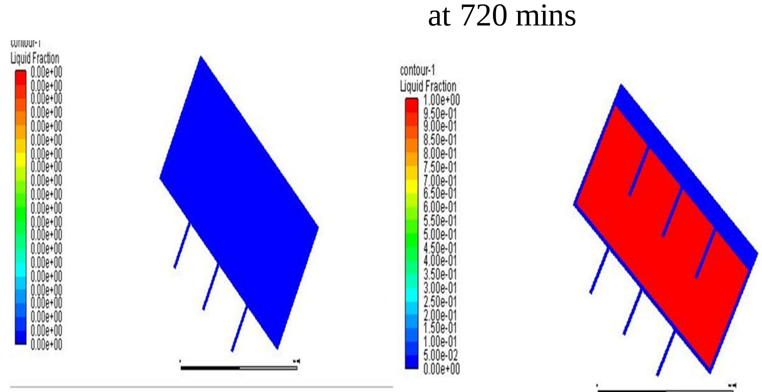

Fig 9. 3 fins 35^0 model complete melting at 605 mins

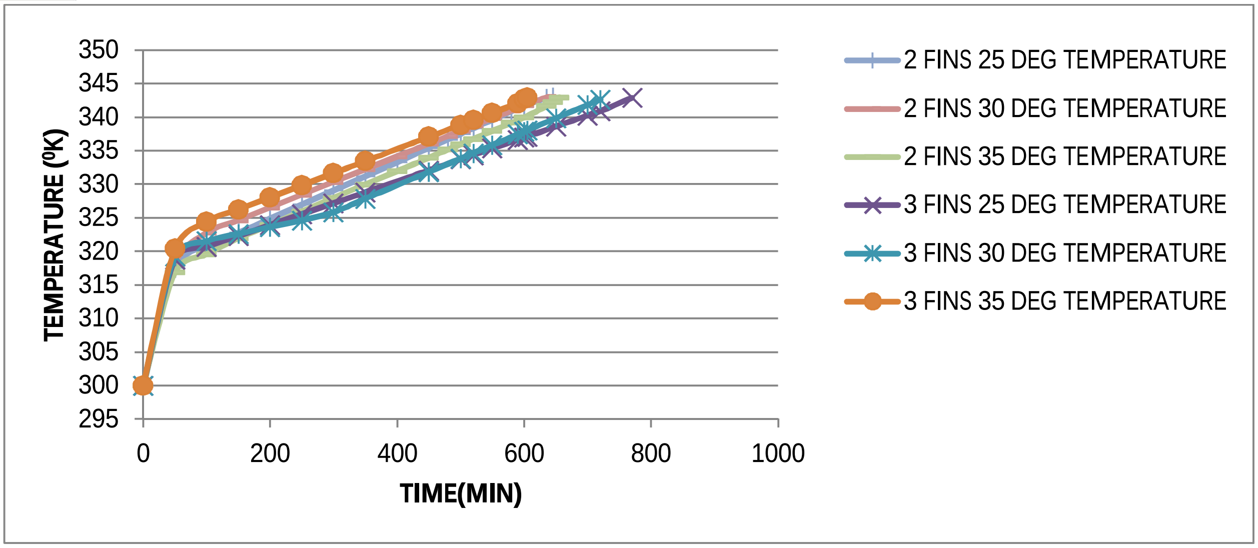

Fig 10. Variation in Temperature distribution over the Time period in PV-PCM heat sink

B. Effect of Inclination angle in Liquid Fraction variation of PCM over the time Period

The heat transfer from the PV panel to the PCM starts increasing due to temperature of PV panel. The PCM absorbs heat in the form of sensible heat during solid state and when the transient state temperature is reached the energy will be stored in the form of latent heat. The melting of PCM in the liquid form is seen as shown in figures 7, 8 and 9 in three finned PV integrated PCM heat sink. The melting of PCM in sink is done in both conduction and convection mode of heat transfer but in this case convection plays a major role due to fins that are placed at equidistance in heat sink. The simulation results are listed in table 5 and table 6 for the melting fraction of PCM in 2 and 3 fins PV-PCM heat sink with the inclination angles of 25^0, 30^0 and 35^0. The fig 11 has shown the liquid fraction of PCM at a different time interval.

TIME (MIN)	2 FINS 25 DEG LIQUID FRACTION	2 FINS 30 DEG LIQUID FRACTION	2 FINS 35 DEG LIQUID FRACTION
0	0	0	0
50	0.47746	0.50081	0.47621
100	0.6225	0.67484	0.6005
150	0.658	0.72352	0.6442
200	0.693	0.751747	0.681047
250	0.728	0.780247	0.715988
300	0.763	0.808747	0.750928
350	0.798	0.837247	0.785869
400	0.833	0.865747	0.820809
450	0.868	0.894247	0.85575
480	0.889	0.911347	0.876714
500	0.903	0.922747	0.89069
520	0.917	0.934147	0.904666
550	0.938	0.951247	0.92563
575	0.9555	0.965497	0.943101
600	0.973	0.979747	0.960571
635	0.9975	0.999697	0.985029
645	0.9997		0.992017
655			0.999005

Table 5. Variation in Liquid fraction (melting) of PCM at three different inclinations of 2-fins PV-PCM based heat sink to time

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TIME	3 FINS 25 DEG LIQUID FRACTION	3 FINS 30 DEG LIQUID FRACTION	3 FINS 35 DEG LIQUID FRACTION
0	0	0	0
50	0.51638	0.53253	0.56973
100	0.5912	0.682	0.7246
150	0.622493	0.73144	0.755725
200	0.652863	0.76504	0.78232
250	0.683233	0.78764	0.808915
300	0.713603	0.81024	0.835509
350	0.743973	0.83284	0.862104
400	0.774343	0.85544	0.888699
450	0.804713	0.87804	0.915294
500	0.835083	0.90064	0.941889
520	0.847231	0.90968	0.952527
550	0.865453	0.92324	0.968484
590	0.889749	0.94132	0.98976
600	0.895823	0.94584	0.995079
605	0.89886	0.9481	0.997739
650	0.926193	0.96844	
700	0.956563	0.99104	
720	0.968711	0.99999	
770	0.999081		

Table 6. Variation in Liquid fraction (melting) of PCM at three different inclinations of 3-fins PV-PCM based heat sink to time

More importantly, during the melting process, the mass transfer of PCM inside the PCM cavity leads to an enhanced thermal conductivity of PCM [19]. Due to the thermal conductivity enhancement, the melting process is accelerated and results in more heat transfer from the PV panel in comparison to the heat transfer without considering the convection effect. The 3 fins 25^0 inclined PV-PCM heat sink is taken longer time then followed by 3 fins 30^0 inclined PV-PCM heat sink as seen in fig 11. It should be concerned that lesser inclination angle with three fins configuration has shown longer melting time.

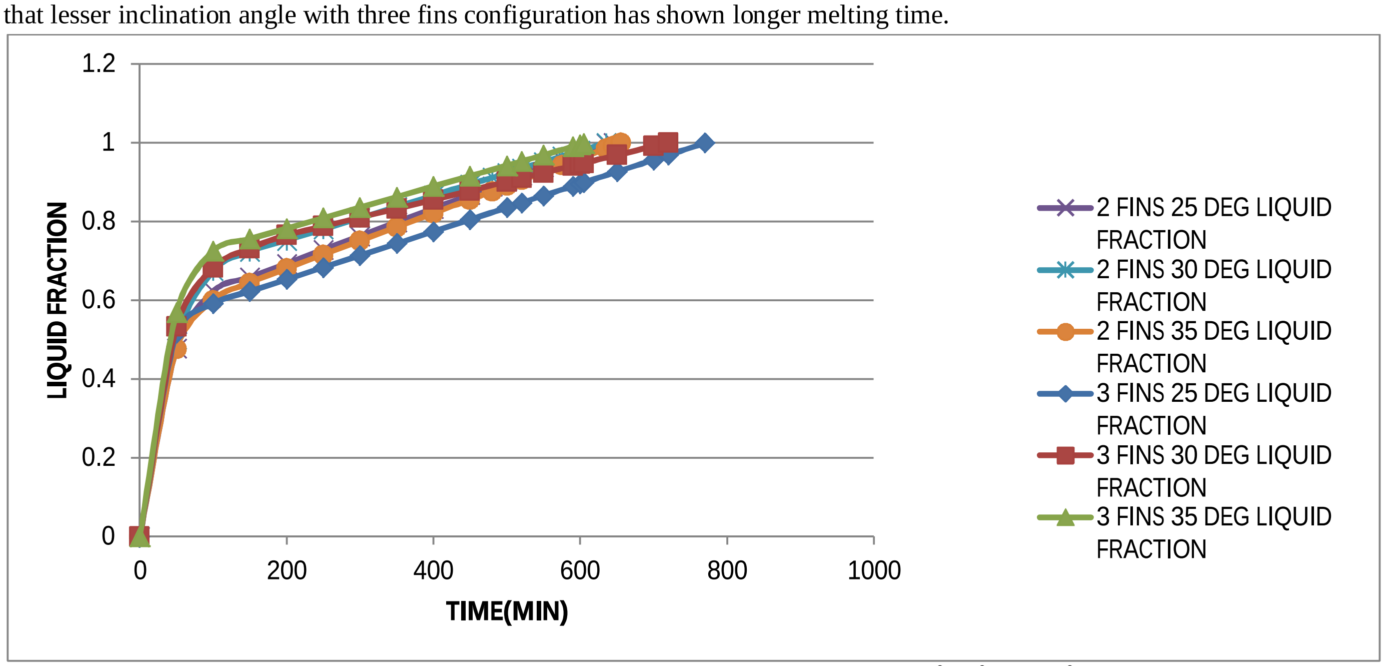

Fig 11. Variation in liquid fraction over the Time period at inclinations of 25^0,30^0 and 35^0 in PV-PCM heat sink

The melt front propagation is seen at the PCM domain due to inclination and natural convection effects at the rear end of the PCM heat sink. Earlier modeling of PV integrated with PCM transient analysis only the conductive heat transfer inside the PCM is considered during its fusion and solidification [15],[16]. However, when PCM container volume is large enough to allow for macroscopic fluid particle displacement[17],[18] the convectional currents gives high rate of heat transfer and melting process is also speeds up with decreasing PV panel surface temperature.

C. Effect of inclination angle in Heat transfer enhancement in PCM over the time Period

The melting of PCM gets enhanced as the time is increasing after a period of time the PCM in sink comes in contact with aluminum plate and it is accelerated to liquid phase by storing the heat energy in the sensible form later it is converted into latent heat as the flow of heat from aluminum back plate to PCM is continued after the fusion process is completed the heat transfer enhancement is decreased due to natural convection currents. The heat transfer is almost reduces to zero after complete melting of PCM in heat sink as of all the six cases 2 fins PV-PCM heat sink at the inclination of 35^0 as enhanced the heat flow with the maximum of 8.24% at the time interval of 50 minutes as in table 7,

TIME (MIN)	2 FINS 25 DEG PERCENTAGE OF HEAT ENHANCEMENT IN PV-PCM HEAT SINK	2 FINS 30 DEG PERCENTAGE OF HEAT ENHANCEMENT IN PV-PCM HEAT SINK	2 FINS 35 DEG PERCENTAGE OF HEAT ENHANCEMENT IN PV-PCM HEAT SINK
0	14.33333	14.33333	14.33333
50	8.211085	7.817559	8.2497
100	6.890212	6.257745	7.328368
150	6.261037	5.652241	6.534973
200	5.574194	5.037513	5.877269
250	4.896174	4.429898	5.227635
300	4.226807	3.829272	4.585925
350	3.565929	3.235515	3.951994
400	2.913379	2.648511	3.325702
450	2.269	2.068145	2.706911
480	1.886232	1.723064	2.339181
500	1.632641	1.494304	2.095488
520	1.380309	1.26657	1.852952
550	1.004152	0.92688	1.491301
580	0.630776	0.58946	1.132209
600	0.383388	0.365764	0.894223
635	0.061262	0.00379	0.395141
645	0.005831		0.219138
655			0.014579

Table 7. Effect of inclination angle on Heat Enhancement of PCM in 2-fins PV-PCM based heat sink

The heat enhancement will vary according to the fin number and orientation of heat sink as it is seen from table 7 and 8. 2 fins 35^0 PCM containers have taken much time to reduce it to zero from constant wall temperature. In the case of 3 fins PCM heat sink, the heat transfer is more for 3 fins 25^0 PCM container it means less number of fins with increased inclination angle will provide better heat enhancement. The fig 12 represents the variation of heat transfer enhancement in six cases of PV-PCM heat sink.

TIME (MIN)	3 FINS 25 DEG PERCENTAGE OF HEAT ENHANCEMENT IN PV-PCM HEAT SINK	3 FINS 30 DEG PERCENTAGE OF HEAT ENHANCEMENT IN PV-PCM HEAT SINK	3 FINS 35 DEG PERCENTAGE OF HEAT ENHANCEMENT IN PV-PCM HEAT SINK
0	14.33333	14.33	14.33333
50	7.594341	7.449408	7.057024
100	6.969939	6.684084	5.717368
150	6.427816	6.317029	5.131951
200	5.891161	5.988505	4.555107
250	5.35989	5.662005	3.984559
300	4.833924	5.263158	3.420204
350	4.313183	4.621016	2.861941
400	3.79759	3.986661	2.309673
450	3.287068	3.359952	1.763304
500	2.781544	2.740752	1.222739
520	2.580718	2.495144	1.008118
550	2.280945	2.128927	0.687887
590	1.883962	1.644688	0.264058
600	1.785198	1.524345	0.090636
605	1.735887	1.46428	0.030447
650	1.294233	0.92688	
700	0.807982	0.336405	
720	0.614787	0.102145	
770	0.032022		

Table 8. Effect of inclination angle on Heat Enhancement of PCM in 3 fins PV-PCM based heat sink over time period

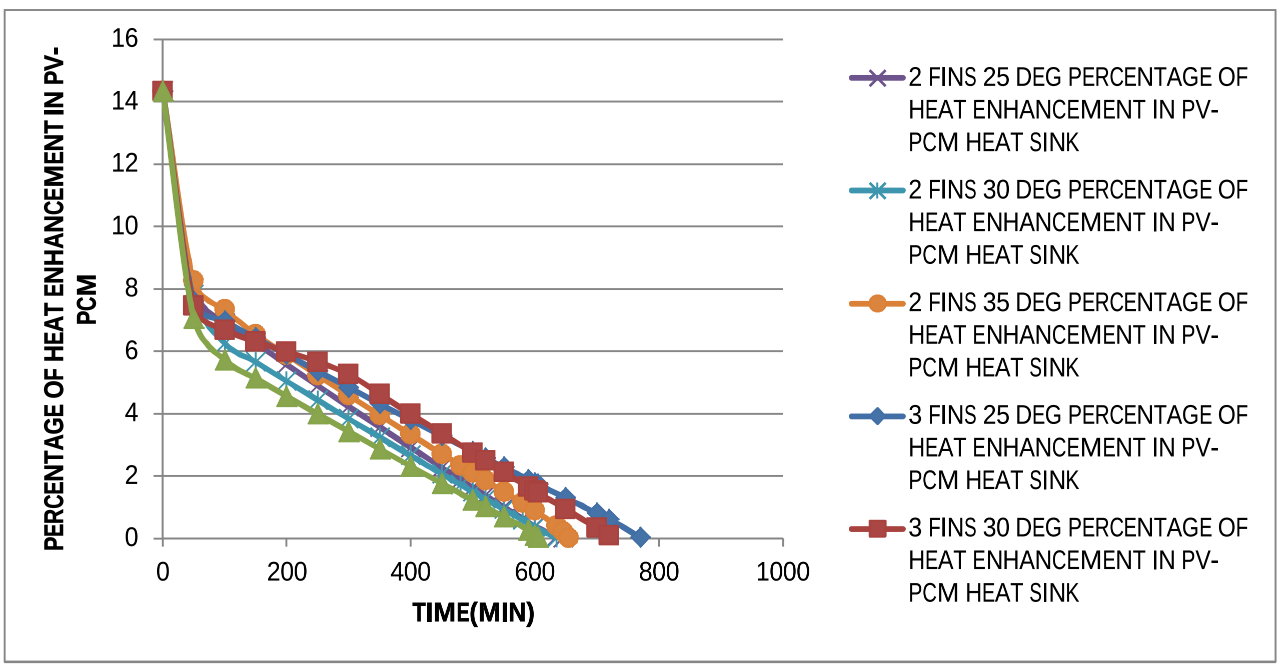

Fig 11. Variation in percentage of heat enhancement over the Time period at inclinations of 25^0,30^0 and 35^0 in PV-PCM heat sink

V. CONCLUSIONS

In a region of hot climatic conditions, the temperature on the PV panel is very high. So, the use of RT42 as PCM will trap the heat from the panel for a longer time. The fins that are provided internal of the sink provide easy flow of heat with the maximum heat distribution from the back panel of PV, external fins will dissipate heat to the environment, the transient analysis on the performance of the top mode heating PCM heat sink is considered with 2 and 3 fins configuration at three different inclinations (25^0.30^0 and 35^0).The results of temperature distribution, liquid fraction, and heat transfer enhancement are presented

1) It has seen the improvement in melting time with lesser inclinations in both the cases of 2 fins and 3 fins arrangement
2) No further improvement is seen if the fins are less than three as the three fins configuration gives the maximum time for temperature distribution
3) The mass of PCM is neglected in the present case of finned PCM heat sinks as the melting time reduction due to the mass penalty is very low.

However, the study that is conducted on constant temperature on PV cell of 343^0K and it is seen that the practice of PCM will provide the reduction of temperature to 315^0K for 755 minutes and it increases the efficiency of PV cell which highly depends on temperature. In the future, it is recommended to perform numerical simulation and experimental analysis on variable temperature conditions as the value is varied in real time conditions.

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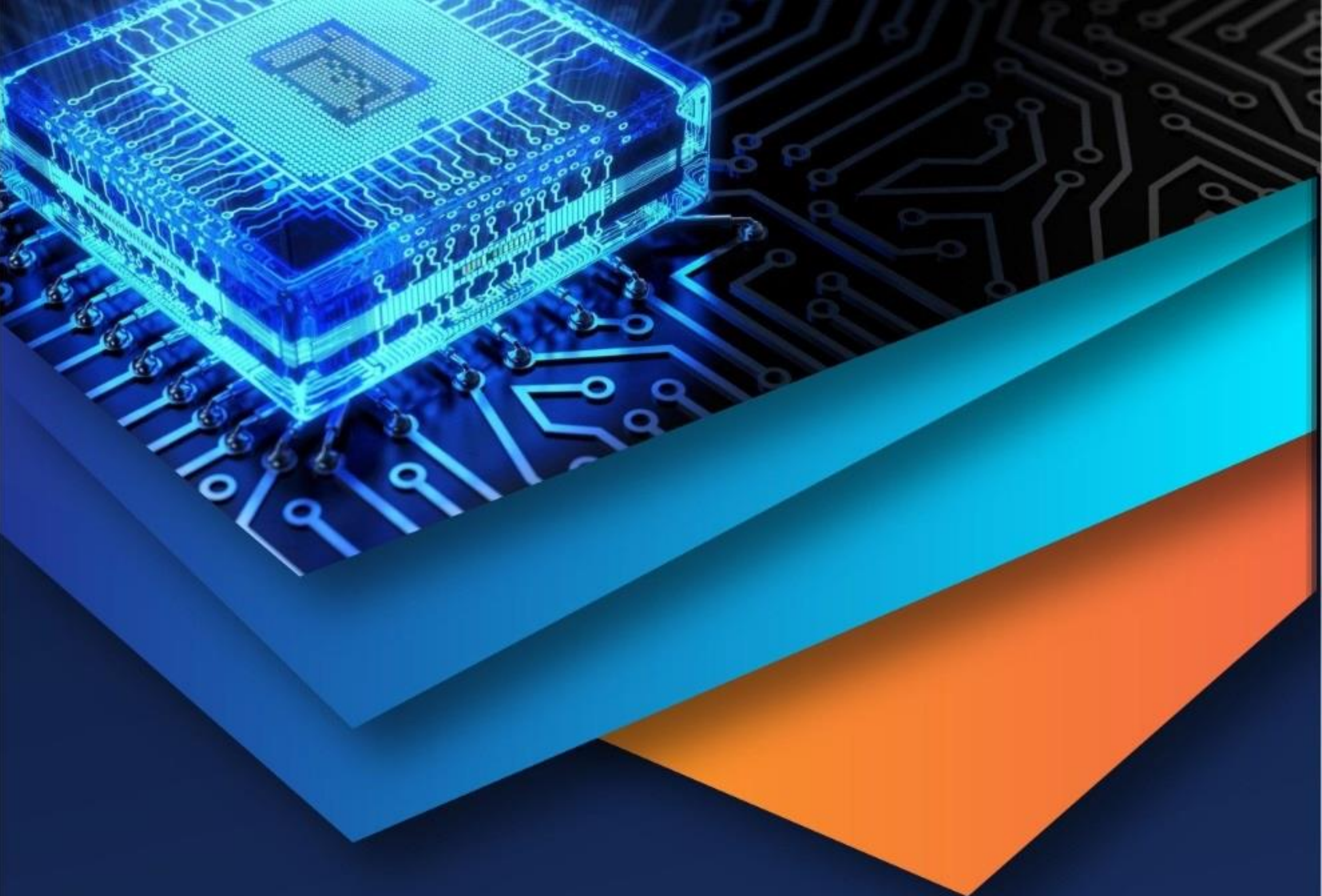

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