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Modelling and Interpretation of A Novel Battery-Motor amalgamated Thermal Management System using rGO/CO_3O_4 based Hybrid Nano-composite Coolant for Electric Vehicle Applications

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Abstract

*Battery and motor have to be given equivalent importance to maintain the lifetime, thermal characteristics, efficiency and safety of Electric Vehicles (EVs). Thermal management of EVs need to be considered for battery and motor because of dynamic loading conditions. This research proposes a novel Battery-Motor Integrated Thermal Management System (BMITMS) for EV applications. An EV assembled with $LiFePO_4$ battery pack and a three-phase induction motor has been considered on this research work. This paper describes about the cooling of the battery and motor in EV using (rGO/CO_3O_4) Water based Hybrid Nano-fluid coolant. The battery pack consists of 1000 cells totally which are all arranged in 10(series)*100(parallel) matrix format. The cooling tubes are circulated around each battery cell and through the motor to control the temperature in the steady state condition. A three-phase induction motor is utilized to drive EV. The heat energy dissipated by the battery and motor during working condition is controlled by using Computational Fluid Dynamics (CFD) in ANSYS software. The heat energy from battery and motor gets transferred to the coolant, this coolant is cooled by using the radiator setup. Catia V5 software is used to sketch and design the battery, coolant pipes, Motor, Radiator, inverter and insulators.*

Keywords: ANSYS, battery-motor integrated thermal management system (BMITMS), Catia V5, computational fluid dynamics (CFD), electric vehicles (EVs)

INTRODUCTION

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EVs are invading the market very rapidly because of the advantages like eco-friendly, less operating cost, newer technology. Most of the common EVs especially four wheelers and commercial vehicles like tesla are adopted with $LiFePO_4$ battery and induction motor [1]. The need of Thermal Management Systems (TMS) for Battery Electric Vehicles (BEVs) are discussed and its design procedure is developed [2]. To extend the lifetime and ensure operating safely of the $LiFePO_4$ battery, the operating temperature must be retained at the optimum level of 15°C to 35°C [3]. Also, the rise in temperature of the motor affects the performance of EV. During the running condition of the EVs, huge amount of heat is produced by the battery and motor, so that the heat generated inside the battery and motor should be controlled or dissipated to environment. The main objective of TMS is to cool the battery as well as the motor to keep the temperature stable during normal working condition [4-5]. The transient thermal characteristics of lithium-ion cells are simulated and optimized using rapid meta-model [6] which gives a clear idea about the effect of temperature in EV batteries.

There are many cooling methods are available for battery and motors such as direct, indirect, liquid, air, hybrid cooling etc., Air cooling is used in Honda Insight and Toyota Prius. Indirect liquid cooling is used in Chevrolet volt and Tesla model S. The common basic fluids are water, ethylene glycol and oil [7]. A leaf vein structure based bionic temperature controller is designed to enhance the thermal behavior of Gallium Nitrite High Electron Mobility Transistors (GaN HEMTs) [8], which inspires the thermal management researchers to investigate in natural way. The methodologies for active temperature regulation of battery during peak temperatures are deliberated in detail [9]. The effect of temperature rise in battery electrodes are analyzed under various drive cycles [10] and the influence of heat generation in battery busbar along with its solutions are discussed in [11].

The temperature of the battery depends upon its charge discharge current rating. The thermal characteristics of $LiFePO_4$ batteries are verified experimentally in several ambient temperatures with various charge discharge ratings by conducting three simple experiments. The energy stored in the battery is utilized at 2C, 3C and 4C current ratings. During this process, the temperature of the battery surface is observed by the infrared thermographic camera. The emittance of the battery is calculated as 0.86 [12]. The aging factor of the battery due to variations in operating temperature is analyzed by measuring the internal series impedance of the battery cells. The average battery resistance is measured by 4800 cycles tested in 50 to 500 MHz frequency range and10°C to 80°C temperature range. [13].

The impact of temperature distribution on LIB pack under various C rating is simulated and its performance is practically verified investigated. Here normal water is used as coolant. This study reveals that excess heat generation in a battery accelerates chemical reactions, leading to faster self-discharge and reduced efficiency [14]. By using the pseudo-adiabatic instrument, the thermal runaway of four commercial $LiFePO_4$ based Lithium–ion batteries were studied by hyper heating. This experiment clarifies the runaway hazards of $LiFePO_4$ batteries and gives the logical clarification for the temperature rise, spark and blowing up of buses rig-out with large $LiFePO_4$ batteries. It is clearly identified that, the rise in battery temperature directly affects the ion mobility of the battery which leads to increase in its internal resistance. This will finally reduce the overall capacity of the battery [15].

The impact of coolant movement track on battery temperature maintenance can be evaluated by analyzing the temperature of battery. It is examined by varying the physical properties of coolant tubes such as size, thickness and number of lines, etc., which guides to select the optimal size of coolant tubes [16]. The effect of temperature on batteries such as efficiency, safety is examined under three different temperature ranges [17]. To cut short battery overheating, a refrigerant spray cooling is introduced in [18] which reduces the sudden changes in battery temperature and delays thermal runaway.

The main causes of heat generation in a battery are predicted and examined clearly using analytical and experimental methods under different environmental conditions[19-20]. Conventional coolants have more drawbacks such as low thermal conductivity, low heat transfer efficiency, high viscosity leads to high energy consumption by coolant pipes, degradation due to oxidation and contamination [21]. The heat transfer characteristics of (rGO/CO_3O_4) Water based Hybrid Nano-fluid coolant is much better than the other coolants which is also verified experimentally in different combinations [21-22].

While considering motor, the rise in temperature affects the performance of the motor in speed, efficiency and life time. The thermal characteristics of a Permanent Magnet Synchronous Motor (PMSM) is evaluated practically using several temperature reduction strategies [23] indicates that water cooling is better than the conventional cooling methodologies. The thermo-electromagnetic analysis of induction motor is examined using finite element analysis [24] which clearly discusses the effect of temperature in motor.

The major parts of EVs are batteries and motors which needs efficient cooling while operation. The researchers are focusing about either battery or motor cooling. The temperature rise in any one will gives direct impact on other which will leads to inefficient operation. In this research pouch type LiFePO4 battery cells and three phase induction motor along with common rectangular cooling tubes are implemented which will reduces the effect of heat generated in both battery and motor. Each battery cell is surrounded by cooling pipes and foam cushion to make the batteries and pipes not bouncing while the EV is in operating condition. The work is carried out using Computational Fluid Dynamics (CFD) in ANSYS software. The designing work of the battery, coolant pipes, Motor, Radiator and insulators are drawn by using the Catia V5 software.

The main intention of this research work is described as follows:

i. To design a novel Battery-Motor Integrated Thermal Management System (BMITMS) which controls the thermal properties of battery and motor.
ii. To examine the behavior of the proposed BMITMS under charging, discharging as well as loaded conditions.
iii. To improve the heat dissipation of the EV using the proposed water-based Hybrid Nano-fluid coolant (rGO/CO_3O_4) and optimum radiator design.

BATTERY-MOTOR INTEGRATED THERMAL MANAGEMENT SYSTEM

The schematic diagram of the proposed BMITMS is depicted in Figure 1. The system includes a battery pack, inverter, motor and a centralized thermal management system.

The main objective of this system is to control the heat generated in EV by controlling the temperature rise in battery as well as motor within the prescribed limit. This proposed system aims to avoid the requirement of two different thermal management system by integrating both of them together. The size, cost and control complexity of thermal management system can be diminished by the proposed system.

GEOMETRY MODELLING AND STRUCTURAL DESIGN

Modelling of theLiFePO$_4$ battery

A battery pack which consists of 1000 LiFePO$_4$ battery cells is selected for this research work. The LiFePO$_4$ battery cells are arranged in 10*100 matrix format (10 cells in series and 100 cells in parallel). The space between the two coolant pipes are decided to be 10mm and also in between the two battery cells foam cushion is implanted. The design specifications of the battery is given in Table 1.

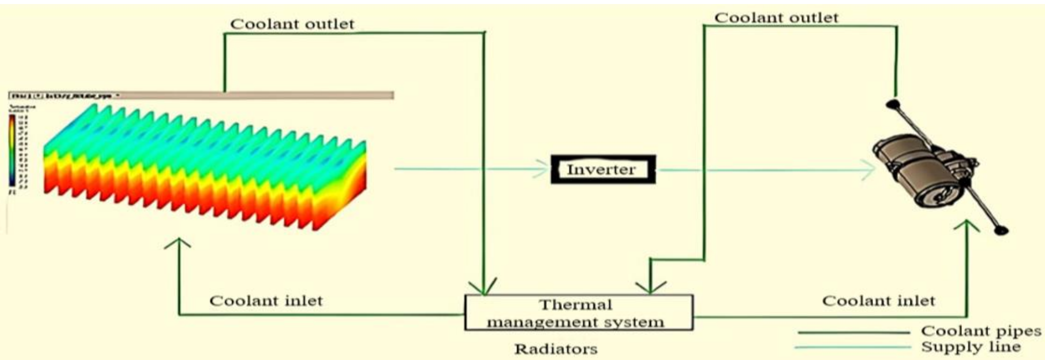

Figure 1. Battery-motor integrated thermal management system.

The volumetric heat generation rate of each battery cell is given by

$$Q_v = R_h I^2 - \frac{T\Delta E_i}{mH} \quad (1)$$

Here,

Q_v − Volumetric heat generation
R_h − Heat resistance / m^3
I − Discharge current / m^3
m − No. of Electrons transferred
H – Faraday's constant
E_i – Entrophy

The cathode of $LiFePO_4$ is made up of 90% cathode composition, grade, 5% of carbon (superior graphite) and 5% of polyvinylidene fluoride (PVDF). Silicon and graphite anodes are used. Zinc Chloride ($ZnCl_2$) electrolyte with 15Mol/Kg ρ=1.78cm^3 concentration is used.

Modelling of The Coolant Tubes

Copper based coolant pipes are selected because of its good thermal conductivity and excellent corrosion resistance. The coolant pipes are located from starting to end of the battery horizontally. The copper material can retain its mechanical and electrical properties at cryogenic temperatures from -150℃ to -273℃. At this temperature the molecular motion comes closer which is theoretically possible to cease completely. The specifications of coolant pipe and copper material are given in Table 2.

Modelling of the Insulators

The coolant pipes are embedded at both the sides of the battery. Five parallel coolant pipes are inserted from top to bottom of the battery with the equal space of 13.3mm. Coolant pipes are inserted at the front and rear side of the battery (65mm). In the side of the battery coolant pipes could not be inserted because side area of the battery is very less compared to the front and rear side of the battery. The heat energy produced in the battery gets dissipated by the coolant flowing through the coolant pipes.

Table 1. Battery design specifications.

Parameter		Specification
Battery cell dimension		(65x10x133) mm
Cell weight		180g
Nominal cell voltage		3.2V
Minimum voltage		2.0V
Maximum voltage		3.65V
specific power		200W/kg.
specific energy		90-160Wh/kg.
Volumetric energy density		220Wh/L (790KJ/L)
Gravimetric energy density	Min	90Wh/kg (320J/g)
	Max	160Wh/kg (580 J/g)
thermal capacity		320-580 J/g
Average specific heat capacity		932.5±78.0 J/kg/K.
Battery life cycle	With 100% DOD	2,000 to 7,000 cycles
	With 10% DOD	> 10,000 cycles
Coolant speed		10m/s.
Coolant temperature		25°C.
Heat flux		4000 W/m^2

Table 2. Specifications of coolant tube design.

Parameter	Specification
Coolant tube material	Copper
Wall thickness	2mm
Width	7mm
Height	13.3mm
Total length	740mm
Properties of Copper	
Electrical resistance at 25℃	16.78nΩ·m
Melting point	1357.77 K (1084.62 °C)
Boiling point	2835 K (2562 °C)
Density	8.96 g/cm^3
Molar heat range	24.440 J/ (mol·K)
Thermal conductivity	401W/ (m·K).

Foam cushion is selected as an insulator due its light weight. The foam cushion will be fixed vertically between the batteries and horizontally between the two coolant pipes. The insulators are located at both the sides of the battery. Five foam cushions will be inserted from top to bottom of the battery with the equal space of 13.3 mm.

The foam cushion is employed in between two batteries as well as in between the two coolant pipes next to the battery. The insulators are equally fixed in between the coolant pipes. The width of the insulator is 7 mm. The height of the insulator is 13.3mm and the length is 740 mm. In between each battery and coolant tube there is an air gap. While driving the EV the batteries and the coolant tubes will get dislocated and damaged. To overcome this difficulty, the insulators are fixed in between the batteries and coolant tubes.

Optimal Arrangement of Battery, Coolant Pipe And Insulator

The battery, coolant pipe and Insulators are drawn using the Catia V5. One single row of battery, Coolant pipe and Insulator is created and it is mirrored to 100 rows. The whole battery is created in 3D format first as a solid element. The coolant tubes are drawn separately with a wall thickness of 2mm and in centre 9.3mm gap is given for the flow of coolant in the pipes. The horizontal and vertical foam cushions are made up of solid element.

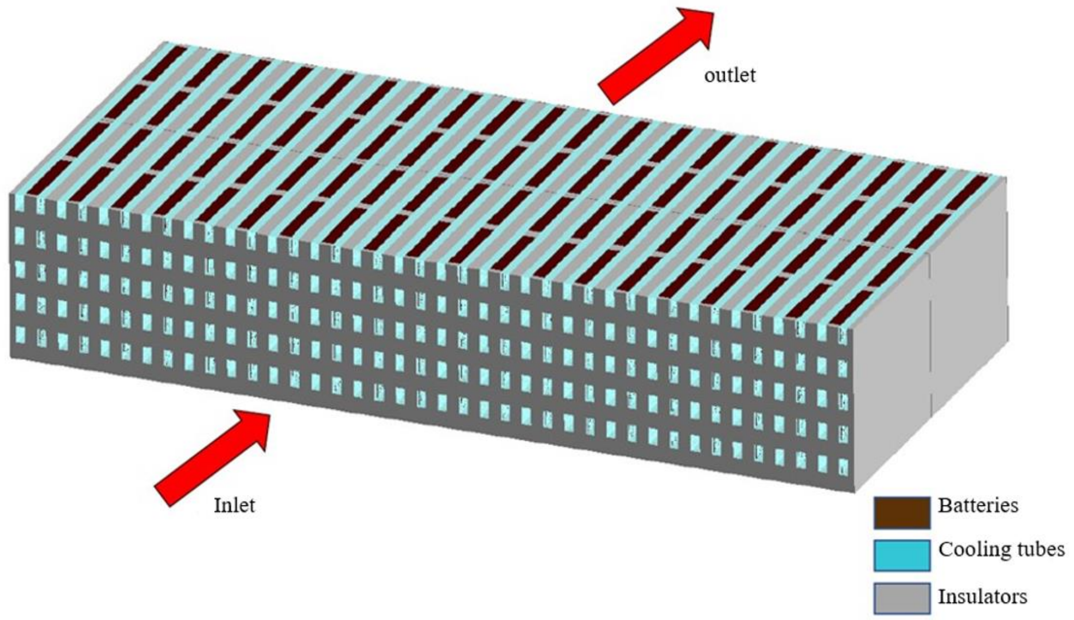

Figure 2. Arrangement of battery, coolant pipe and insulators

The terminals of the batteries are made as a circular part with 2mm as diameter and 1mm as a height. First the battery is positioned on the allotted space, then from the top side of the battery coolant pipes are inserted with 13.3mm height following to the coolant pipe then insulator is commissioned for 13.3mm. Like in the same manner coolant pipes and insulators are placed one after the other for the height of 133mm. The battery pack is surrounded by coolant pipe and insulators. Coolant pipes and insulators are inserted between each adjacent battery in horizontal and vertical directions.

The batteries, coolant pipes and insulators are modelled as illustrated in Figure 2. A single module of the battery is taken for better understanding. The batteries are shown in brown color, cooling tubes are shown in the blue color and Insulators are shown in grey color. The inlet and outlet of the coolant in the coolant tubes are shown in the above drawing.

Duplicating of Battery, Coolant Pipe and Insulators

By using the transformation feature rectangular pattern, in the first direction 17mm is mentioned for spacing and in the second direction 85mm is mentioned for spacing to embed the battery Coolant tube and Insulators. For both first and second direction in the parameters column Instance and Spacing should be mentioned. In the first direction instance should be mentioned as 100 and in the second direction instance should be mentioned as 10. One row of battery with coolant tube and Insulators are drawn as 10 batteries, coolant tubes and Insulators by using the pattern feature the battery is duplicated to 100 columns. The model is saved in .iges format.

Construction of Reduced Graphite Oxide / Co_3o_4 Nano Composite

Here, the rGO/CO_3O_4 (Reduced Graphite Oxide with cobalt teraoxide) water-based hybrid nano fluid is used as a coolant material. This is mixed with the water and passed through the coolant pipes. The powders of graphite oxide and cobalt tetroxide are mixed with the water. Graphite Oxide is obtained from the natural graphite powder. A homogeneous Graphite Oxide was suspended at 0.5mg/mL in water which is then achieved by ultrasonication for 3 hours. The reduction of Graphite Oxide and Cobalt Chloride ($CoCl_2$) is prepared at the same time by using borohydride ($NaBH_4$) as a reduction agent at a room temperature. rGO/CO_3O_4 nano composite is prepared during the chemical reduction of Graphite Oxide and Cobalt Chloride with sodium borohydride ($NaBH_4$). Basically, a 5ml of 1mg/ml Graphite Oxide gets suspended in Milli-Q water then the 50mg of Cobalt Chloride was added. The final amalgam was rapidly agitated using sound for 10 min. Then 5ml of 0.1M $NaBH_4$ liquid solvent was added in the amalgam at room temperature. A black precipitate was formed and washed repeatedly with water.

Flow of Coolant In Cooling Tubes

The coolant will flow at the rate of 10m/s at 25 deg C. The coolant material is injected through the rectangular pipes. The heat generated in the battery is absorbed by the coolant. The prepared coolant is injected to flow in horizontal direction because the front side of the battery generates more heat than the other sides of the battery. The coolant absorbs the heat generated in each battery cell while passing through it. The battery is cooled by the indirect liquid cooling method.

Modelling of Motor and coolant Tubes for Motor

A three-phase induction motor is drawn using the CATIA V5. The coolant is circulated by using the coolant tubes around the motor for cooling. The battery is fixed with the inverter to convert DC into AC. Since the motor and the battery are fixed in the same location, the heat from the motor is transferred to the inverter so the inverter also circulated with the coolant tube. The dimensions of the motor and motor with coolant tube are selected as shown in Figure 3 (a) and (b) respectively.

The outlet of coolant pipe which is circulated around the motor is connected to the radiator fins. The OD of the coolant tube is 7mm and ID is 5mm. The cylindrical shaped copper is used as a coolant

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tube. The motor voltage is 350V with maximum torque 100 N-m. The motor and inverter are fixed as illustrated in Figure 4.

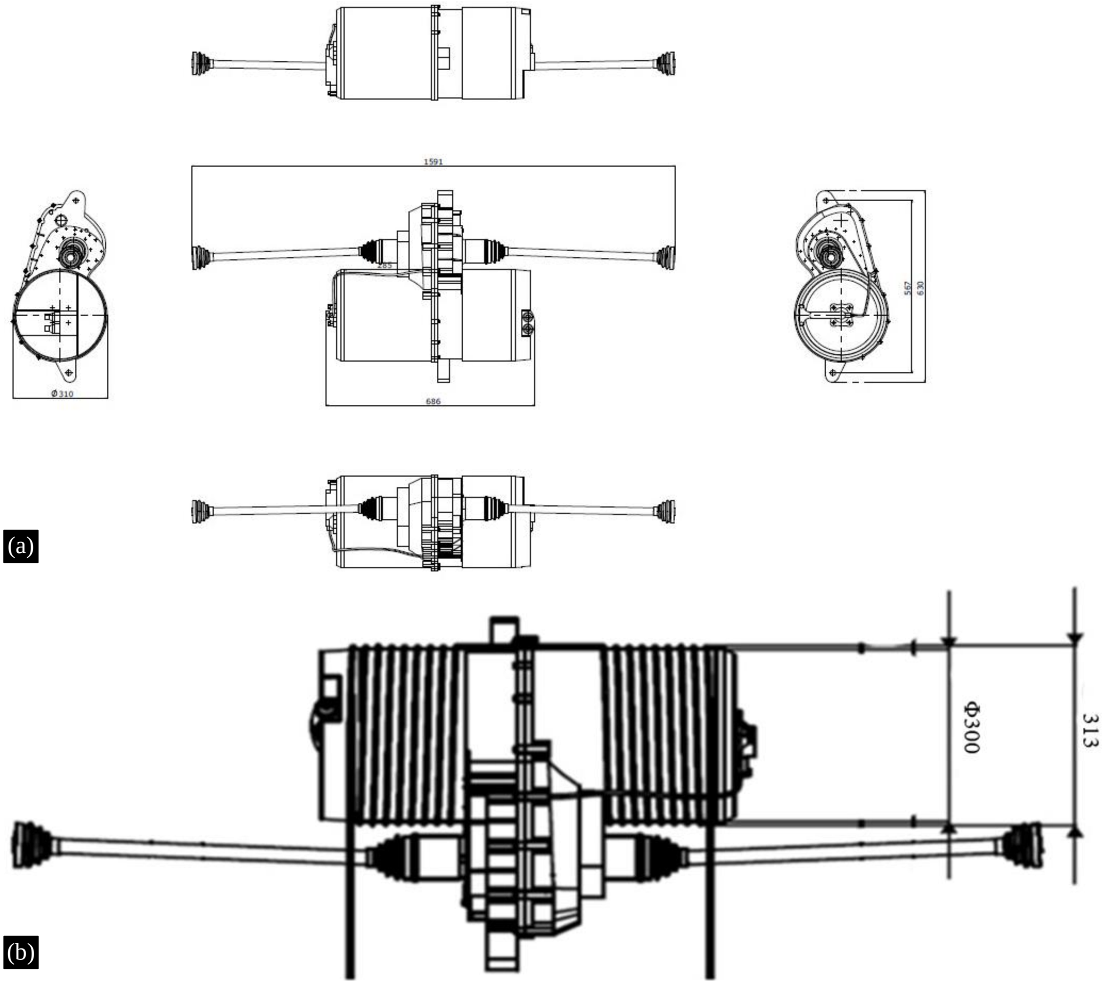


Figure 3. Dimensions of the (a) Motor (b) Motor with coolant tube.

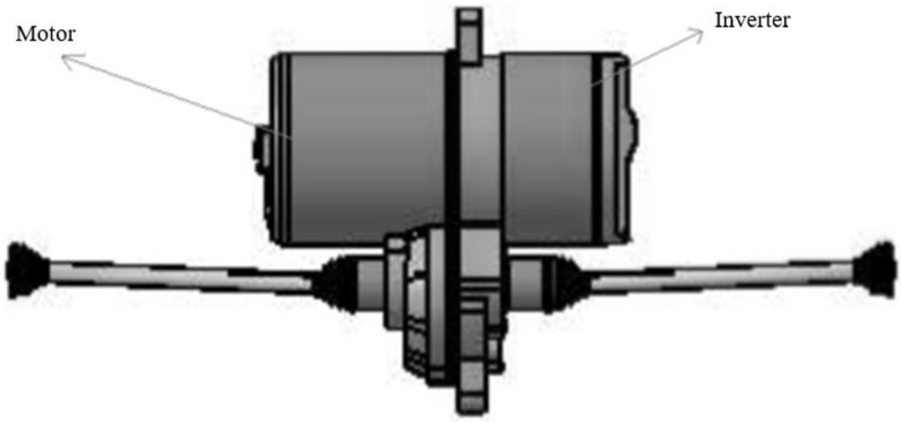


Figure 4. Locating motor and inverter

The maximum stator current of the motor is given by

$$I = \frac{P}{\sqrt{3} \times V \times Motor\ efficiency} \quad (2)$$

The torque output of the motor is 100 N-m, which is nominal for a typical four-wheeler EV. Wheel torque (T_w) can be increased by using a gear reduction system

$$T_w = T_m \times R \tag{3}$$

Where,
Tw - Torque at the wheels,
Tm - Motor torque (100 N-m),
R - Gear ratio.

Here, wheel to motor gear ratio is selected as 10:1. So, the maximum wheel torque becomes

Tw = 100 × 10 = 1000 N\cdotpm

This is adequate for a small or medium-sized vehicle under typical conditions.

The relationship between power and torque is given by

$$P = T \times \omega \tag{4}$$

Where,
P - Power in watts,
T - Torque in N-m,
ω - Angular speed in rad/s.

At 100 N-m and 10 kW, the maximum angular speed is estimated as

$$\omega = \frac{P}{T} = \frac{10{,}000}{100} = 100 \text{ rad / s.} \tag{5}$$

The operating speed of the motor is

$$Motor\ Speed = \frac{\omega \times 60}{2\pi} \approx \frac{100 \times 60}{6.28} \approx 955\ RPM \tag{6}$$

This is a low-speed motor and is suitable for a vehicle with proper gearing. Assuming a small EV weighing 1000 kg with a wheel radius of 0.3 m, the acceleration can be estimated as

$$F = \frac{T_w}{r}, a = \frac{F}{m} \tag{7}$$

Substituting Tw = 1000 N\cdotpm, r = 0.3 m and m = 1000 kg the force and acceleration is calculated as,

$$F = \frac{1000}{0.3} \approx 3333\ N, \qquad a = \frac{3333}{1000} \approx 3.33\ m/s^2$$

The specifications of the motor is given in Table 3.

Modelling of Radiator

The coolant tube from the motor is connected to one radiator fin and coolant tube from battery is connected to another radiator fin. Both the radiator fins are inserted one after the other with 10mm distance between the fins. Behind the radiator fins the fan with eight blades is fixed to eliminate the heat of the coolant in the radiator fins. The height of the radiator fin is 602 mm, length is 594 mm and breadth is 69 mm. The diameter of the fan is 573 mm. The dimensions of radiator is illustrated in Figure 5 (a) and dimensions of the fan are modelled as shown in Figure 5 (b) respectively.

Table 3. Specifications of the Motor.

Parameter	Specifications
Rated Voltage	350V
Rated Power	10Kw
Maximum Torque	100 N-m
Efficiency	85%
Maximum stator current	20A

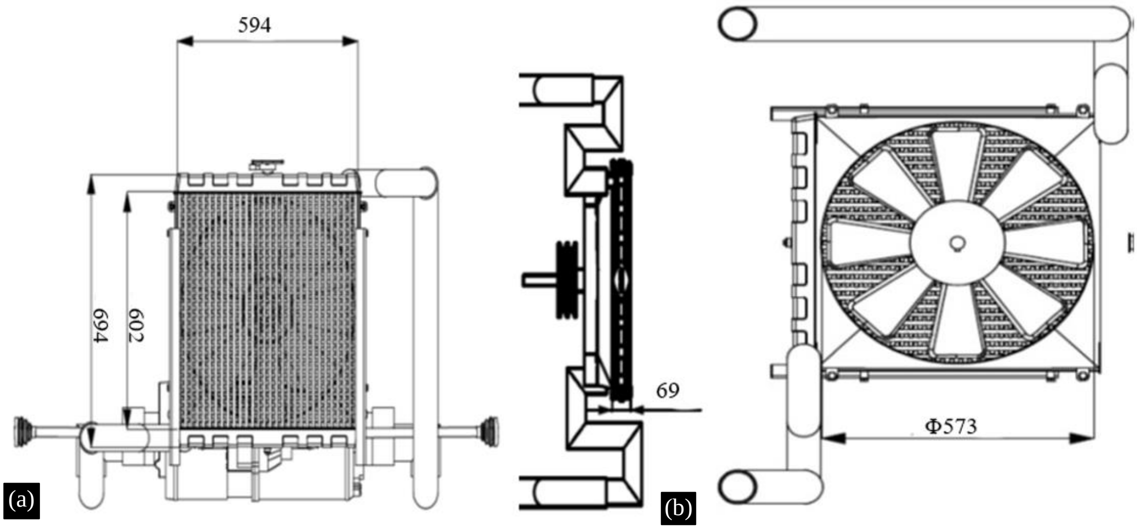


Figure 5. (a) Dimension of the radiator (b) dimension of the fan.

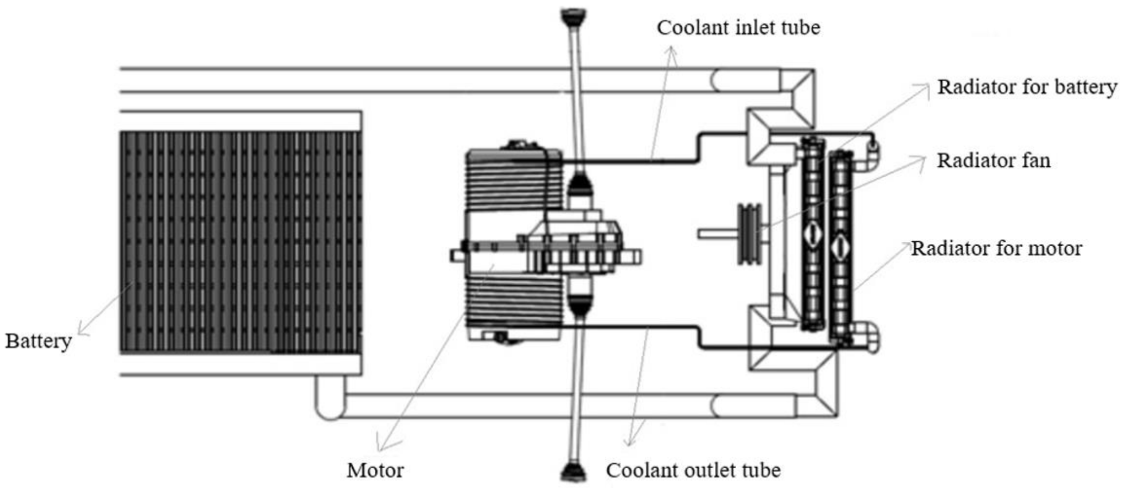


Figure 6. Assembly drawing.

Final Setup

The coolant tubes are inserted near to the battery is combined and connected to common passage, one common passage for output and another common passage for input both are connected to the radiator fins to inlet and outlet valve. Motor coolant pipe one end is connected to the inlet of radiator fins and another end is connected to outlet of radiator fins. The fan is fixed behind the two radiator fins. The total assembly of the EV with battery, motor, coolant tubes arrangement is illustrated in Figure 6.

RESULT AND DISCUSSION

Meshing the Battery in Ansys

The ANSYS workbench is opened and Mesh is selected. In Mesh geometry should be selected and battery model should be opened. After opening in the place of question mark tick symbol will be projected right next to the geometry and next to mesh one circular symbol will be projected. The total battery pack is modelled as shown in Figure 7.

Then the circular part in the mesh to be clicked and opened for Meshing. All the parts in the model should be mentioned as solid in the column material. The element data for meshing is mentioned as 2160846, the faces in the model are 5339318 and the nodes in the model are 1202144 with 7 cell zones and 70 face zones.

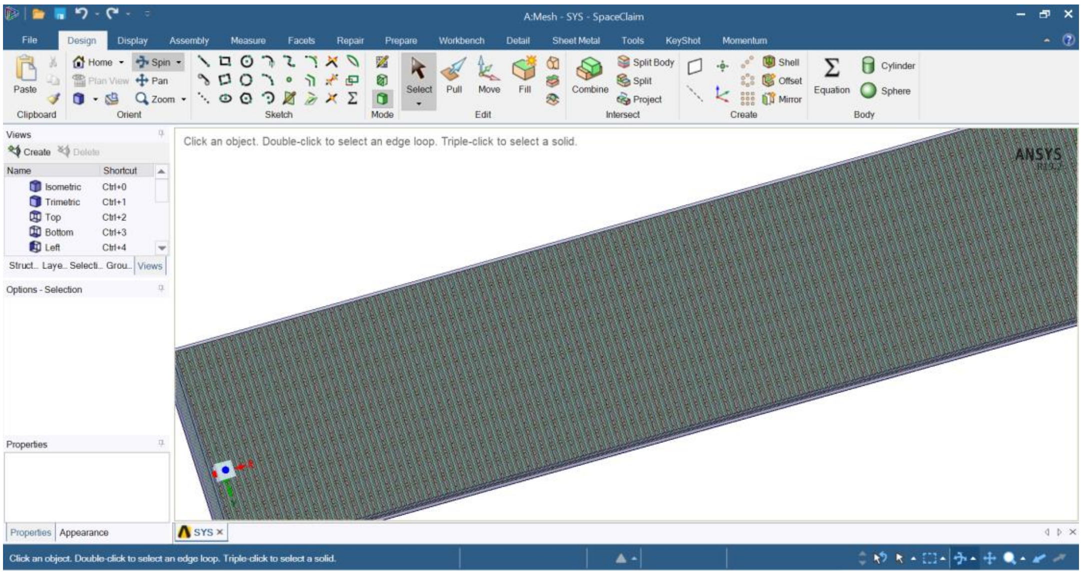


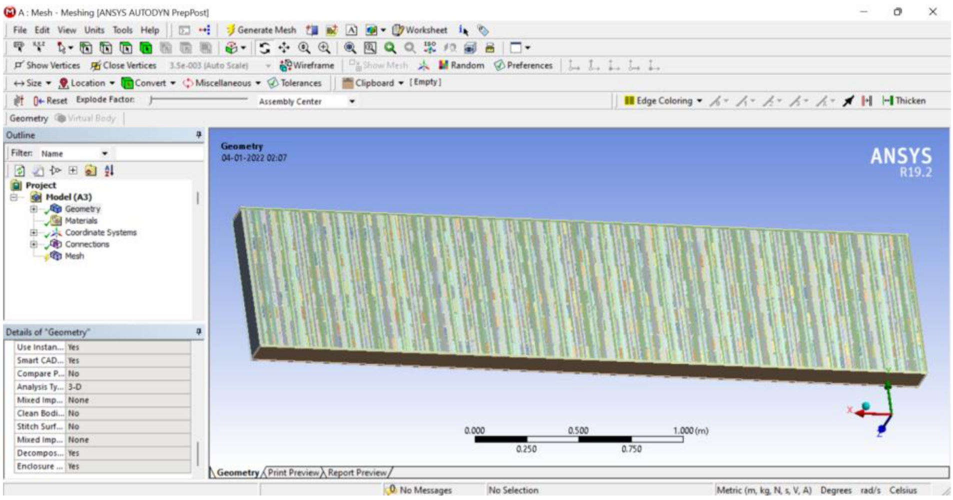
Figure 7. Battery model in geometry.

For all the parts in details reference frame should be mentioned as Lagrangian. Behavior in the definition should be mentioned as none. By using the body option in the toolbar all the solid faces to be named, by using the face option the tool bar all the solid surface top area to be named and by using the edges option in the toolbar all the edges which are in contact to another solid surface to be named. All the names should be mentioned by using the right clicking on it and by selecting create named selection. The meshing should be done clicking on the generate mesh in the toolbar menu.

In meshing one single volume of the battery gets divided into n number of faces and nodes it is shown on Figure 8 (a) and the meshing of the battery is shown in Figure 8 (b).

Designing a Battery in Fluent

The fluent file is dragged from the components systems toolbox and inserted on project schematic. The fluent is opened and the setup is clicked to open the fluent toolbar then in the file is opened and in mesh import is selected to open the meshed geometry. In the fluent setting up physics toolbar is selected first in the solve column time should be mentioned as steady, type should be mentioned as pressure-based and velocity formulation should be selected as absolute. In the models energy should be marked.



(a)

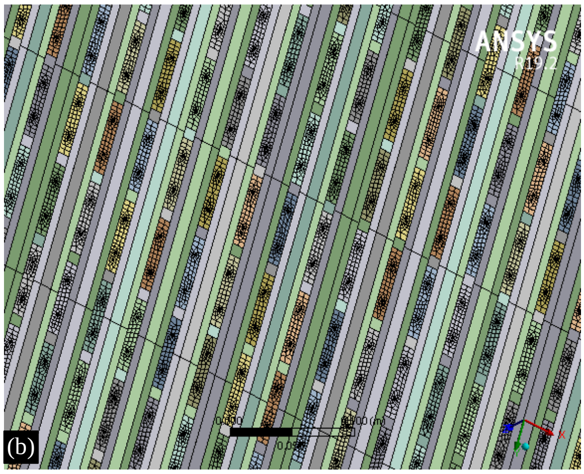


Figure 8. (a) Battery Model in Mesh (b) Meshing of a Battery.

The following steps should be proceeded to design battery in fluent. In the fluent tree material is selected again in materials solid is selected. The outer part of the battery is made up of Aluminum. The selection of material properties for battery, insulator (Thermocol) and air flow is mentioned in the following flow chart. To avoid thermal decomposition inside the battery and motor, it is decided to keep the coolant temperature as 25℃ with flow velocity of 10 m/s. The selection of material properties in fluent for battery, insulator and airflow is depicted in Figure 9.

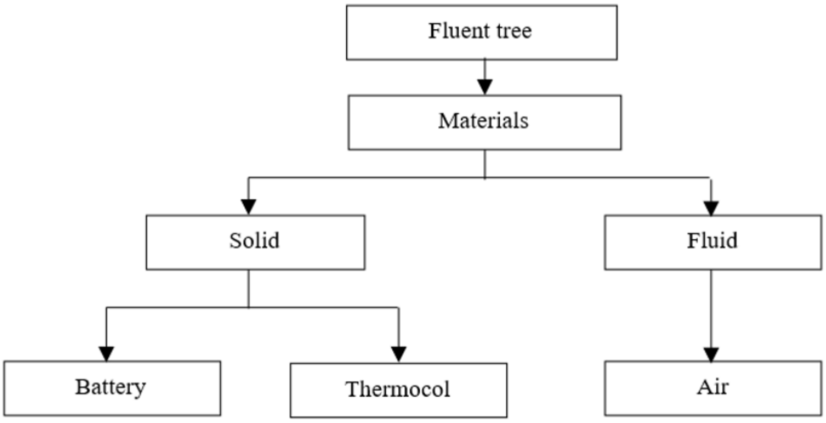


Figure 9. Selection of material properties for battery, insulator (thermocol) and airflow.

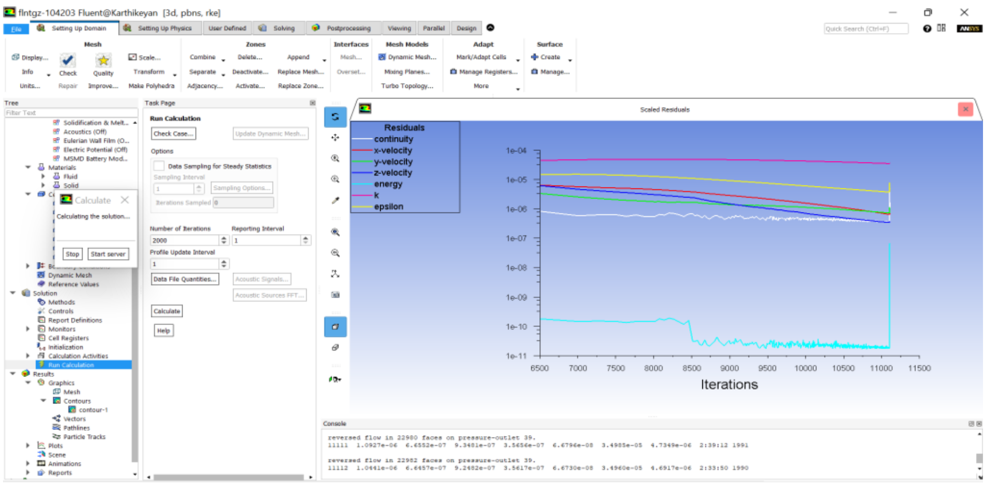


Figure 10. Simulation results.

ANSYS Simulation of the Proposed Model

After filling all the details, the model is made to run by selecting run calculation in the solution toolbar. The number of iterations is selected as 12,000 to get better solution and calculate button to be clicked. The number of iterations should be increased to get better results. The graph will be made to run the iterations on X-axis and temperature on Y-axis. The console column shows the number of iterations completed and time taking to finish the iterations. The simulation results are displayed in Figure 10.

Discharging of the Battery Without Coolant

The battery is charged and made to run at the voltage of 3.0 ~ 3.2 V. The thermal energy dissipated form the battery is accumulated at the bottom of the battery because the air flow at bottom will be very less. The battery temperature lies between 25℃ to 54.2℃ during the charging / running condition under its nominal C rating.

The total heat energy dissipated from the battery is given by the following calculation. Since the battery pack is in cuboid structure, the battery pack has three different pair surface areas totally six surfaces.

A1=65X133=8645=8645/10,00,000=0.008645
A2=10X133=1330=1330/10,00,000=0.00133
A3=10X65=650=650/10,00,000=0.00065

(Converting m to mm^2 so divide by 10,00,000)
A1=0.008645X2=0.1728
A2=0.00133X2=0.00266
A3=0.00065X2=0.0013

(There are two surfaces for each area so multiply by 2)
0.1728+0.00266+0.0013=0.0125
Heat flux=4000W/m^2
4000X0.0125=85W
LX B X H=0.065X0.01X0.133=0.0008645
85/0.0008645=9,83,227.299W/m^3.

The coolant is passed through the copper pipes to reduce the heat energy released from the battery. The temperature of the battery is reduced at the locations where the coolant pipes are flowing. The temperature observed in the battery is shown in contour bar from 25℃ to 27.9℃. The top of the battery is left without cooling because the battery top part is exposed to the air directly so less heat is generated due to presence of air. The temperature gradient of the battery with and without coolant can be observed from the contour bar shown in Figure 11 (a) and (b) respectively.

Meshing the Battery and Radiator

The motor and the battery are meshed to convert all surfaces into faces. For all the parts in details reference frame should be mentioned as Lagrangian. By using the body option in the toolbar all the solid faces to be named, by using the face option the tool bar all the solid surface top area to be named and by using the edges option in the toolbar all the edges which are in contact to another solid surface to be named. All the names should be mentioned by using the right clicking on it and by selecting creates named selection. The meshing should be done clicking on the generate mesh in the toolbar menu. In meshing one single volume of the battery gets divided into n number of faces and nodes. After meshing the fluent should be opened in the workbench by using the toolbox on the left. Then the setup should be clicked and then the file should be opened.

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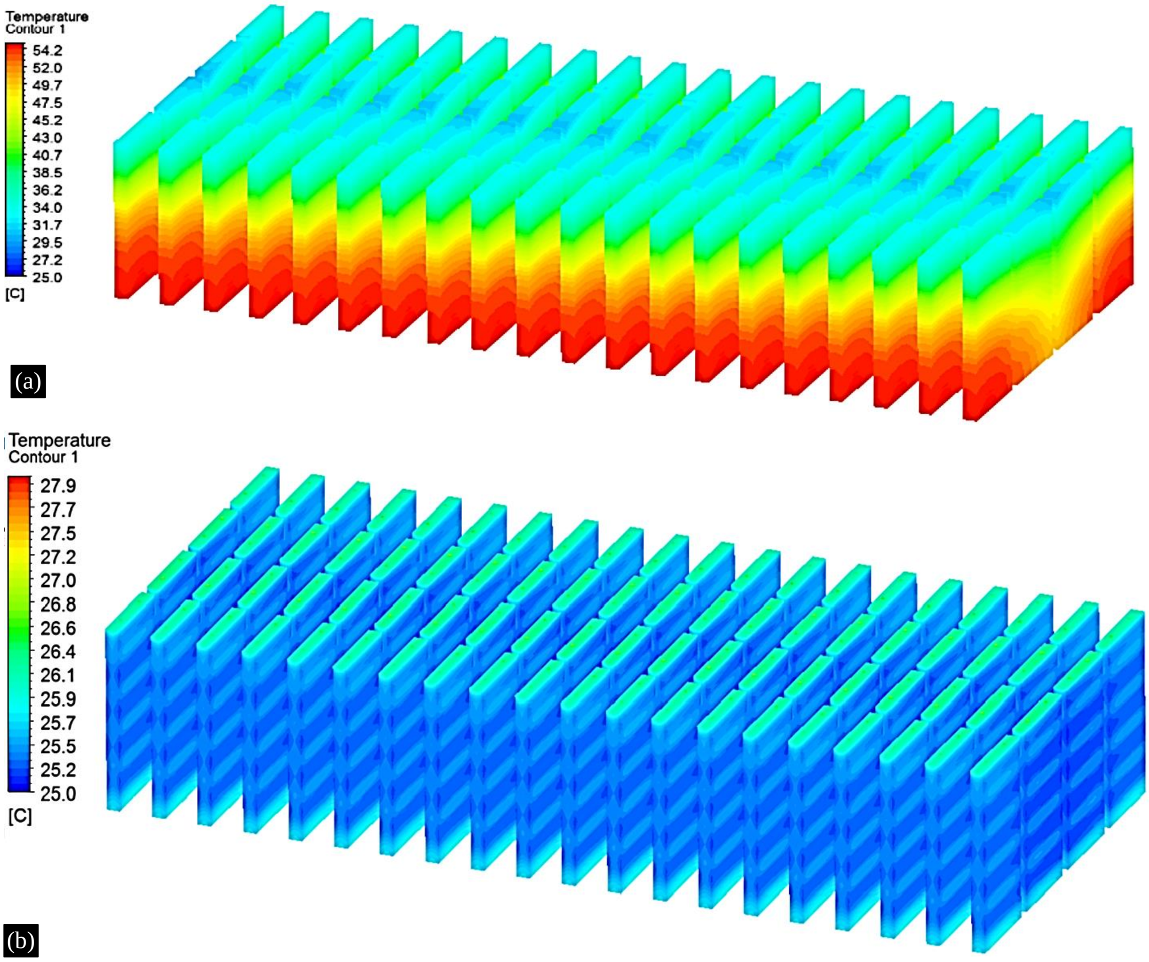


Figure 11. Temperature gradient of the battery (a) Without coolant (b) With coolant.

Designing the Battery and Radiator in Fluent

Mild steel is considered as a material to design motor. The heat from the motor is dissipated to the inverter also so the coolant tubes are circulated to the inverter to reduce the heat. Heat generated by the motor is given by the input as W/m^3.

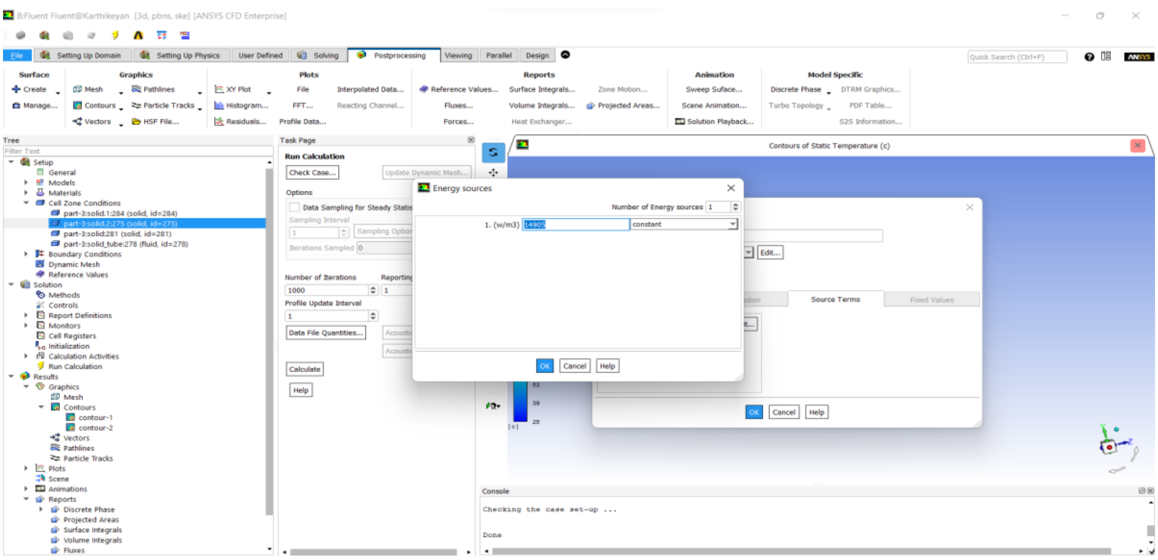


Figure 12. Thermal properties of the motor.

It can be seen through the following steps

Filter Text ⟶ Cell zone conditions ⟶ part3 solid.2:275 ⟶ source terms ⟶ Energy (edit)

The volume can be seen through the following steps

Filter Text ⟶ Reports ⟶ Volume Integrals ⟶ report type as volume ⟶ total volume (m^3)

The system itself calculates the volume of the surface. The thermal properties of the motor can be selected as shown in Figure 12.

Energy Loss Calculation of the Motor

The loss of the motor is observed in the form of a heat. Here the motor rating and the heat energy dissipation by the motor is selected as 10 kW and 150W per kW respectively. So, the total heat energy dissipation by the motor is given by

10X150 = 1500watts=1.5kW

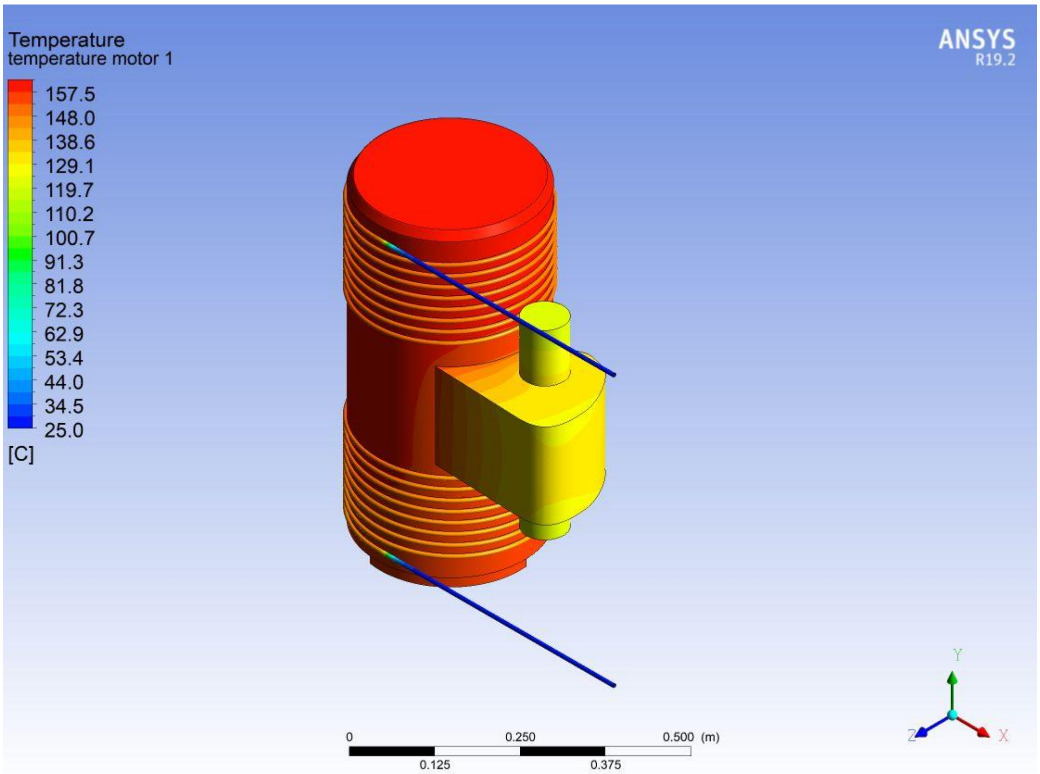
The rest of the energy

10kW-1.5kW=8.5kW is the output of the mechanical energy.

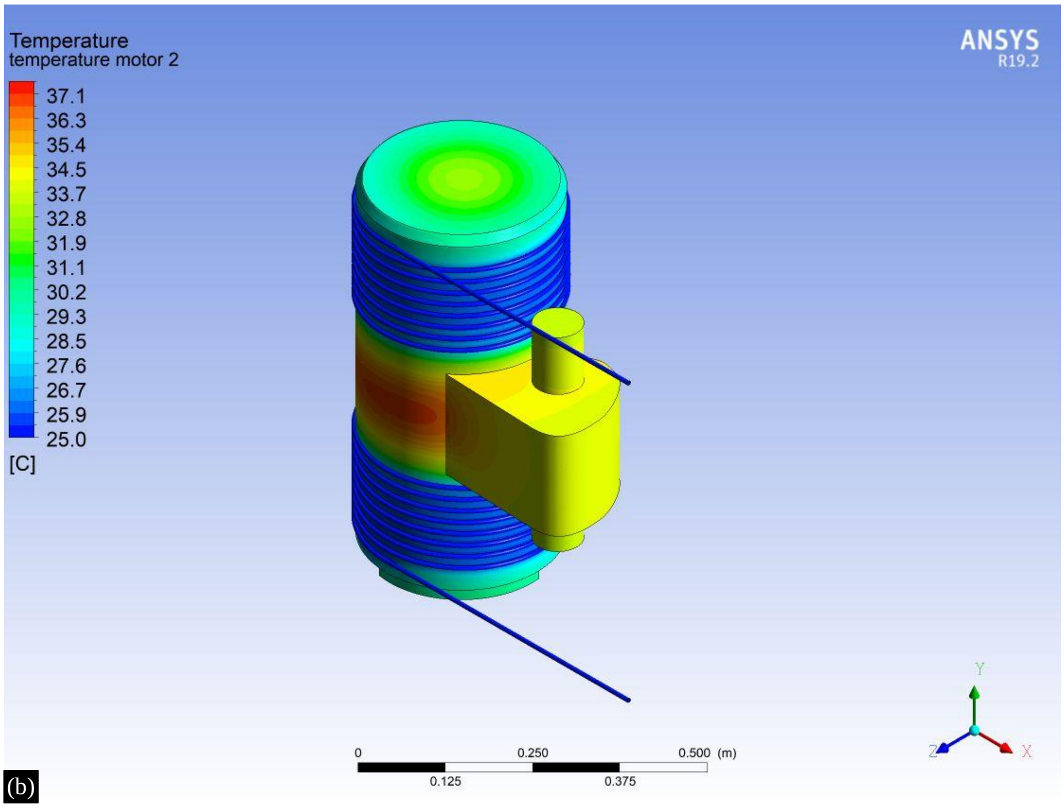
From the designing module or using the CAD the values are observed as 0.44927m and 0.045211 surface area.

(1500X0.44927)/0.045211=14905W/m^3.

The evaluated parameters are utilized as input of this research work. The heat distribution of the motor is measured and displayed the Figure 13.



(a)



(b)

Figure 13. Temperature Distribution of the Motor (a) Without Coolant (b) With Coolant.

Analyzing The Thermal Characteristics of The Motor Without And With Coolant

During the running condition, at peak load the maximum temperature of the motor reaches as high as 157.5˚C. Here the motor loss occurs in the form of heat which is calculated in the above section 4.7. Also, the temperature rise directly affects the lifetime of the motor. Here, the motor is loaded to its maximum capacity and its thermal characteristics are analyzed. The temperature distribution of the motor depends upon numerous factors such as speed and loading conditions of the motor, environmental conditions, materials utilized for motor design coil thickness, flux distribution, current intake by the motor etc., It is much difficult to analyze all the parameters at once. Since this research work aimed to reduce the temperature distribution, full load condition of the motor is considered and heat distribution at this condition is analyzed.

The prepared coolant is circulated through the motor to absorb the heat generated in the motor. Then it is made to flow through the radiator for heat transferring. The temperature gradient of the motor without and with coolant are illustrated as shown in Figure 13 (a) and (b) respectively.

Radiator Design in Fluent

The radiator fins are implanted near to the fan. The distance between the two radiator fins are 10mm. The coolant in the two radiator fins are cooled by using on common fan. The fan emits 2000 CFM through the radiator fins to despite the heat. The atmospheric air is passed by the fan through the radiators to cool the coolant in the radiator fins. The dimensional calculations for the radiator are given as follows.

1CFM = 0.00047194745 m^3/s

2000X0.00047194745=0.9438949m^3/s

2.83451921921m is the surface area which is derived from the designing module or using the CAD.

0.9438949/2.83451921921=0.333m/s.

The thermal properties of the radiator fins are displayed as shown in Figure 14.

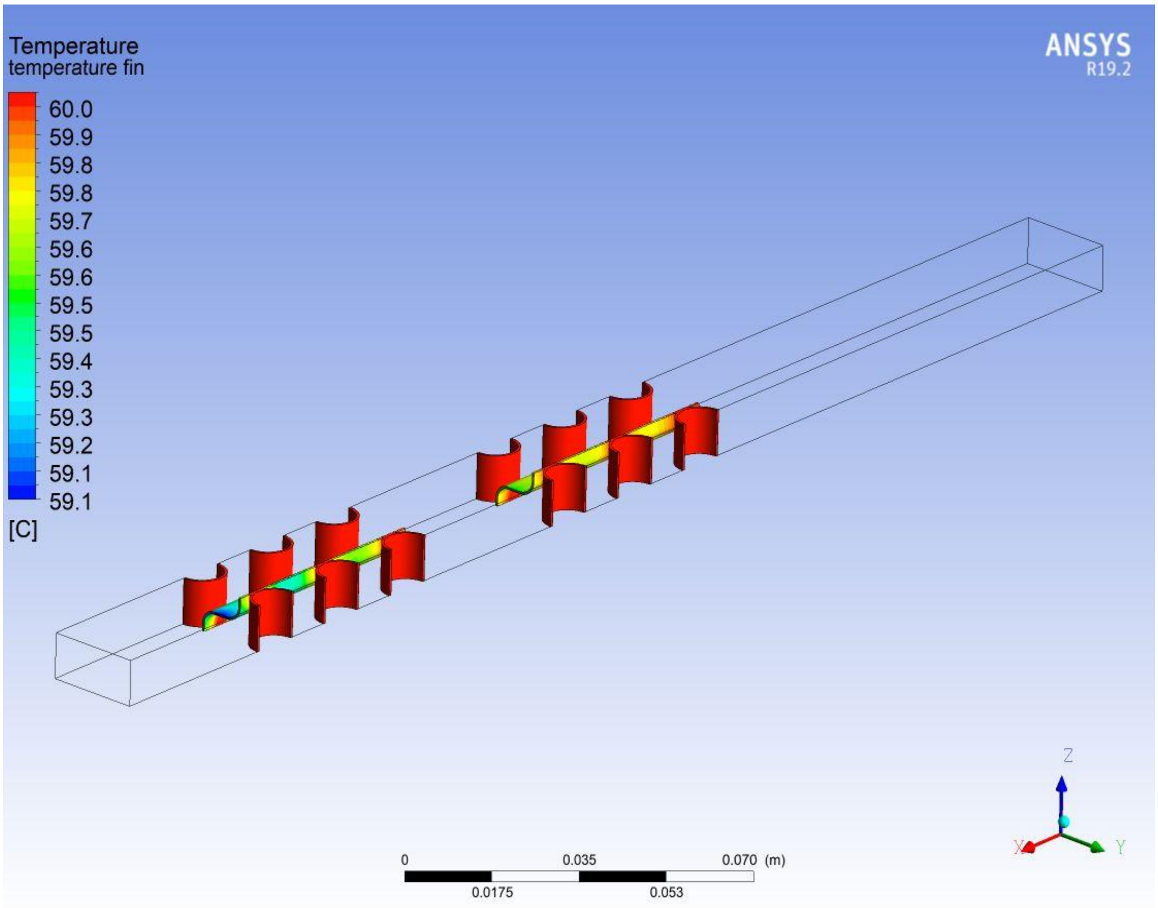
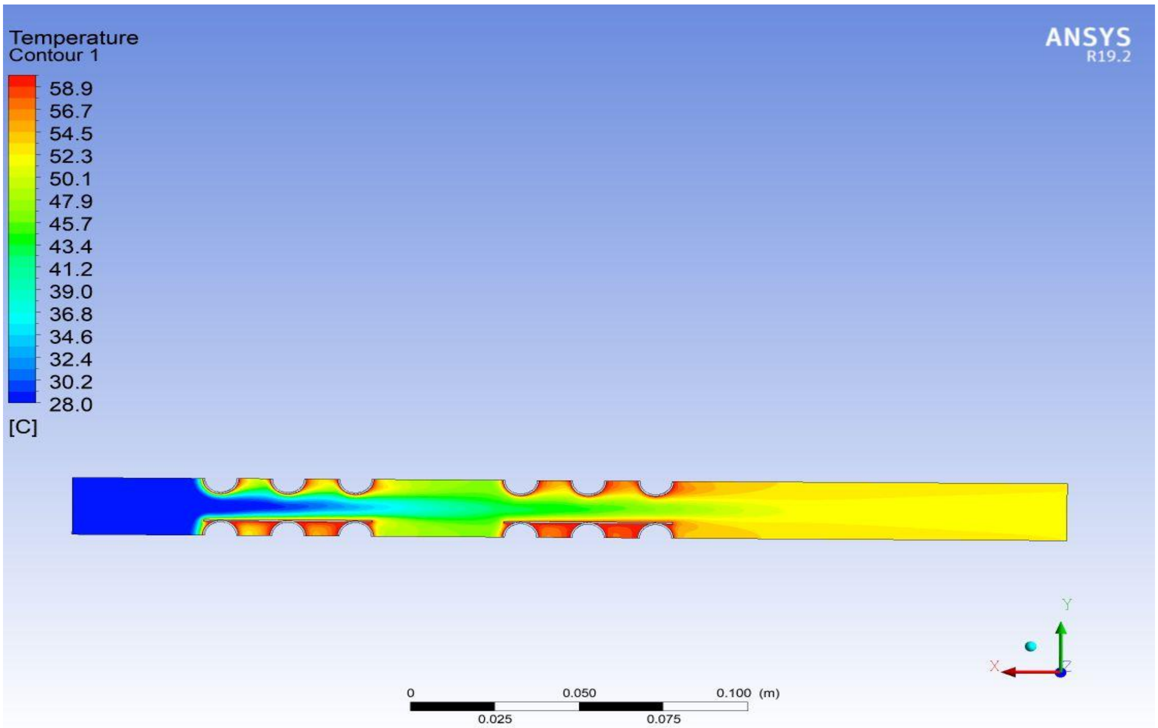


Figure 14. Temperature in radiator fins.



(a)

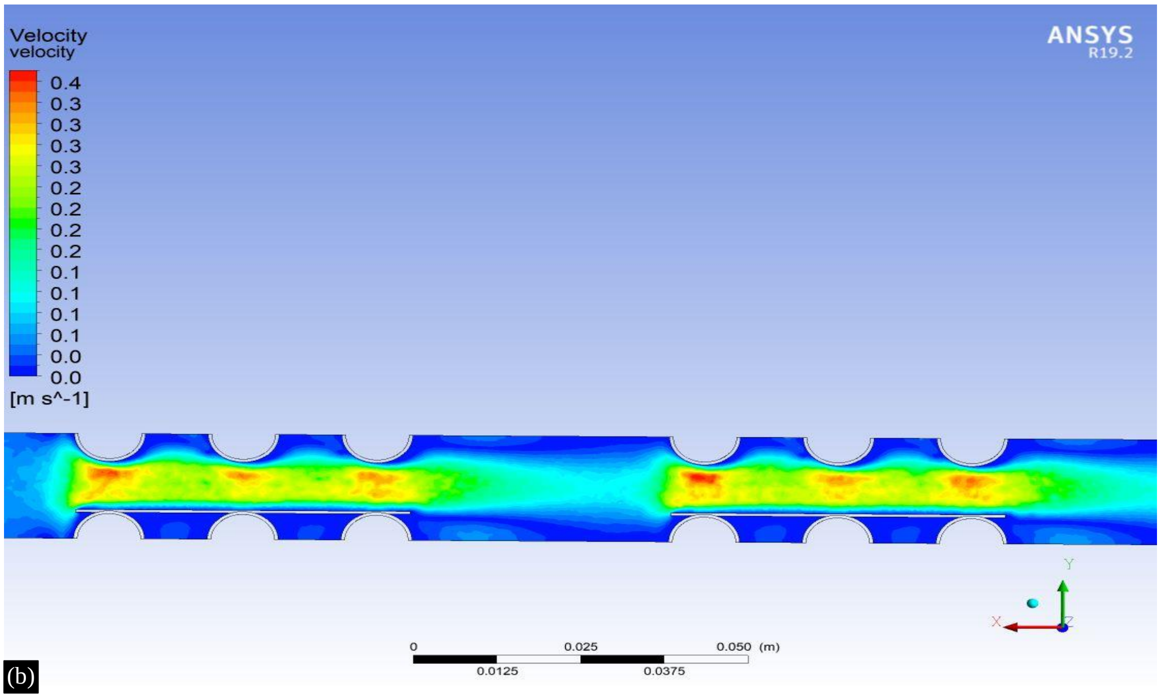


Figure 15. (a) Heat Dissipated by the fan (b) Velocity of the airflow through radiators.

Analyzing the Heat Dissipation of The Coolant in the Radiator

The temperature level is maintained to 60˚C by the coolant in motor and battery. This heat is dissipated by using the fan and the temperature drops to 50˚C. By using the radiator fans the temperature gets dropped in the coolant. Again, the cooled coolant is passed to the battery and radiator to absorb the heat. The heat dissipated by the fan is displayed in Figure 15 (a).

The U-shaped radiator fin which is facing upward is for Motor and the U-shaped radiator fin which is facing downward is for Battery. The velocity of the air flow by the fan through the radiator fins is analyzed, due to the two U shaped radiators are arranged near to the outermost part of another outermost part of the radiator, so the velocity of the air flow is very high in this area recorded as 0.4m/s this is shown in the Figure 15 (b). Due to this the heat generated in the battery and motor are controlled together.

CONCLUSION

In this research, the performance of a novel Battery-Motor Integrated Thermal Management System (BMITMS) for EV applications is verified in various aspects. The thermal characteristics and behavior of the battery is displayed for only one module of which consist of 20 parallel and 4 series cells. The thermal behavior of the battery is analyzed during both charging and loading conditions. It is also analyzed with and without coolant. When the battery is charged without coolant, the temperature of the battery reaches up to 54.2℃.But, after passing the coolant through the coolant pipes the temperature of the battery gets decreased. The highest temperature obtained in the battery with coolant during charging is 27.9℃. The temperature of the battery is maintained around ambient temperature during charging. At full load condition, the temperature of the motor reaches up to 157˚C without coolant. The motor temperature is decreased from 157˚C to 37.1˚C by passing the coolant. The heat observed by the coolant is passed to the radiator fins there the heat in the coolant is removed by using the fan. The temperature of the coolant drops up to 5˚C while passing through the radiator.

FUTURE SCOPE

- The thermal behavior of the battery can be analyzed with different charge rating of the battery with various loading conditions of the motor.

- The temperature distribution can be analyzed for different coolants with different coolant speed.
- The same model can be applied with different motor loads such as BLDC hub motor, PMDC motor, synchronous motor. These types of batteries are low maintenance, long life and can be easily disposed. Also, the possibilities of practical implementation can be analyzed.

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