An Investigation of Thermal Analysis in Tractor Cabin using smart material in Rollover Protection Structure

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Abstract

A tractor is one of the basic equipment of a farmer and the production on the farm mainly depends on the performance of the tractor and its safety provided by the OEM. A tractor rollover protective structure (ROPS) that reduces the incidence of serious injuries, head injuries and saves the life of the tractor operator and also increases the safety of other passengers along with the tractor operator or driver. In the summer season, farmers mostly use tractors for various farm operations, but in this season, the temperatures are very high and further tire the tractor operators, so it is not safe to operate the tractor. The temperature inside the tractor cabin is very important to ensure a comfortable condition for the tractor driver and passengers. The temperature at the bottom of the inside of the ROPS chamber will improve when the tractor is parked in direct sunlight. The radiation episode at a surface varies from second to second based on its geographic location (latitude and longitude of a place), orientation, season, time of day, and atmospheric conditions. Without clouds, the daily average illumination of the Earth is almost 220-230 W/m. The 14 hottest cities in these four zones were considered to study the internal temperature and heat content of the tractor cabin. Temperature data for these cities between 11:30 AM and 3:00 PM was collected for the month of April to mid-June for the years 2017 to 2022, and the average maximum temperatures and relative humidity were identified for those years. These values are further used for calculations of zenith (elevation) angle, azimuth (longitudinal) angle and sky temperature. In mathematical modeling, CFD analysis and heat transfer mechanism - the equations for conduction, convention and radiation through the tractor body and ROPS are important to determine the internal temperature in the tractor cabin, distribution and heat, then the change of the tractor material depending on the CFD analysis. Done. Materials such as thermoelectric materials, phase change materials, and solar cells are implemented with an electrical integration system. This research suggests a new perspective that implementing these materials can achieve a greater reduction in the interior temperature of the tractor cabin

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and increase fuel efficiency in summer. Overall, changing materials is the best method to reduce the internal temperature in the tractor cabin.

Keywords: Tractor Cabin with ROPS, Smart Material, Thermal Analysis, Thermoelectric material, safety system, tractor operator

1.Introduction

Even in motion or stationary, the tractor is always exposed to the sun, when the tractor is in motion, the heat is reduced by cooling systems or air conditioning, but when the stationary heat input is captured and its temperature increases, the heat can cause damage to the materials inside the cab and even be caused by toxic chemicals or materials that vaporize perfumes from upholstery due to heat. Many people who often wait a long time in the Traktor in the parking lot to dissipate the heat, the driver tends to turn the cooling system of the Traktor to the maximum, which would certainly bring a lot of unnecessary fuel consumption.

According to sources, about 55% of solar radiation hits the earth's surface, of which 51% is absorbed by the surface, 4% is reflected from the surface, 19% of solar radiation is absorbed by clouds and the atmosphere, 20% is reflected from clouds, and only 6% is reflected from atmosphere. In a recent case study, when outside temperatures range from 80 degrees to 100 degrees, the temperature inside a car parked in direct sunlight can quickly climb to 130 to 172 degrees. So the rise in temperature depends on various factors like geographical location (latitude and longitude) of the place, duration of parking.

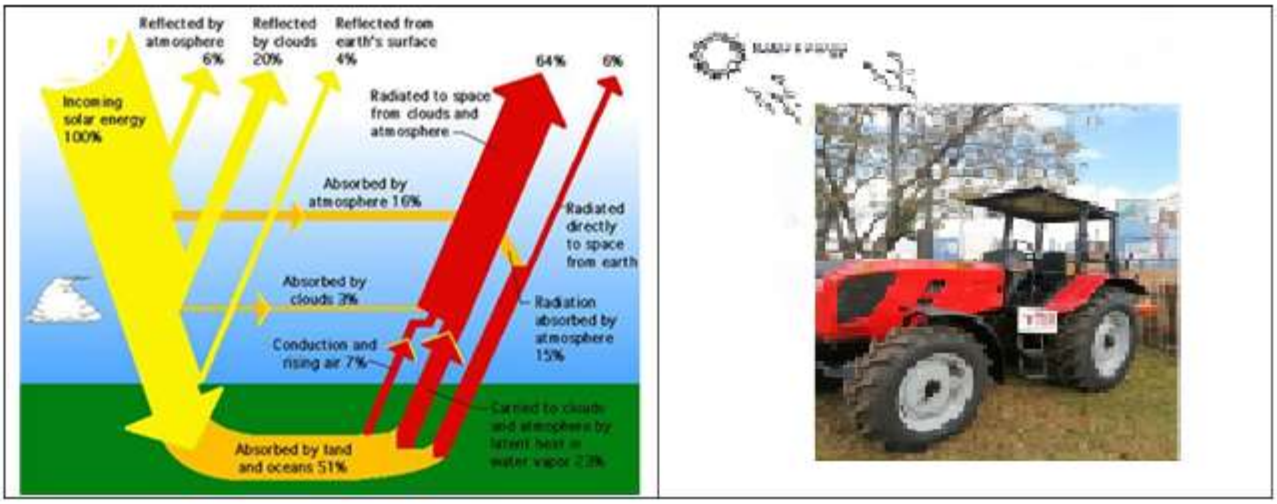

Figure1:RepresentationoftemperatureriseonthesurfaceandontheTractor cabin

If the sensible energy balance is dominated by the incoming solar radiation, the temperature inside the Tractorstabilizeswithinarangebetween25and45Kabovetheoutsidetemperature(Figure1).

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Various researchers such as Gibbs et ala have worked on the outcome of heat exposure in a closed car, Gregory and Constantine have studied and analyzed hyperthermia in dogs left in cars in certain parts of the world. Researchers Jascha and Keck worked on how to transport veterinary drugs in insulated boxes to avoid heat damage from heating or freezing, King et al and associates analyzed heat stress in motor tractors to prevent infant deaths in the tractor cab during the summer. Unlike other researchers, McLaren et al worked to reduce heat stress from enclosed tractors and also found that moderate ambient temperatures caused a significant increase in temperature in enclosed tractors. Roberts and Roberts did work to reduce heat stress in car cabins, and eventually Surpure predicted a disease that could be caused by an increase in car cabin temperature and the side effects that would lead to health problems in humans. Grundstein et al developed simple models to calculate the equilibrium temperature of tractors as a function of outdoor air temperature, solar irradiance, and cloud cover. In most cases, a value close to the equilibrium temperature is reached about 20–60 minutes after the end of ventilation. Corrosive environment in the interior of a stationary car can be the cause of heatstroke as a warning symptom of life recorded in humans and animals. It can result from exposure to environmental heat stress and is characterized by core body temperatures >50°C in humans.

The aim of this paper was the enhancement of a dynamic structure for the cabin temperature run by the threemeteorologicalparameters:outdoortemperature,solarradiationandwindvelocity,allof whichareavailableonanhourlybasisatstandardmeteorologicalstations.In the study(Table1) 13major hottest cities inthese fourzones(Figure3)wereconsideredto studyinteriortemperatureandheatcontents in theTractor cabin. The basic requirement to development and design of the ROPS for various advantages which not only protects the operator from heavy winds, Environmental climates like rain, summer , winter but also protects in case of tractor roll over. The design , development manufacturing the ROPS to fulfill the various needs of the tractor operators after critically analysis the QFD analysis from various literature reviews. The roof top of the ROPS content the special material which reduces the temperature and keep the cabin temperature maintain. This is having number of advantages to the tractor

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Fig.No.2. Actual photos of ROPS Design Development

Table1:Citieswithstudyofinteriortemperatureandheatcontents

City	2017	2018	2019	2020	2021	2022	Avg.Temp	Avg.RH	HeatIndex
Pune	39	39	40	39	40	41	40	59	61.8
NewDelhi	46	46	47	46	47	45	46	54	82.7
Calcutta	40	40	41	42	41	40	41	71	78
Chennai	41	41	42	40	42	41	41	70	77
Mumbai	39	40	39	39	41	39	40	75	77
Ahmadabad	42	42	42	40	41	41	41	55	62.3
Hyderabad	42	42	42	42	42	42	42	56	67.2
Nagpur	47	48	47	46	48	47	47	67	81,2
Jaipur	43	42	42	43	43	43	43	64	80.4
Akola	45	45	46	44	45	45	45	49	72.2
Hissar	44	44	45	44	46	44	45	60	85.6
Jabalpur	46	47	45	46	45	45	46	76	116
Kota	40	40	41	40	40	41	40	44	50.7
Bhuj	41	40	42	41	40	41	41	63	69.7

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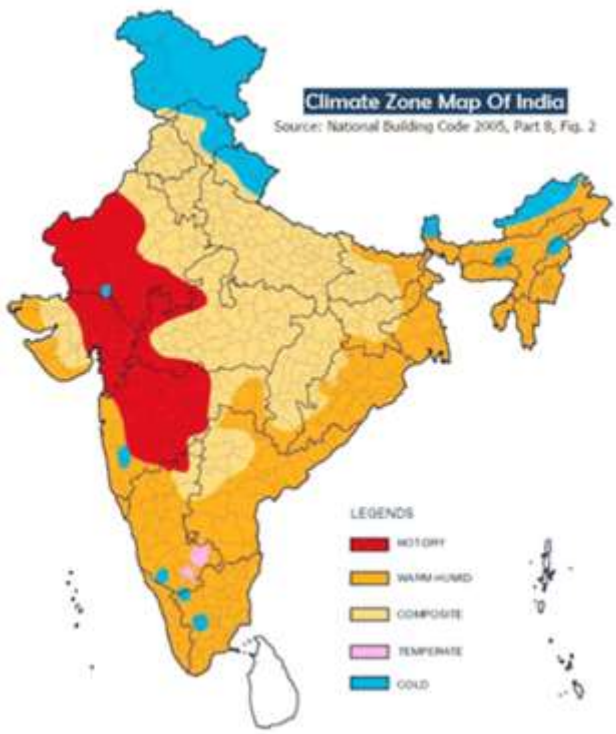

Figure3:ClimatezonemapofIndia

2.Tractor Cabin Air Temperature Model

The tractorcabinairheatingrate with the use of ROPS ,orrateatwhichtheinternalenergyofthe tractorcabinairΔUtwithtimet,is

$$dU/dt = m_a c_v \frac{dT_s}{dt} \quad [1]$$

wherem_a is the cabin air mass, $c_v$is the specific heat of air at constant volume, and $T_s(t)$is the tractor cabin airtemperature. The tractor cabin air is transparent to both sunlightandthermal radiation, but exchanges haet with the airconditioner and the cabin surface. If the air is welled mixed, a simple model for the variation of cabin airtemperaturewithtime.

$$dT_s/dt=\alpha[T_v(t)-T_s(t)]+\beta[T_s(t)-T_s(t)] \quad [2]$$

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3.Temerature measurement inside the Tractor Cabin

Averagetemperatureinsidethetraactorismeasuredby[12]

$$T_f = \frac{(TMAX + TMIN)}{2} \quad [3]$$

Tmax=maximum

Temperature in the tractor

Tmin=minimumTemperatu

reinthetractor

Theheattransferintoatractorisassumedtobeonedimensionalandsteadyheatconduction.Theroof ismadeofsteelandplasterandtheircombinedthermalresistance(combinationofsteel&plaster)ca nbewrittenas[12]

$$R_T = \frac{Xi}{kiAr} + Xp / kpAr \quad [4]$$

Where,

X_i / k_iA_r is the thermal resistance of steel and

X_p/ k_pA_r is the thermal resistance of plaster on the roof

The thermal resilience of the roof cover rely on the structure and the thermaleffectsof the roof materials. Thetransitionfromlaminarandturbulentflowdependsonthesurfacegeometry,surfaceroughn ess,free-streamvelocity, surface temperature, and the type of fluid. The flow system rests largely on the proportion of inertiaintensitytoviscousintensityinfluid.ThisratioiscalledtheReynoldnumber,whichisadi mensionlessquantity,andcan beexpressed[13]for external flow as

$$Re = (\rho u^2)/(\mu u / L)$$

$$= \rho \, u \, L / \mu \quad [5]$$

When the Reynold number is less than 2000, the flow is laminar and when the Reynold number is greater than2000, the turbulent flow will occur, Nusselt number at a location for laminar flow over a flat plate (Tractor roofsurfaceconsider flat)hasbeendefinedas(Gengel, 2004)[14]

$$Nu=hl/ka =0.332Re^{0.5}Pr^{1/3}$$

[6]WherePr isPrandtlnumber

The temperature inside the compartment is shown in Figure 4. Figure 4 shows that the most heated parts of the tractor body is the roof because most of the incident sunlight is absorbed by the roof materials (Table 2). This heat is transferred (Figure 5) from the roof to the plaster by conduction and then from the plaster to the indoor environment by convection (Table 3). The temperature on the glass is the lowest because the incident sunlight passes through the glass into the interior of the tractor.

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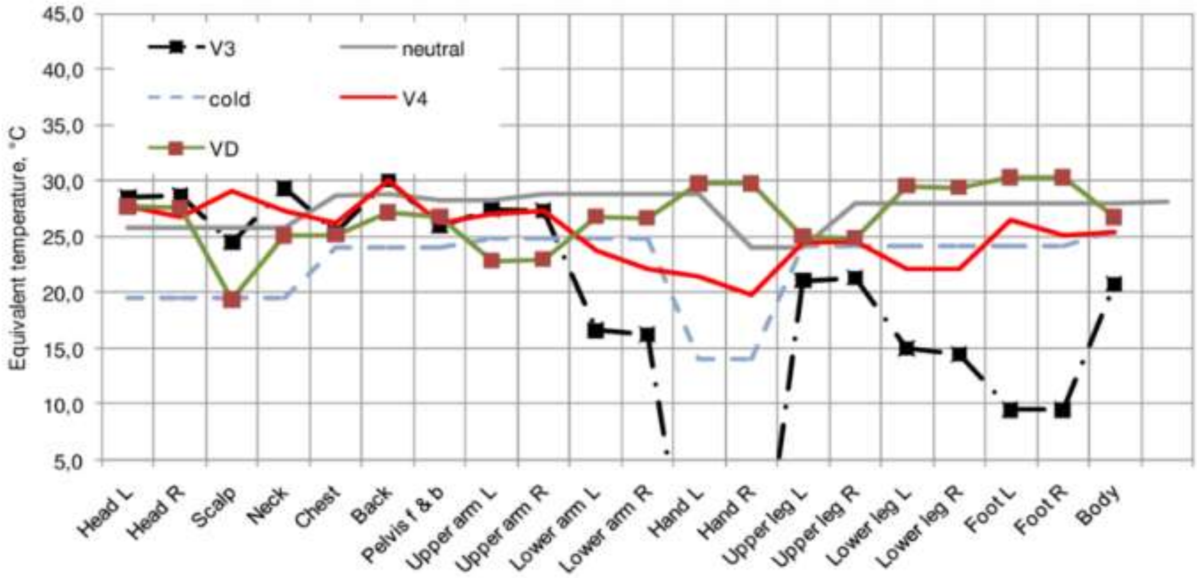

Figure 4: Representation of temperature measurement inside tractor cabin and Thermal processes between a tractorcabandhotenvironment

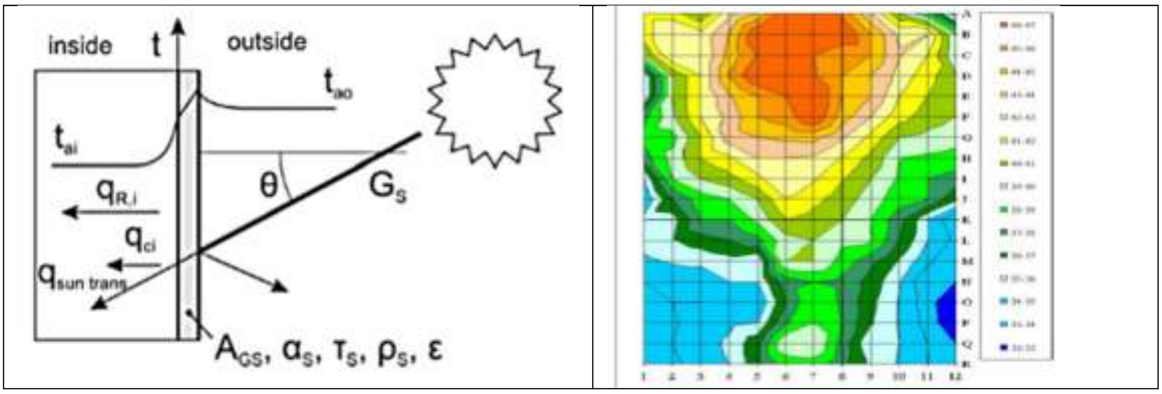

Figure-5:(a)SolarenergytransmissionthroughSides(b)fluidnodes,solidnodesbyradiation

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4.THERMALCHARACTERISTICSOFCABMATERIALS

Table2:ThermalcharacteristicsofTractorcabmaterials

S.No	**Item**	**SolarAbsorptivity(αs)**	**SurfaceEmissivity,ε**	**Thermal Conductivity k(W/Mk)**	**Normal solartransmissvity,t**
1	Plastic,white	0.23-0.49[16]	0.90-0.97[17][18][16]	0.12[18]	-
2	Tempered singleglass,Clear	0.08[19]	0.8-0.95[19][16][17][18]	0.8[19]	0.84.0.90[20][18]
3	Tempered singleglass,greentinted	0.45[19]	0.8-0.95[20][16][17][18]	0.8[19]	0.49[19]
4	metal,paintedwhite	0.21-0.25[19][16][17]	0.85-0.96[20][17][18]	40-45[18][21]	-
5	Meatl,paintedblack	0.80[18]	0.970.8-0.95[19][18][17]	40-45[18][21]	-

5.AVAILABLEMATERIALPROPERTIES

Table3:AvailableMaterialpropertiesforThermalanalysis[22]

Substance	Density	Specificheat	Conductivity	Diffusivity
Aluminum	2700	896	204	0.8*10-4
Steel	7833	465	54	1.5*10-4
Glass	2600	800	0.81	
Concrete	2000	900	1.3	0.7*10-6
Air	1	1000	0.026	2.6*10-5

6.Drawing provides for Tractor Cabin Design with ROPS :

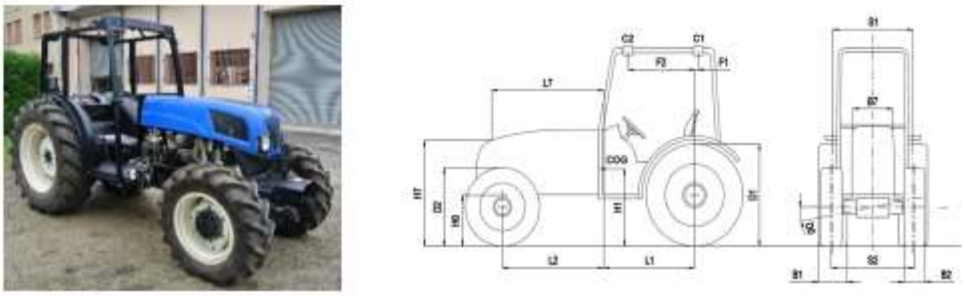

Figure6: DrawingsprovidedforTractorcabindesigninCatiaV7

Table4:Materialdetailsforcabinteriorpart

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S No	PartDescription	Materialdetails	Remarks
1	Instrument panel / Door Column /Pillarand FloorTrims	PP+T20	Injectionmoldedparts
2	Side Trims /Rear Wall Trim(SoftTrims)	Carrier:PP+Jute Toplayer–Stitchbondfabric	Thermoformed
3	Headliner	Carrier : Foam + glass strands + PEfilm TopLayer–Stitchbondfabric	Thermoformed
4	FloorMat	Top Layer : TPO+TPEBottomlayer: PUFoam	Thermoformed
5	Seats	Fabric+PUfoam	

Required Drawings(Figure5, Figure6 & Figure 7) & Specifications; Material Data(Table 4):RequiredDimensions tocalculate Area

Windshield (Glass):

Lx W x

tWindows:(Glass)

LxWxt

Doorandseepingchamber (Figure8)DimensionsLxWxt

7.DESIGNEQUATIONS :

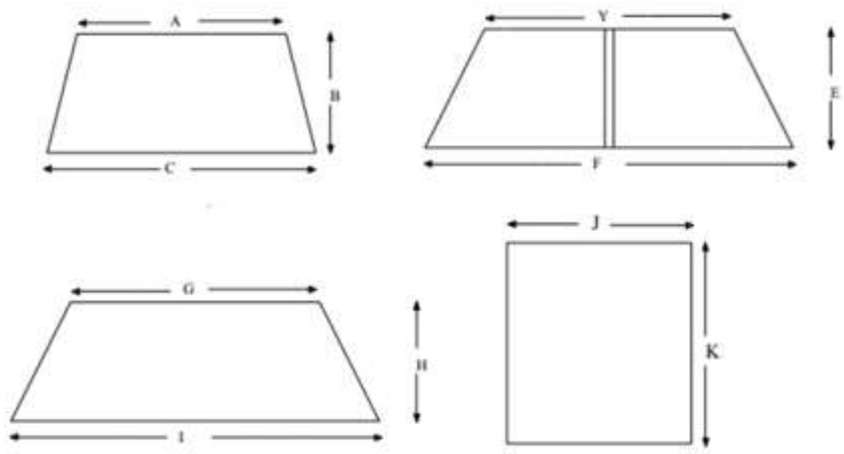

Figure 7:DesignparameterforTractorcabinGlassandroof[11]

TotalAreaofGlassWindows[24]:(Fig.A–C)

A_g=1/2(A+C)(B)+1/2(G+I)(H)+2(1/2)(D+F)(E) [9]

TotalAreaofRoof[24]:(Fig.d)

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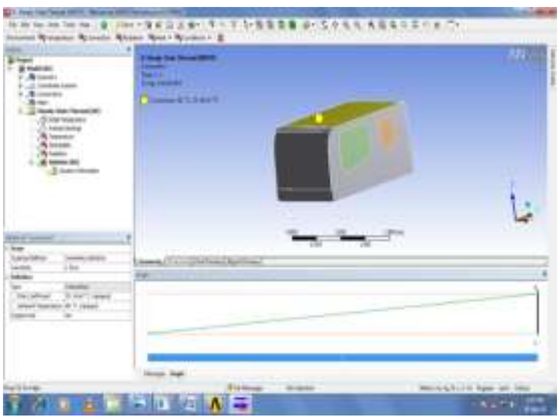
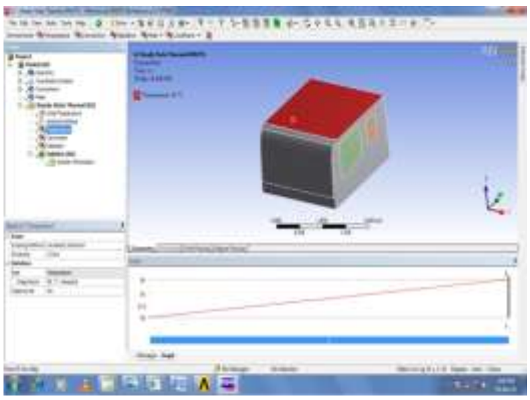
A_r=(J*K) [10]

Where 1/2(A+C)(B) is the area of front window,1/2(G+I)(H)istheareaofbackw indow 2(1/2)(D+F)(E)isthetotalareaofsidewindow,and(J*K)istotalareaofroof

8.Implementation of Smart Materials in the tractor ROPS system to reduce the tractor cabin temperature

Figure.8:Implementationofsmartmaterials with thermoelectric phase change material characteristic intheprefinedlocationsinthetractor cabin

CONVECTION	TEMPARATURE
	

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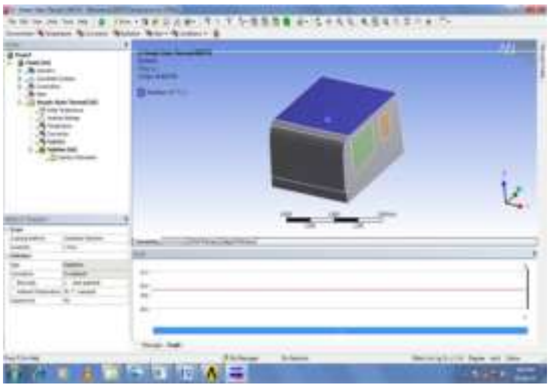
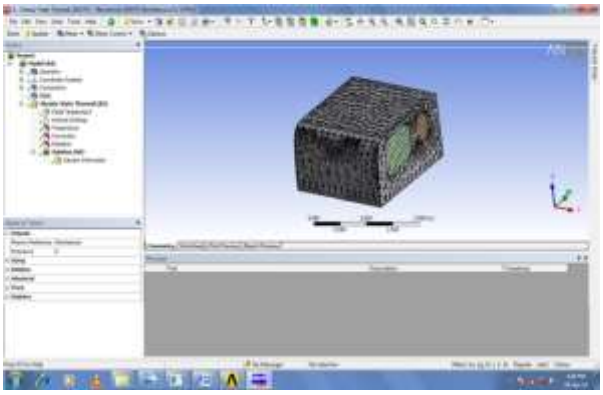
RADIATION	MESHING
	

Figure 9:Thermal analysis perfomed with parameters such as convection, Temparature and radiationTwo samples of Acetic acid and bismuth tellidrium were taken for thermal analysis(Figure11&Figure12) forresearchwork.

1.1 PhaseChangeMaterail-AceticAcid

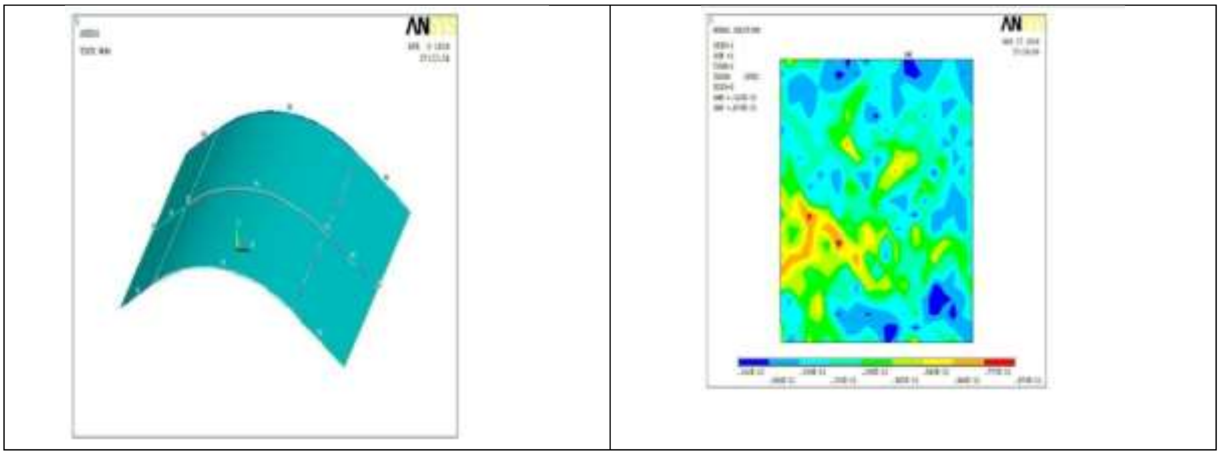


Figure10:ThermalanalysisofPhaseChangeMaterail(AceticAcid)

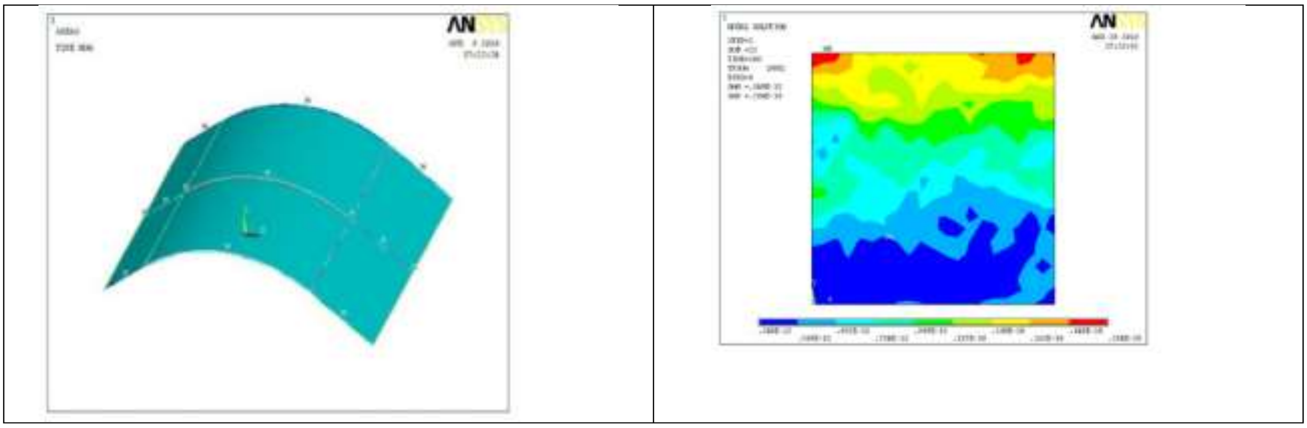


Figure-11:ThermalanalysisofThermoelectricMaterail(BismuthTellidrium)

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9.Conclusion

In this work, the existing material is modified with smart materials with different properties to increase the flow rate and decrease the steady state temperature inside the tractor cabin space. Different materials are designed at different locations using CFD analysis performed on the tractor cab according to available material properties. In our research, the materials provide a higher level of comfort than previously available. The flow rate is increased 5.52 times compared to the existing one. Thermal conductivity, density, absorption are much higher than existing materials used in the construction of these materials. Various suppliers in the industry are provided in our project along with the materials they have and these material properties are also detailed. Lowering the temperature will reduce the power consumption of the device and also reduce the fuel consumption to a small extent than the existing one. The reduced temperature will further enhance the attractive appearance of the interior parts. In this way, the overall safety of the tractor operator is improved, the level of fatigue is reduced and ultimately the productivity of the farm operation is increased.

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