

DESIGN OF EXTERNAL COOLING SOLUTION FOR ELECTRIC VEHICLE BATTERY PACK WHEN PARKED

A PROJECT REPORT

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BONAFIDE CERTIFICATE

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ABSTRACT

In this project, the effect of temperature on electric vehicle battery pack when parked under direct sun is studied. Temperature sensor array is used to measure the temperature of the battery cover. The sensors are calibrated using calibrated thermometer and percentage of error was found. The obtained temperature values between battery cover and battery when parked under direct sun is calculated and analysed in ANSYS and the result indicate that higher amount of heat transfer takes between left and right side of the battery cover to the battery as it has the higher contact surface area with the battery. The obtained temperature values were used to find the amount of coolant required and diameter of the copper channel. Battery cover is designed with cooling system to reduce the heat transfer between battery cover and battery. Ethylene glycol and water mixture is used as a coolant. Pump is used for the circulation of the coolant, which is powered by a separate battery. The battery is recharged by solar power. Copper is used as the channel tube material and steel is used as battery cover material. The coolant will be stored in the reservoir which is attached to the back of the battery cover. Arduino setup is used to control the pumping operation of the coolant only when the temperature rises above 35 °C. The results were obtained with the reduction of temperature from 39 °C to 34 °C on the battery surface and cover. Finally, it is concluded that the cooling system can be installed on electric vehicle battery pack to reduce the temperature rise when parked under direct sun but at a slight elevation of gross weight.

Keywords: Battery pack, temperature effects, cooling system, Ethylene glycol

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CHAPTER 1

INTRODUCTION

The automotive industry is step-by-step shifting from producing conventional cars powered by internal combustion engines (ICE) to less carbon-intensive drive technologies, including fully battery-electric vehicle. The battery packs in electric vehicle are built from thousands of cells, with electronics to manage charging and discharging. To prevent overheating, some unit include an active cooling system. But temperature raise on battery due to heat transfer from vehicle body frames through convection and radiation when parked under direct sun is not considered in any of the vehicles that are sold in India. When the vehicle was parked under direct sun, a increase in temperature of 4°C from optimal working temperature of lithium ion battery is observed in the battery pack in the peak time-afternoon. This is due to the heat transfer made possible through the chassis, battery cover, clamps, and battery cover mount. This will substantially reduce the calendar age of the battery because it promotes the unstable SEI formation on the battery. The proposed solution is to place a cooling channel with serpentine design which is in direct contact with battery cover. Mixture of water and ethylene glycol is used to flow inside the channels, the flow is achieved by using pump. Using this, we can reduce the temperature raise of the battery pack due to heat transfer from battery cover, clamps, and battery cover mount.

1.1 PROBLEM STATEMENT

Tropical countries like India are famous for its scorching weather, especially during the summer months that start from March and extend up to September. Regardless of the season, many parts of India experience surging temperatures all throughout the day. Parking Electric vehicle under shed is a major problem in urban areas in both developed and developing countries. Most people are forced to park their vehicles, directly under sun. This will heat up the vehicle body and frame gradually, and this heat is transferred to the battery through conduction, convection radiation raising the temperature of the battery. Increased storage temperature of the battery

promotes the growth of inorganic species at the SEI layers, which lead to the increase of impedance inside the batteries, thus reducing the range and cycle life of the battery. The cooling system present in the current Electric vehicles that are sold in India, is to reduce the temperature of the battery only when the vehicle is operated at high load and high speed. The rise in temperature during parked under direct sun should also be considered when designing the battery thermal management system. So, we planned to design a cooling channel with ethylene glycol flowing through it, for battery cover which will reduce the heat transfer between battery covers to battery.

1.2 LITHIUM ION BATTERY

The battery usage is very usual because, after electricity, it is the main source of energy. The battery is not only used to start the mini toy but also use in automobiles and industries. There are different types of batteries that are used worldwide, but lithium-ion battery is one of the most famous and expensive among others. It will require a specific temperature that will keep it in working order. The productivity and durability of the lithium-ion battery are depending on its charging rate. The temperature plays an important role in discharging and charging the battery.

The battery efficiency is depending on its recharge rate and discharge rate. Its capacity and life are directly related to the temperature. If we talk about the charging rate of the lithium-ion batteries, it's more delicate as compared to discharging rate. It requires special care, especially in extreme weather or temperature. The optimal operating temperature range for lead – acid battery is 20 to 25° C. In their tips for maximizing battery life in solar application, stated that for every 10° C (18° F) rise above room temperature (25 °C or 77 °F), battery life decreases by 50% and the optimal temperature range for lithium – ion battery operation is between 15 to 35°C.

1.3 LITHIUM BATTERY COMPONENTS

The cathode of Li-ion battery is made of a lithium metal oxide such as LiMO_2 and LiCoO_2 while the anode is made of graphitic carbon. The electrolyte is non-aqueous organic liquid containing dissolved lithium salts, such as LiClO_4 . Li-ion

battery have their response time, power density and energy in the order of milliseconds, 75–200Wh/kg and 150–2000W/kg respectively. They further stated in their publications that Li-ion batteries have high cycle efficiencies, up to 97%. The main drawbacks of Li-ion BES system are that Depth of Discharge (DoD) cycle could affect the Li-ion battery's lifetime and that the battery pack usually requires electronic controllers to manage its operation. This of course increases its overall cost. The performance also depends on operating temperature just like Lead Acid battery.

1.4 HOW TEMPERATURE AFFECTS LITHIUM ION BATTERY?

The batteries are given different work efficiency at different temperatures. On the high temperature, the battery will start to swell and sometimes it may blast but in extreme cool weather, the lithium-ion batteries are not charging.

The rate of chemical reactions to produce electric power in Li-ion batteries reduces as temperature decreases. The decrease in temperature causes contraction of the electrode materials, which slows down ion movements in the intercalation spaces. As this continues, the electrodes will stop accommodating current flow thereby resulting in reduced power output as well as irreversible capacity loss due to Lithium plating of the anode. On the other hand, operating Li-ion battery at high temperatures gives rise to a different set of problems which can result in the destruction of the cell. First, the magnitude of available power and capacity start decreasing after 35°C. However, it has that operating Li-ion battery slightly above 50 °C also reduces cycle life and at above 70 °C the threat of thermal runaway arises.

1.5 HEAT GENERATION IN BATTERIES

The heat is generated either in the reversible process or the irreversible process in Li-ion batteries rises. There are many irreversible processes that can generate heat, including active polarization process, ohmic heating process, heating due to mixing and enthalpy change.

The polarization is resulted from the overpotential between operating potential and open circuit potential of the batteries. It leads to the increase of charge transfer

resistance at electrode-electrolyte interface, or Solid Electrolyte Interface (SEI). When lithium ions overcome such resistance at interface for their intercalation/deintercalation, heat is produced. The ohmic heating process occurs in both the electrode and electrolyte. It is due to the resistance of electrodes and electrolytes that hinders the transportation of charges.

1.5.1 AGING

Aging is an effect during the application of LIBs at high temperatures. Aging not only affects the performance of LIBs, but also reduces their lifetime. In general, the aging of LIBs includes cycle aging and calendar aging. These two types of aging, however, always occur in combination due to the complex composition and working process of LIBs. Increasing the operating temperature of LIBs above the optimal scope will accelerate the aging process and lead to the degradation of LIBs.

1.6 BATTERY TERMINOLOGIES

1.6.1 LIFE CYCLE

Battery Cycle Life is defined as the number of complete charge - discharge cycles a battery can perform before its nominal capacity falls below 80% of its initial rated capacity. Key factors affecting cycle life are time t and the number N of charge-discharge cycles completed.

1.6.2 C – RATE

In general, discharge current is often expressed as a C-rate in order to normalize against battery capacity, which is often very different between batteries. A C-rate is a measure of the rate at which a battery is discharged relative to its maximum capacity.

1.6.3 DEPTH OF DISCHARGE

This expresses the percentage of battery capacity that has been discharged expressed as a percentage of maximum capacity. A discharge to at least 80 % DOD is referred to as a deep discharge.

1.7 REASON FOR CHOOSING COPPER TUBE?

Copper as a metal has highly anti-corrosive properties compared to aluminium. During the cooling process, they encounter air which causes oxidation within these pipes. Copper can better handle oxidation and corrosion for longer periods ultimately a longer lifespan.

Cooling on copper pipes is much faster due its lower specific heat quality. The term ‘specific heat’ describes the amount of heat per unit mass required to raise temperature by 1°C. Lower the specific heat quantity, better the heating up and cooling down capabilities. As copper pipes have low specific heat quantity, they can rapidly dissipate heat into external environments and cool down quickly to absorb more heat. As aluminium pipes require more time to heat and cool down, they consume more energy and have comparatively lower cooling.

Due to copper’s less ductile nature, copper pipes are stronger and can easily withstand minor accidental damages. Even in case of cracks or punctures, copper pipes can be easily soldered. As aluminium pipe is fragile, soldering or repairing them is a chore and is better replaced.

1.2.1 PROPERTIES OF COPPER

SL No.	Properties	Copper
1	Melting point (°C)	1083
2	Specific heat (kJ/kg K)	0.39
3	Thermal conductivity ($\text{Wm}^{-1}\text{K}^{-1}$)	401
4	Thermal expansion (25 °C) ($\mu\text{m m}^{-1}\text{K}^{-1}$)	16.5

Table 1.1 Properties of copper

1.2.2 PROPERTIES OF COPPER TUBE

SL No.	Properties	Copper tube
1	Nominal or standard size	3/8
2	Outside diameter	11 mm
3	Inside diameter	10 mm
4	Thermal expansion (25 °C) ($\mu\text{m m}^{-1} \text{K}^{-1}$)	0.5 mm
5	Weight of tube	400 g/m

Table 1.2 Properties of copper tube

1.8 AIR COOLING VS LIQUID COOLING

An effective air-cooling BTMS could dissipate excessive heat within the battery pack and control the maximum operation temperature below a certain value as well as maintain the maximum temperature differences within a required range.

For liquid cooling BTMS, the heat is carried by the convection and conduction from the battery cells to the coolant via cooling channels. The coolant is usually water and Ethylene glycol solution, which could provide a wide operation temperature range from $-40\text{ }^{\circ}\text{C}$ to $105\text{ }^{\circ}\text{C}$. Due to the high thermal conductivity of these liquid coolant, the liquid cooling BTMS has both higher cooling capacity and cooling efficiency than other systems. To remove same amount of heat, the required flow rate for the liquid cooling BTMS is much lower than those for other systems due to the higher specific heat capacity values of the liquid coolant.

In addition, the noise level of electric water pumps is usually lower than that of the same power electric air fans. On the other hand, the liquid cooling BTMS is usually

large and heavy. Due to the high electric conductivity of the water-based coolant, the sealing of the whole BTMS is critical to the safety of the system. Although the air cooling consumed an extra amount of power in a higher heat load condition, its basic advantages outweigh those of the liquid cooling system.

1.9 DIRECT AND INDIRECT COOLING

- Direct cooling systems place the battery cells in direct contact with the coolant liquid. Because the battery is in contact with the liquid, the coolant needs to have low to no conductivity.
- Indirect cooling systems circulates liquid coolant through a series of metal pipes. It will look different for each electric vehicle manufacturer.

1.10 REASON FOR CHOOSING LM35

- It can measure temperatures more accurately than thermistors
- It does not require amplification of the output voltage
- It uses very little power and does not heat up

1.11 OBJECTIVE

- To develop a cooling system for the battery pack with the use of solar power when parked under direct sun
- To design a best channel to minimize the temperature rise during hot weather in parked condition
- To provide ideal thermal conditions for the battery pack when parked under direct sun.

CHAPTER 2

LITERATURE SURVEY

2.1 LITERATURE SURVEY

1) **Temperature effect and thermal impact in lithium-ion batteries: A review:**

Shuai Ma, Modi Jiang, Peng TaO, Chengyi Song, Jianbo Wu, Jun Wang, Tao Denga, Wen Shang

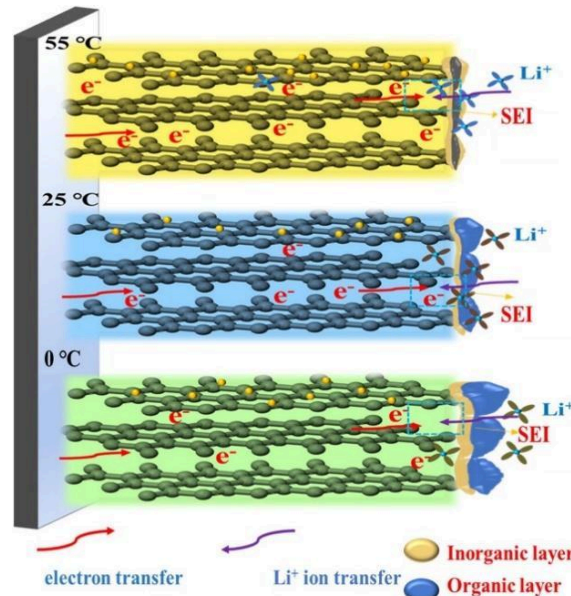
The migration of lithium ions in internal circuit and electrons in external circuit leads to the operation of LIBs. The high temperature effects will also lead to the performance degradation of the batteries, including the loss of capacity and power. The optimal operating temperature range of LIBs is generally limited to 15–35 °C. Both low temperature and high temperature out of this scope will affect the performance and may cause irreversible change to the LIBs. Generally, the loss of lithium and the reduction of active materials under high temperature will result in the loss of the capacity, while the increase of internal resistance is responsible for the loss of power.

Aging is an effect during the application of LIBs at high temperatures. Aging not only affects the performance of LIBs, but also reduces their lifetime. In general, the aging of LIBs includes cycle aging and calendar aging. The carbonates species disappeared, and inorganic species increased at the SEI layers at high temperature, which led to the increase of impedance inside the batteries. Heat generation within the batteries is another considerable factor at high temperatures.

2) **Effect of temperature on formation and evolution of solid electrolyte interphase on Si, Graphite, C anodes:**

Hong Dong, Jie Wang, Peng Wang, Hao Ding, Ru Song, Ning-Shuang Zhang, Dong-Ni Zhao, Li-Juan Zhang, Shi-You Li

The electrolyte is generally oxidized and reduced on the electrode surface during the first few charge–discharge cycles to form the so called “solid electrolyte interface” (SEI) film. It is generally accepted that the SEI film is essential to protect active materials from corrosion, limit continuous electrolyte decompositions and enhance comprehensive performances of LIBs. It has been proved that structure and



composition of SEI film show a big difference with the variation of anode material type, surface properties and ambient temperature.

Figure 2.1 Evolution of SEI film on Si at Graphite

At room temperature of 25 °C, a stable SEI film can be formed on the electrode interface, which is conducive to charge transfer. The high temperature accelerates the dissolution of organo-alkyl lithium salts, allowing the SEI structure to reform continuously at high temperatures until it completely blocks the electrons.

3) Simulative method for determining the optimal operating condition for a cooling plate for lithium-ion battery cell modules:

Joshua Smith a,b,, Michael Hinterberger b, Peter Hable b, Juergen Koehler*

An effective thermal management strategy is one method of enhancing system lifetime increasing vehicle range. Vehicle-typical space restrictions favour the minimization of battery thermal management system (BTMS) size and weight, making their production and subsequent vehicle integration extremely difficult and complex.

This paper presents a computational fluid dynamics (CFD) model and multi-objective analysis technique for determining the thermal effect of coolant flow rate and inlet temperature in a cooling plate data range of vehicle operating conditions don a battery system. The goal of a BTMS is to increase the lifetime of Lithium-ion cells by regulating the temperature influences on the cell.

A BTMS is especially effective when cells are susceptible to high rates of charging and discharging and when the vehicle is operated in very high or low ambient temperatures. And helps to maintain the uniform temperature all over the battery (25 and 35°C). Various models are designed and served as the basis for the presented analysis method to determine the optimal coolant inlet temperature and flow rate at a variety of vehicle operating conditions. Commercially available CFD-software is used for the model generation, meshing, and solving. The model setup is critical to the effectiveness of the multi-objective optimization and analysis. Then competing effect of coolant inlet temperature and flow rate on the maximum cell temperature, difference in the individual cell temperature gradients and the coolant pressure drop along the plate can be visualized using the presented analysis method, thereby allowing the thermal system designed to maximize the lifetime and capacity of the battery cells, and we can increase vehicle range. Thus, we can conclude the optimal cooling plate operating conditions (coolant flow rate and inlet temperature) to guarantee ideal thermal conditions for the battery cells and reduce the energy consumption of the thermal management system.

4) Novel external cooling solution for electric vehicle battery pack:

Kawtar Benabdelaziz, Badreddine Lebrouhi, Anas Maftah, Mohammed Maaroufi*

Electric vehicles in the southern regions of the world could face several problematics related to high temperature, mostly when charging at high power. In that paper we will know about the 3D-thermal model has been developed in order to investigate and to analyse the temperature distribution over the battery pack and

provide new cooling solution for the EV batteries at higher temperature. The thermal behaviour of the pack is investigated by using the thermal model as used for the battery module. The battery modules have been considered as heat sources with a maximum heat generated (5134 Wm^{-3}). Moreover, the investigation's result of the thermal behaviour of each module has been used as thermal parameters inputs. As the heat transfer to the battery pack is made possible through the chassis and different area of attachment of the battery compartments. Then introducing the cold plate which includes one or more internal channel through which a liquid is flowing, in order to increase the cooling efficiency and reduce the amount of liquid and the power consumption. The heat is generated by the battery, transferred into the cold plate, and removed throughout the cooling channels.

The simulation of the different cooling plate design is performed by using the same conditions, physical and cooling parameters. The impact of the cold plate's designs on the battery pack behaviour is investigated by considering the heat removed by the water ethylene glycol and the heat dissipated through the ambient air with convective coefficient of $100 \text{ W/m}^2\text{K}$.

5) Design and analysis of a multipoint temperature datalogger:

O. Ojike C. C. Mbajiorgu, E. Anoliefo and W. I. Okonkwo

Temperature level can affect various types of measurement recorded; hence, temperature must be maintained within certain limits to achieve repeatable results, reduce the cost of tedious corrections, and meet regulatory and correctness requirements. The objectives of the work are to develop a low-cost multipoint temperature logger using LM35 and carry out a performance evaluation to compare its accuracy with already existing thermometers.

LM 35, a semiconductor temperature sensor, is chosen for this project. It has an output voltage that is proportional to the Celsius temperature. The LM 35 can generate output voltages higher than that of thermocouples and generally does not require

amplification of the output voltage, it uses very little power. The thermal response time of LM35 as observed at three different temperatures (40° C, 45° C and 50° C) of the oven replicated twice. It could be observed that in all cases it takes the sensor shorter time to recognize higher temperature than to return to ambient temperature. Then establishing the relationship between Mercury thermometer, Alcohol thermometer, Digital meter, and the different sensors of the designed multi point temperature data logger at ambient conditions. Then calculating the mean temperature among them, a cumulative standard deviation of 0.4°C was calculated for the designed system. After the comparison from that, LM35 maintains an accuracy of +/-0.40C at room temperature. Hence, the system is recommended for use in monitoring low temperature systems, that is, systems whose temperatures are in the range of -55°C to +150°C.

6) Experimental and Numerical studies on the Heat transfer characteristics of Small Shell and Tube Heat Exchanger:

*Vinayak P.Khatawate N.R.Banapurmath R.S.Hosmath Mallesh B.Sanjeevannavar
Shailesh M.Golabhanvi*

This paper presents the experimental and numerical investigations on the effectiveness of a small shell and tube heat exchanger for coolant combinations consists of ethylene glycol (EG) and the deionized water with the varied percentage of the former. According to the combinations ethylene glycol (EG) and the deionized water viz, 60EG:40DW, 30EG:70DW, 20EG:80DW were used. The base fluids of EG and DW were used for the comparison of the heat transfer characteristics respectively selected coolant combination.

Experiments are conducted to study the temperature distribution across both shell and tube sections using the coolants with the varied combinations of the ethylene glycol (EG) and the deionized water. Ansys fluent used as the tool for CFD analysis, the experimental and simulation-based temperature on both the shell and the outlet sides. Accordingly, EG60:DW40 coolant combination showed improved heat transfer

with higher temperature difference compared to EG70:DW20 and EG20:DW80 respectively. Even though water has better heat removal capacity, ethylene glycol is preferred in cold environment due to its antifreeze property. Mixture of both water and ethylene glycol have cooling effects very nearer to base fluid water.

CHAPTER 3

METHODOLOGY

3.1 METHODOLOGY

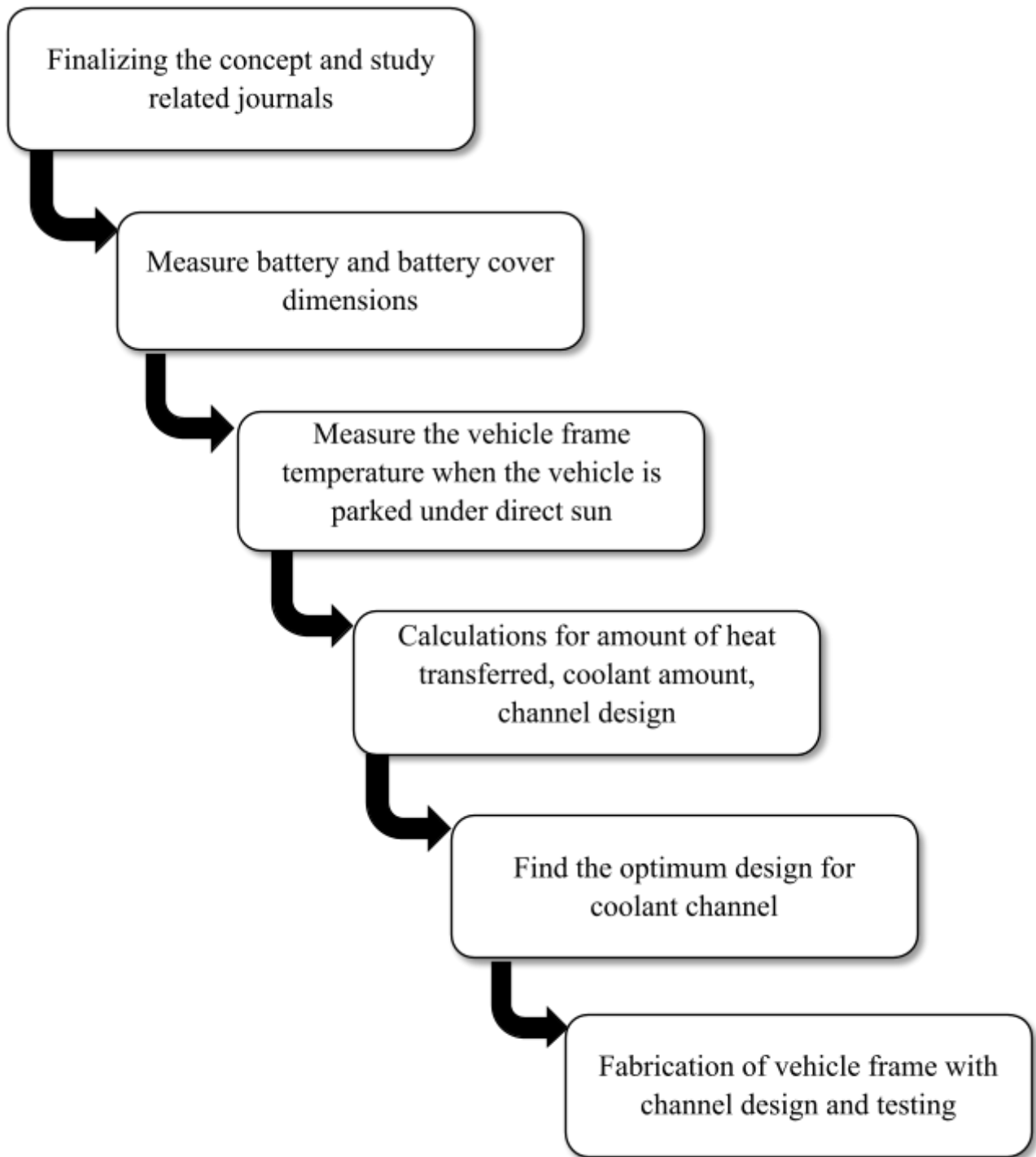


Figure 3.1 Waterfall Model of Methodology

CHAPTER 4

MATERIALS REQUIRED

4.1 ARDUINO UNO

The project uses Arduino UNO board which is also an open source based on microchip ATmega328P microcontroller and developed by arduino.cc. The board is equipped with sets of digital and analogue input/output (I/O) pins that may be interfaced to various expansion board and other circuits.

In our project, we use Arduino to measure the temperature and control the pump operation.

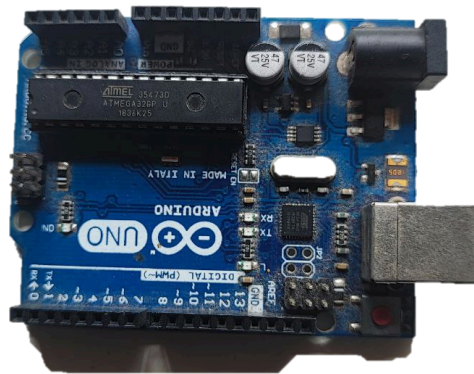


Figure 4.1 Arduino UNO

4.2 LM 35

LM 35, a semiconductor temperature sensor, is chosen for this project. It has an output voltage that is proportional to the Celsius temperature. It does not require any external calibration or trimming and maintains an accuracy of $\pm 0.4^{\circ}\text{C}$ at room temperature and $\pm 0.8^{\circ}\text{C}$ over a range of 0°C to $+100^{\circ}\text{C}$.

We used LM35 sensor to measure the temperature of the battery cover and battery when parked under direct sun. And to provide signal to the Arduino when the battery is above 35°C .



Figure 4.2 LM 35

4.3 BATTERY

A battery is power source consisting of one or more electrochemical cells. Battery is a device that convert chemical energy directly into electrical energy. Every battery (or cell) has a cathode, or positive plate, and an anode, or negative plate. The electrode materials and the electrolyte are chosen and arranged so that sufficient electromotive force (measured in volts) and electric current (measured in amperes) can be developed between the terminals of a battery to operate lights, machines, or other devices. Since an electrode contains only a limited number of units of chemical energy convertible to electrical energy, it follows that a battery of a given size has only a certain capacity to operate devices and will eventually become exhausted. Here 12v battery is used to operate the pump. Battery is charged using solar panel.



Figure 4.3 Battery

4.4 COPPER TUBES

The copper tube is used as a path for the refrigerant and coolant to flow between system components and to contain it from escaping to the atmosphere. Copper as a metal has highly anti-corrosive properties compared to aluminium. During the cooling process, pipes encounter air which causes oxidation within these pipes. Copper can better handle oxidation and corrosion for longer periods ultimately gives air conditioners a longer lifespan. We use copper tube for the channel design of cooling system.



Figure 4.4 Copper tubes

4.5 PUMP

The pump is the heart of the cooling system, it pushes coolant from the reservoir through the coolant system, into the channel. We are using a 18W wiper pump to circulate the coolant.



Figure 4.5 Pump

4.6 SOLAR PANEL

A solar panel is a collection of solar (or photovoltaic) cells, which can be used to generate electricity through photovoltaic effect. Solar panels collect clean renewable energy in the form of sunlight and convert that light into electricity which can then be used to provide power for electrical loads. We are using a 10-Watt solar panel to charge the 18-Watt battery which is used to provide electrical energy for the pump.



Figure 4.6 Solar Panel

4.7 ETHYLENE GLYCOL SOLUTION

The primary purpose of glycol is to help the system stay as consistently cold as possible without freezing. When glycol is mixed with water, the freezing point of the water drops as low as -60 degrees Fahrenheit. It acts as a coolant to reduce overheating in the summer. We are using a mixture of 60 % Ethylene glycol and 40% Water.

SI. No	Properties	EG/W (60:40)	EG/W (30:70)	EG/W (20:80)	Water	EG
1	Density (kg/m ³)	1157.4	1135	1125	998.2	1111.4
2	Specific Heat C _p (J/kg-K)	3529.71	3772	3871.60	4182	2415
3	Thermal Conductivity K(W/m-K)	0.55	0.50	0.48	0.6	0.252

Table 4.1 Properties of Ethylene glycol and water mixtures



Figure 4.7 Ethylene glycol solution

4.8 RESERVOIR TANK

We are using a coolant reservoir tank which has a storage capacity of 2 litres. The pump is mounted on a bottom dent region on the reservoir tank. Ethylene glycol solution is used as coolant.



Figure 4.8 Reservoir tank

CHAPTER 5

CALIBRATION OF TEMPERATURE SENSOR

The goal of temperature sensor calibration is to verify the amount of offset from the true reading and document that offset. We used these following steps to calibrate LM35 and DHT11 temperature sensor using calibrated thermometer (range 0°C to 42°C).

- 1) Make water warm to 40°C by constantly measuring the temperature using calibrated thermometer.
- 2) Now transfer the water to a different container and verify the water is in 40°C using calibrated thermometer.
- 3) Now place the LM35 and DHT11 temperature sensor around the container.
- 4) Note the readings from LM35, DHT11 and calibrated thermometer.
- 5) Now allow the water to cool 2°C through natural convection and note the value
- 6) Now repeat the same experiment, until it reaches 30°C.
- 7) Now repeat the same experiment in reverse, until it reaches 40°C.

5.1 READINGS

S.NO	Calibrated thermometer (°C)	LM35 (°C)	Difference (°C)	Thermistor (°C)	Difference (°C)
1	40.72	43.6	2.88	37.7	3.02
2	36.17	39.02	2.85	33.1	3.07
3	34.70	37.56	2.86	31.8	2.90
4	32.91	35.72	2.75	29.9	3.01
5	30.51	33.22	2.71	27.6	2.91
6	33.30	36.17	2.87	32.3	2.90
7	35.40	38.19	2.79	32.3	3.10
8	36.41	39.23	2.82	33.4	3.01
9	39.72	42.51	2.79	36.8	2.92

Table 5.1 Readings of LM35 Thermistor and calibrated thermometer

5.2 CALCULATION OF ERROR PERCENTAGE

Sensor error is the deviation of the measured value from the actual value of the property being measured. Real value can be obtained by subtracting the error percentage value from measured value.

5.2.1 ERROR PERCENTAGE FOR LM35 SENSOR

$$\text{Error percentage} = \frac{| \text{measured value} - \text{real value} |}{\text{real value}} \times 100 \%$$

- i. $\frac{43.6-40.72}{40.72} \times 100\% = 7.07\%$
- ii. $\frac{39.02-36.17}{36.17} \times 100\% = 7.87\%$
- iii. $\frac{37.56-34.70}{34.70} \times 100\% = 8.24\%$
- iv. $\frac{35.72-32.91}{32.91} \times 100\% = 8.35\%$
- v. $\frac{33.22-30.51}{30.51} \times 100\% = 8.88\%$
- vi. $\frac{36.17-33.30}{33.30} \times 100\% = 8.61\%$
- vii. $\frac{38.19-35.40}{35.40} \times 100\% = 7.88\%$
- viii. $\frac{39.23-36.41}{36.41} \times 100\% = 7.74\%$
- ix. $\frac{42.51-39.72}{39.72} \times 100\% = 7.02\%$

$$\text{Mean Error percentage} = \frac{71.66}{9} = 7.41\%$$

5.2.2 THERMISTOR ERROR PERCENTAGE

- i. $\frac{37.7-40.72}{40.72} \times 100\% = 7.41\%$
- ii. $\frac{33.1-36.17}{36.17} \times 100\% = 8.48\%$
- iii. $\frac{31.8-34.70}{34.70} \times 100\% = 8.35\%$

- iv. $\frac{29.9-32.91}{32.91} \times 100\% = 9.14\%$
- v. $\frac{27.6-30.51}{30.51} \times 100\% = 9.53\%$
- vi. $\frac{30.4-33.30}{33.30} \times 100\% = 8.70\%$
- vii. $\frac{32.3-35.40}{35.40} \times 100\% = 8.76\%$
- viii. $\frac{33.4-36.41}{36.41} \times 100\% = 8.27\%$
- ix. $\frac{36.8-39.72}{39.72} \times 100\% = 7.35\%$

$$\text{Mean Error percentage} = \frac{75.99}{9} = 8.44\%$$

5.3 HYSTERESIS LOSS

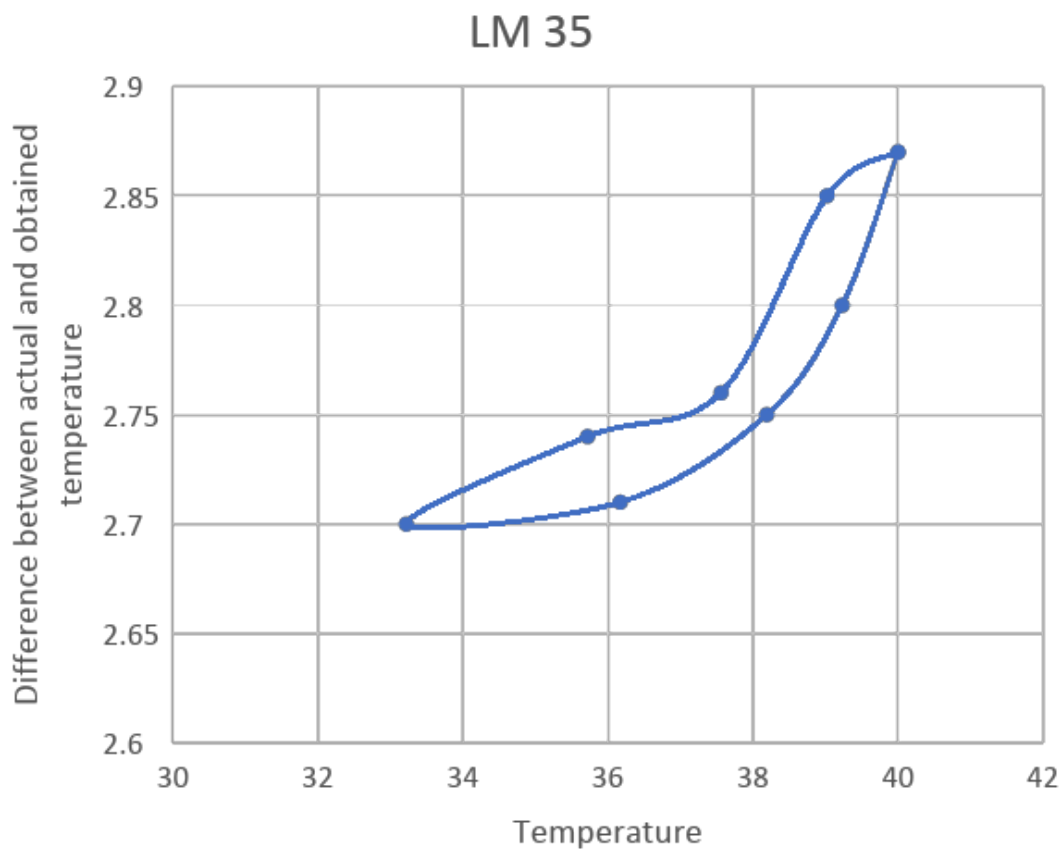


Figure 5.1 Hysteresis loss for LM35

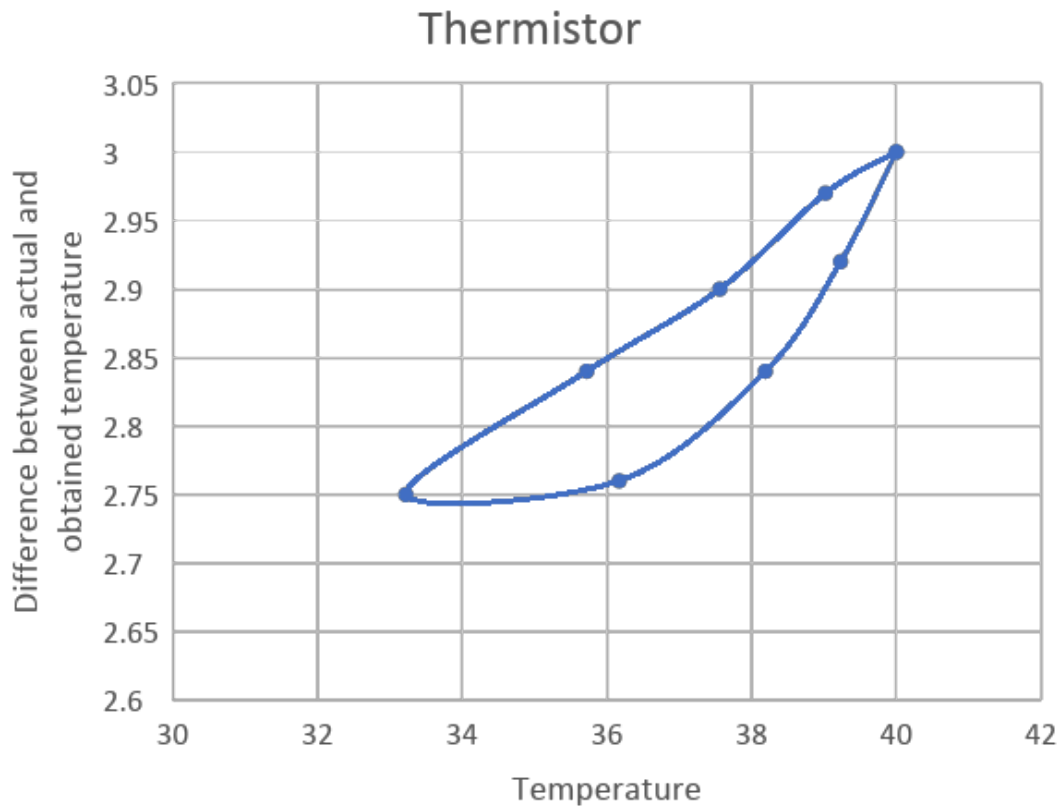


Figure 5.2 Hysteresis loss for Thermistor

5.4 INFERENCE

- i. LM35 sensor is preferred for measuring temperature because it has less mean error percentage compared to DHT11.
- ii. From the Hysteresis loss graph, we observed that LM35 Sensor has less hysteresis loss than thermistor (DHT11).
- iii. LM35 sensor has less self-heating temperature.
- iv. DHT11 sensor takes longer time to attain stability.
- v. Repeatability of the LM35 sensor is more than DHT11 sensor

CHAPTER 6

ARDUINO CODING

6.1 SOFTWARE REQUIREMENTS

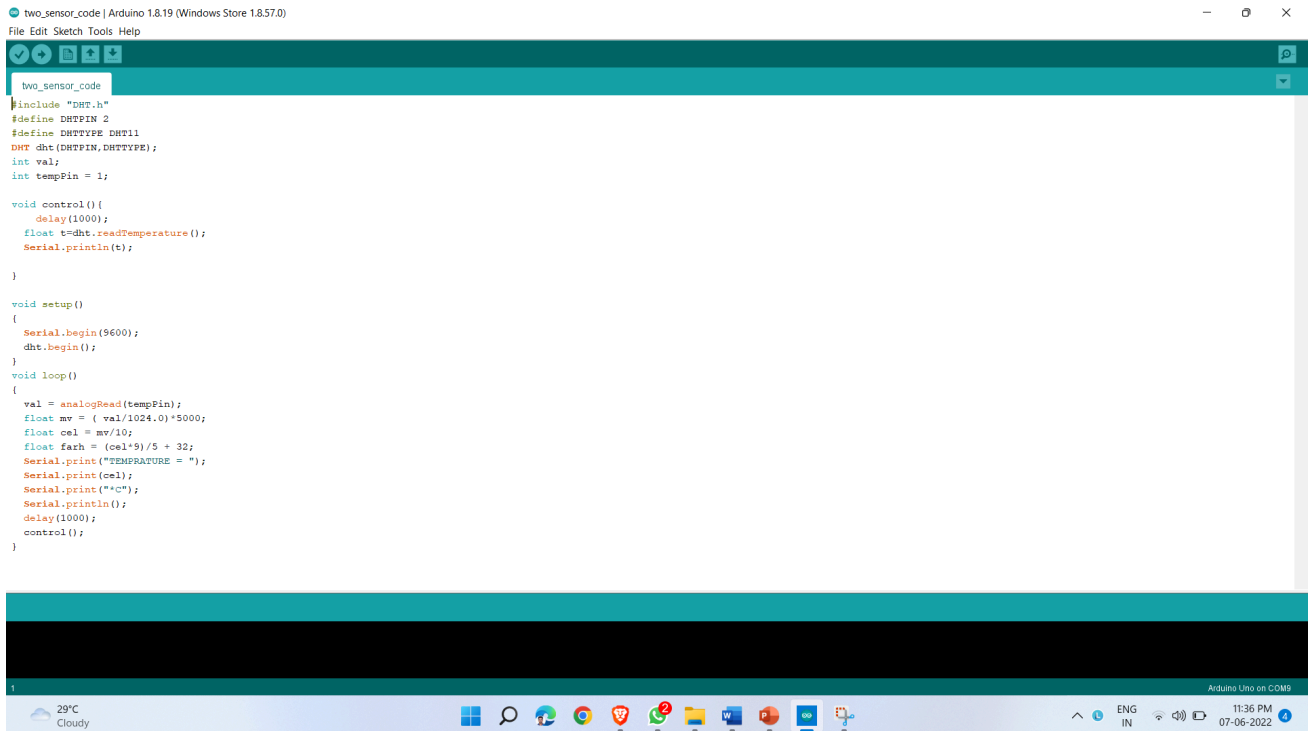


Figure 6.1 Arduino IDE

The Arduino Integrated Development Environment or Arduino Software (IDE) - contains a text editor for writing code, message area, text console, toolbar with buttons for common functions and a series of menus. It connects to the Arduino hardware to upload programs and communicate with them. Programs written using Arduino Software (IDE) are called sketches. These sketches are written in the text editor and are saved with the file extension (.ino). The message area gives feedback while saving and exporting and displays errors. The console displays text output by the Arduino Software (IDE), including complete error messages and other information.

6.2 ARDUINO CIRCUIT CONNECTION

We used an 8-sensor array to measure the temperature of the vehicle battery cover and the battery, positioned around at different locations when parked under

direct sun. The V_{cc} and GND pins of each sensor is connected to bread board. Analog signals from each sensor are converted to corresponding voltage signals and converted to temperature value by Arduino UNO. Outputs are obtained from the serial monitor. Starting from 11:00 am, we have taken readings for every 30 minutes up to 3:00 pm.

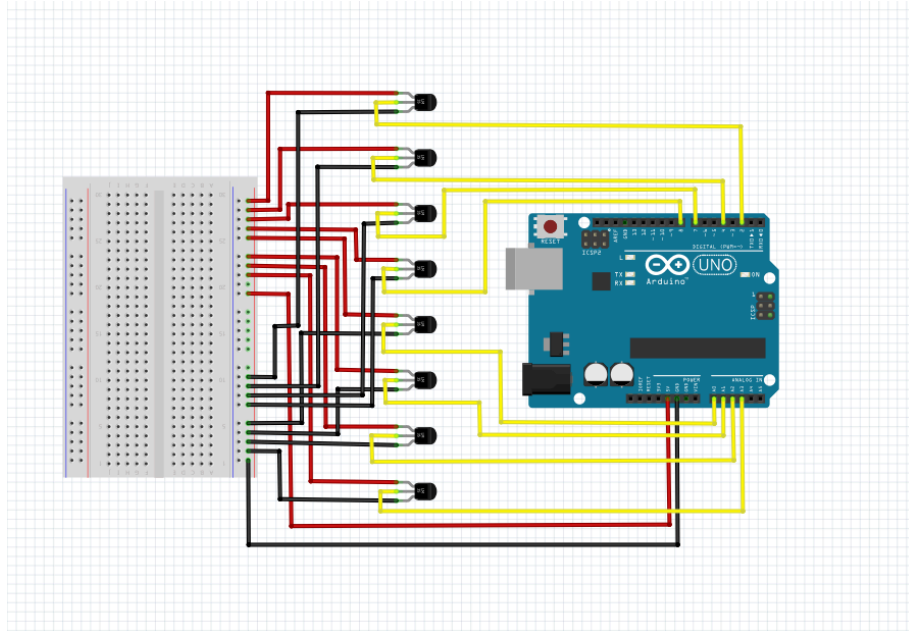


Figure 6.2 LM35 temperature sensor array using Arduino UNO

6.3 ARDUINO SOURCE CODE

This code is developed in C language and compiled successfully without error and uploaded in Arduino UNO board with ATmega328P microcontroller.

```
#define LM35 A0
#define LM36 A1
#define LM37 A2
#define LM38 A3
#define LM39 A4
#define LM40 A5
#define LM41 2
#define LM42 3
float lm_value1;
```

```

float lm_value2;
float lm_value3;
float lm_value4;
float lm_value5;
float lm_value6;
float lm_value7;
float lm_value8;
float tempc1;
float tempc2;
float tempc3;
float tempc4;
float tempc5;
float tempc6;
float tempc7;
float tempc8;
void setup()
{
    Serial.begin(9600);
}
void loop()
{
    lm_value1 = analogRead(LM35);
    lm_value2 = analogRead(LM36);
    lm_value3 = analogRead(LM37);
    lm_value4 = analogRead(LM38);
    lm_value5 = analogRead(LM39);
    lm_value6 = analogRead(LM40);
    lm_value7 = analogRead(LM41);
    lm_value8 = analogRead(LM42);

```

```
tempc1 = (lm_value1 * 500) / 1023;
tempc2 = (lm_value2 * 500) / 1023;
tempc3 = (lm_value3 * 500) / 1023;
tempc4 = (lm_value4 * 500) / 1023;
tempc5 = (lm_value5 * 500) / 1023;
tempc6 = (lm_value6 * 500) / 1023;
tempc7 = (lm_value7 * 500) / 1023;
tempc8 = (lm_value8 * 500) / 1023;
Serial.print("t1 = ");
Serial.print(tempc1);
Serial.print(" ");
Serial.print("t2 = ");
Serial.print(tempc2);
Serial.print(" ");
Serial.print("t3 = ");
Serial.print(tempc3);
Serial.print(" ");
Serial.print("t4 = ");
Serial.print(tempc4);
Serial.print(" ");
Serial.print("t5 = ");
Serial.print(tempc5);
Serial.print(" ");
Serial.print("t6 = ");
Serial.print(tempc6);
Serial.print(" ");
Serial.print("t7 = ");
Serial.print(tempc7);
Serial.print(" ");
```

```
Serial.print("t8 = ");  
Serial.print(tempc8);  
Serial.print(" ");  
Serial.println();  
delay(10000);  
}
```

CHAPTER 7

TEMPERATURE MEASUREMENT ON BATTERY COVER WHEN PARKED UNDER DIRECT SUN

7.1 AMPERE ZEAL

Ampere Zeal runs on a battery of 60 V with capacity of 30 Ah. The Li-ion battery sits on top of the battery cover. There is a clearance of 2.5 mm between the battery cover and the battery. The top of the battery is left open, there is a clamp which holds the battery in position with the battery cover. The battery cover is positioned at an angle of 45° with the vehicle frame. Rubber padding is provided in between the sides of the battery cover and battery.

Condition for Lithium-ion battery	Temperature range
Operating temperature	15 – 35 °C
Maximum operating temperature	0 - 45 °C (charge)
	-20 – 45 °C (discharge)
Storage temperature	-10 °C to 35 °C

Table 7.1 Temperature range of ampere zeal battery on different condition



Figure 7.1 Battery compartment

7.2 ACTUAL IMPLEMENTATION

We have placed eight LM35 temperature sensor on the different position around the vehicle battery cover, to measure the amount of heat transferred from it to the battery, when the vehicle is parked under direct sun. T1 and T2 are placed on top of the battery to measure how much heat is transferred through convection and radiation. T3, T4, T5, T6, T7 and T8 are placed on the outer side of the battery cover. From the readings obtained, the amount of heat transferred due to both side of the battery cover is comparatively higher than heat transferred from bottom of the battery cover and heat tranferred from the bottom of the boot space compartment to the top of the battery.

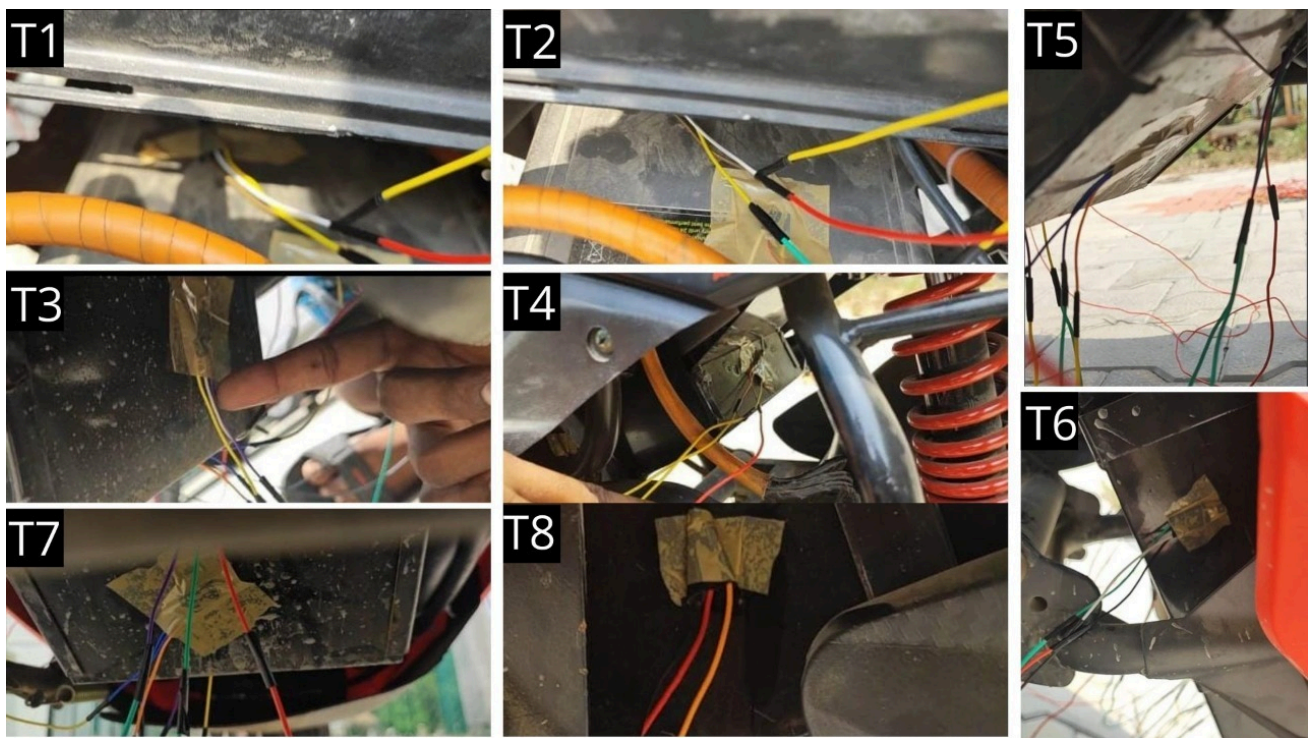


Figure 7.1 Implementation of LM35 sensor array on the vehicle

7.3 READINGS

The readings were taken on the day when there was clear sun, and the weather was reported to reach a maximum temperature of 36°C on that day. The vehicle was parked under direct sun from 10:00 am in the morning. We have started recording the temperature measurements from 11:00 am in the morning. We took reading up to 3 pm

where the temperature started to decrease after reaching maximum temperature in 1:30 pm.

Temp Time	T1 °C	T2 °C	T3 °C	T4 °C	T5 °C	T6 °C	T7 °C	T8 °C
11.00 am	35.10	35.50	35.66	35.40	35.96	35.67	35.21	35.28
11.30 am	36.30	36.68	36.90	36.80	37.15	36.92	35.90	35.95
12.00 pm	37.60	37.80	38.10	38.20	38.40	37.89	36.60	36.60
12.30 pm	38.95	38.05	38.26	38.90	39.20	38.35	37.02	37.97
1.00 pm	39.30	39.40	39.32	37.96	39.31	39.56	38.45	38.65
1.30 pm	39.90	39.87	39.50	38.81	39.95	39.89	38.80	39.58
2.00 pm	38.50	38.80	38.86	38.47	39.28	39.30	38.48	38.88
2.30 pm	38.07	38.13	38.60	37.94	38.38	38.87	38.08	38.19
3.00 pm	37.50	37.60	37.18	37.21	37.67	38.19	37.60	37.85

Table 7.1 Temperature readings

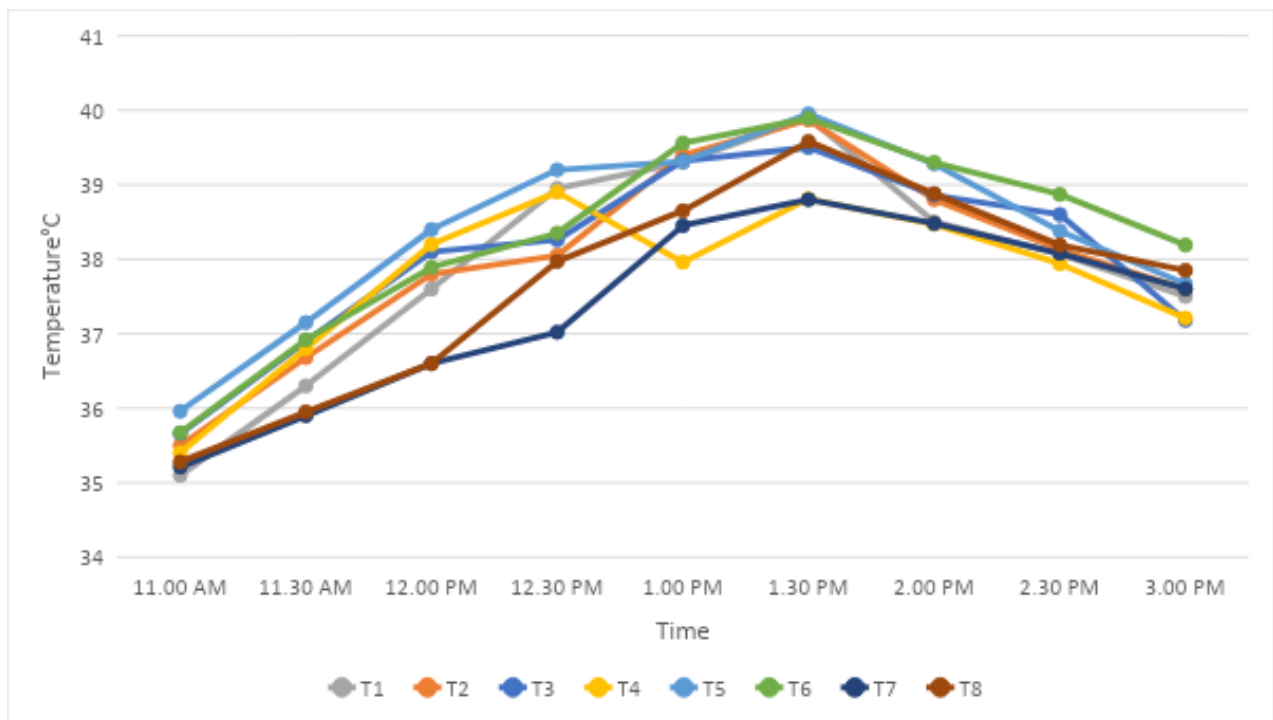


Figure 7.1 Graph of temperature readings

7.4 INFERENCE:

- i. Increase in temperature of (3-4) °C is observed from the ideal battery temperature (35 °C) when parked in direct sunlight (12.30-1.00 pm) compared to other condition (shed and under tree).
- ii. It is observed that the left and right side of the battery has more temperature than bottom of the battery.
- iii. The amount of heat transferred through battery cover (left and right side) is higher than heat transferred through radiation from the road to the bottom of the battery cover and heat transferred through convection from the bottom of the seat compartment to the top of the battery surface.

CHAPTER 8

CALCULATION

8.1 AMOUNT OF COOLING REQUIRED UNDER PARKED CONDITION

Heat is transferred through three modes: conduction, convection, radiation. In our case heat is transferred to battery through all these modes.

8.1.1 CONDUCTION

When heat transfer takes place in a medium from one point to the other only due to the vibrations of the medium particles, without their net motion, it is known as conduction. When a solid is heated to one end, the energy of the atoms or molecules present on that part increases, and they start vibrating faster at their mean position. These high energy atoms and molecules collide with their neighbouring particles and transfer their energy to them. This process continues until the whole solid is heated uniformly. Heat Transfer via conduction mainly occurs in solids. It does take place in liquids but is very insignificant.

8.1.2 COVECTION

Liquids and gases are poor conductors of heat. The transfer of heat in fluids (liquids and gases) occurs mainly by the process of convection because particles of fluids are loosely packed and are free to move from one place to another place. In the convection method of heat transfer, the particles of a fluid (liquid and gas), after gaining heat energy, move from the hotter region to the colder region of the fluid.

8.1.3 RADIATION

Thermal radiation or simply radiation is a mode of heat transfer that does not require any material medium to transfer heat. It can occur in a vacuum too, and it is the fastest mode of heat transfer. The radiation mode of heat transfer happens through

photons. All hot bodies emit heat radiations in all directions. Objects on which these heat radiations fall experience a sense of warmth. Dark objects are good absorbers as well as good emitters of heat. On the other hand, light-coloured objects are good reflectors of heat.

So, first amount of heat transferred through conduction, convection, radiation can be calculated. From this amount of coolant required to reduce the heat transferred can be calculated.

8.2 CALCULATION FOR AMOUNT OF HEAT TRANSFERRED FROM VEHICLE FRAME AND BATTERY COVER:

The dimensions of the (right / left) battery cover is 35cm in length and 11 cm height with 2 mm thickness.

T_1 = Temperature on the steel surface 40 °C.

T_2 = Temperature on the battery 35 °C.

t = thickness 2 mm

The rate of convection,

$$Q = h_c \times A \times (T_2 - T_1)$$

The dimensions of the (bottom) battery cover is 35cm in length and 18 cm breadth with 2 mm thickness.

T_1 = Temperature on the surface 38 °C.

T_2 = Temperature on the battery 37.6 °C.

t = thickness 2 mm

The rate of conduction,

$$Q = \frac{k \times A \times \Delta T}{t}$$

$$k = 45.94 \text{ W/ m K (steel)}$$

$$Q = \frac{45.94 \times 0.35 \times 0.18 \times 0.4}{0.002}$$

$$Q = 463.07 \text{ J/s}$$

The dimensions of the battery clamp are 21cm in length and 2 cm breadth with 2.5 mm thickness.

T_s = Temperature on the clamp 40 °C.

T_f = Temperature on the Battery 39 °C.

t = thickness 2.5 mm

The rate of conduction,

$$Q = \frac{k \times A \times \Delta T}{t}$$

$k = 52 \text{ W/mK}$ (for cast iron)

$$Q = \frac{52 \times 0.21 \times 0.02 \times 1}{0.0025}$$

$$\mathbf{Q = 87.36 \text{ J/s}}$$

The dimensions of the side mount is 25 cm in length and 2.3 cm breadth with 4 mm thickness.

T_s = Temperature on the clamp 45 °C.

T_f = Temperature on the battery 38 °C.

The rate of convection,

$$Q = h_c \times A \times (T_s - T_f)$$

$h_c = 7.9 \text{ W/ m}^2 \text{ /K}$ (for iron)

$$Q = 7.9 \times 0.25 \times 0.023 \times 7$$

$$\mathbf{Q = 0.3179 \text{ J/s}}$$

The dimensions of the battery boot space is 40 cm × 35 cm

T_s = Temperature on the clamp 42 °C.

T_f = Temperature on the battery 38 °C.

The rate of convection,

$$Q = h_c \times A \times (T_s - T_f)$$

$h_c = 10 \text{ W/ m}^2 \text{ /K}$ (for air)

$$Q = 10 \times 0.40 \times 0.35 \times 4$$

$$\mathbf{Q = 5.6 \text{ J/s}}$$

Radiation from the bottom of the boot space with dimension 40 cm × 35 cm.

T_r = Temperature on the clamp 42 °C.

T_c = Surrounding temperature 34 °C.

σ is Stefan's constant $5.67 \times 10^{-8} \text{ W/m}^2\text{K}^4$.

e is emissivity 0.84 for plastic.

The rate of radiation,

$$Q = e \times \sigma \times A \times (T_r - T_c)^4$$

$$Q = 0.84 \times 5.67 \times 10^{-8} \times 0.40 \times 0.35 \times (8)^4$$

$$Q = 5.334 \times 10^{-8} \text{ J/s}$$

Specific heat (C_p) of ethylene glycol = 2.433 J/g-°C

Total Heat transfer from vehicle frame to the battery,

$$Q = (2 \times 282.9) + 463.07 + 87.36 + (3 \times 0.3179) + 5.6 + 5.334 \times 10^{-8}$$

$$Q = 1122.46 \text{ W}$$

8.2.1 ANSYS SIMULATION OF HEAT TRANSFER FROM VEHICLE FRAME AND BATTERY COVER

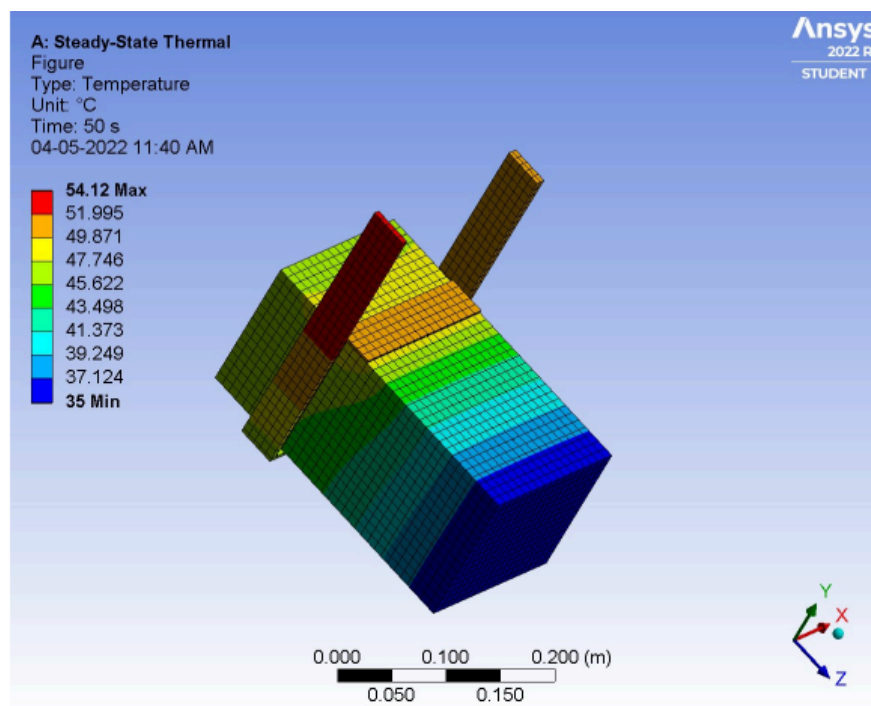


Figure 8.1 Conductive heat transfer from clamp to the battery

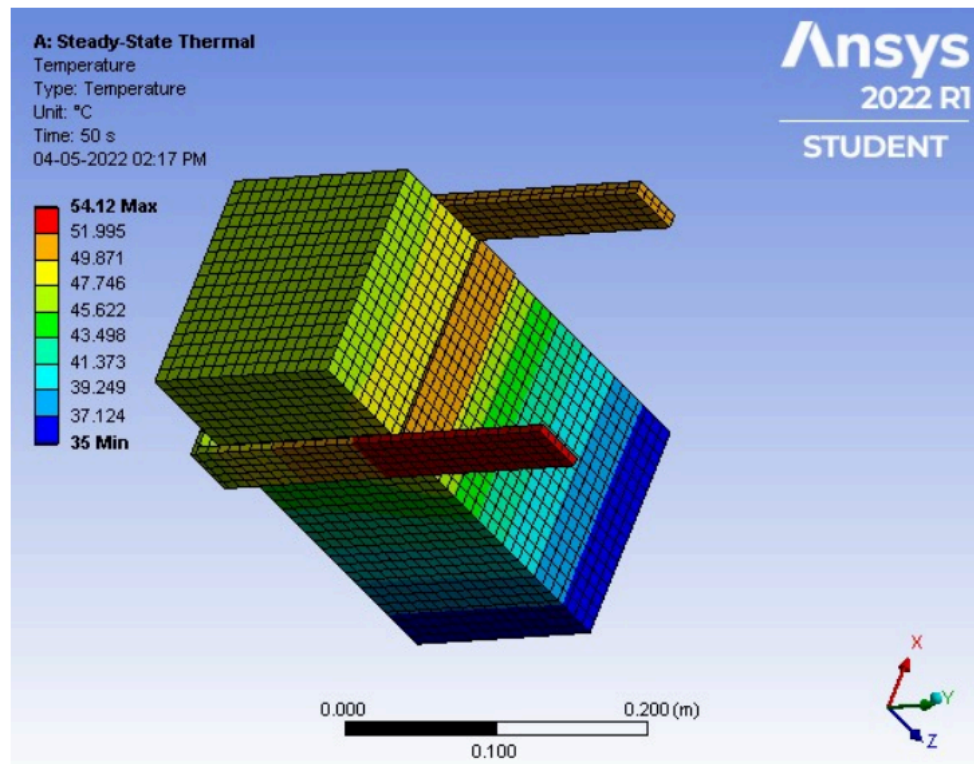


Figure 8.2 Convective heat transfer from metal frame to the battery

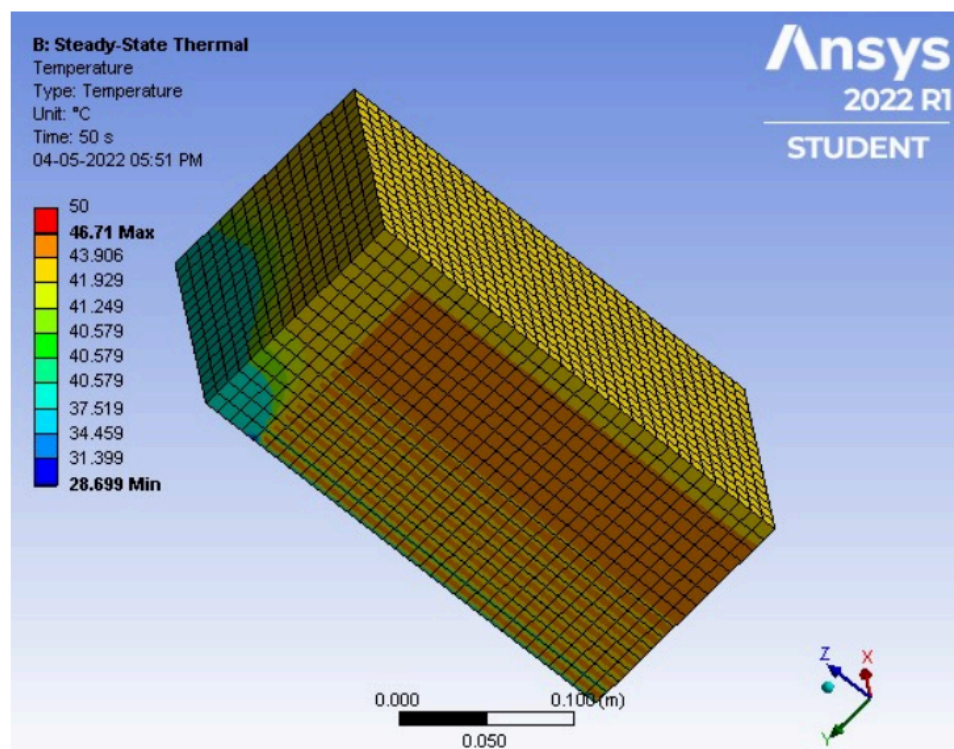


Figure 8.3 Convective heat transfer from battery cover to battery

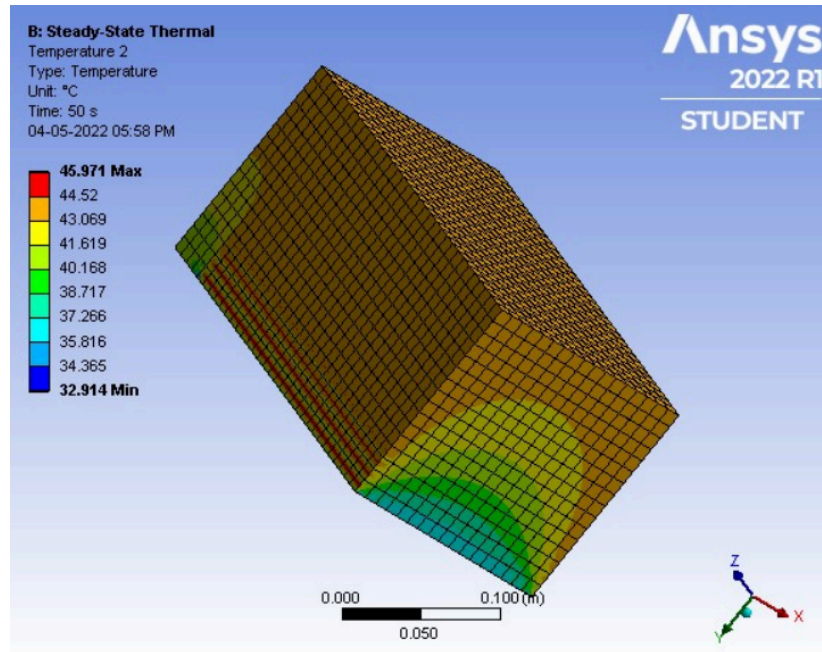


Figure 8.4 Radiation heat transfer from boot space compartment to battery

8.3 CALCULATION OF TOTAL AMOUNT OF HEAT TRANSFERRED

Specific heat, C_p (water ethylene glycol) = 3529.71 J/Kg-K

Assuming inlet temperature of the coolant = 24 °C

Outlet temperature of the coolant = 28 °C

Total equivalent length of the channel = 1.6 m

Density (water ethylene glycol) = 1157.4 Kg/m³

Radius of the pipe (m) = 0.003 m

Diameter of the pipe = 0.006 m

Convective coefficient, h_c (Cu to coolant) = 340

Area of contact = $\pi \times d \times l$

Area of contact = 0.030159 m²

Wall temperature = 40 °C

Required temperature = 35 °C

$$\text{Mass flow rate, } m = \frac{hc \times A \times (T_{out} - T_{in})}{Cp \times (T_{wall} - T_{req})}$$

$$= 0.0048 \text{ kg/s}$$

$$\mathbf{m = 0.288 \text{ litre / minute}}$$

$$\begin{aligned}\text{Velocity, } v &= \frac{\text{Mass flow rate}}{\text{Density} \times \text{area of cross section}} \\ &= \frac{0.0048}{1157.4 \times 0.000028} \\ \mathbf{v} &= \mathbf{0.146 \text{ m/s}}\end{aligned}$$

8.4 CALCULATION FOR AMOUNT OF COOLANT REQUIRED UNDER WORKING CONDITION

$$\text{Area of contact} = 0.030159 \text{ m}^2$$

$$\text{Battery temperature under high load} = 44.98 \text{ }^\circ\text{C}$$

$$\text{Required temperature} = 35 \text{ }^\circ\text{C}$$

$$\begin{aligned}\text{Mass flow rate, } m &= \frac{h_c \times A \times (T_{out} - T_{in})}{Cp (T_{wall} - T_{req})} \\ &= 0.0095 \text{ kg/s} \\ \mathbf{m} &= \mathbf{0.575 \text{ litre / minute}}\end{aligned}$$

$$\begin{aligned}\text{Velocity, } v &= \frac{\text{Mass flow rate}}{\text{Density} \times \text{Area of cross section}} \\ &= \frac{0.0095}{1157.4 \times 0.000028} \\ \mathbf{v} &= \mathbf{0.2931 \text{ m/s}}\end{aligned}$$

8.5 CALCULATION FOR PUMP POWER

Darcy – Weisbach equation: It relates the head loss, or pressure loss, due to friction along a given length of pipe to the average velocity of the fluid flow for an incompressible fluid.

$$\begin{aligned}\text{Friction factor, } f' &= \frac{16}{Re \text{ (for laminar flow)}} \\ &= \frac{16}{1655} = 0.0096 \text{ (dimensionless quantity)} \\ f &= 4f' \\ &= 4 \times 0.0096 \\ &= 0.03 \\ h_f &= f \times \frac{LV^2}{D^2 g}\end{aligned}$$

where, h_f -friction head loss

L -length

V -velocity

f –friction factor

D –diameter

g –gravity

$$\text{Length} = 9 \text{ cm}$$

$$D = 6 \text{ mm}$$

$$V = 1.04 \text{ m/s}$$

$$h_f = \frac{0.03 \times 0.09 \times 1.04 \times 1.04}{0.006 \times 2 \times 9.81}$$

$$\text{Head loss, } h_f = 0.024$$

8.5.1 LOSS OF HEAD DUE TO BEND IN PIPE

When there is any bend in a pipe, the velocity of flow changes due to which the flow from the boundary and formation of eddies takes place. Thus, the energy is lost. Loss of head in pipe due to bend is expressed as:

$$h_b = \frac{k V^2}{2g}$$

where, h_b is the head loss due to bend, V = velocity of flow, k = coefficient of bend.

$$k = 0.2$$

$$V = 1.04 \text{ m/s}$$

$$h_b = \frac{0.2 \times 1.04^2}{2 \times 9.81}$$

$$h_b = 0.011$$

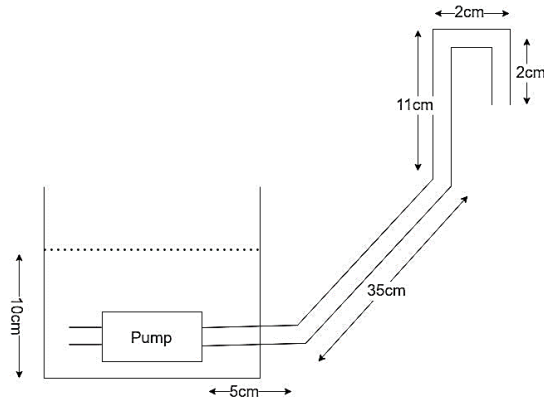


Figure 8.5 Tube measurements from pump

$$\begin{aligned} \text{Total Pressure drop} &= (n \times \text{Head loss due to straight line}) + (n \times \text{Head loss due to bends}) \\ &= \mathbf{0.447 \text{ m}} \end{aligned}$$

8.5.2 CALCULATION FOR PUMP POWER

$$\text{Total vertical head} = 0.43 \text{ m}$$

$$\text{Total pipe length} = 0.55 \text{ m}$$

$$\text{Pipe diameter} = 8 \text{ mm}$$

$$\text{Friction factor} = 0.03$$

$$\text{Required volumetric flow rate, } Q = 4.8 \text{ m}^3/\text{s}$$

$$\text{Velocity of the water in pipe, } v = 0.17 \text{ m/s}$$

$$\text{Liquid level, } z_1 = 6 \text{ cm}$$

$$z_2 = 43 \text{ cm}$$

$$\text{Frictional head loss} = 0.0162 \text{ m}$$

$$\text{Manometric head} = 0.4477 \text{ m}$$

$$\text{Efficiency of the pump} = 95 \%$$

$$\text{Power required} = \frac{\rho \times 9.81 \times Q \times h}{n} = 23 \text{ Mw}$$

This is the minimum power required to circulate the coolant with the obtained head loss. Since the minimum available standard pump is 18-watt pump. We used 18W pump in our system.

CHAPTER 9

DESIGN AND FABRICATION

9.1 DESIGN OF COOLING CHANNEL ON BATTERY COVER

We have designed a cooling system for Ampere Zeal which runs on a Battery 60V, 30Ah Lithium Battery. The battery is placed in the battery cover which is fixed to the vehicle seat chassis and holders, at 45° inclination to the ground. We designed a channel which is kept at -45° inclination, so that the gravity effect on fluid flow is negligible. This makes the channel straight, when looked from side view. Reservoir tank is attached to the back of the extended battery cover. It minimizes the heat transfer from the ground to the bottom of the battery cover. The reservoir is mounted to the battery cover by bolts. The pump is located at the bottom of the reservoir.



Figure 9.1 Ampere zeal vehicle

9.2 FABRICATED DESIGN



Figure 9.2 a) Battery cover with cooling system – Side View



Figure 9.2 b) front view



Figure 9.2 c) back view

The copper tube is embraced to the steel plate. The dimension of the fabricated steel plate is 184 mm × 143 mm × 337 mm. The dimension of the steel plate is made so that it can accommodate both battery and copper tube. Additional 1 mm clearance is provided at both sides of the battery cover. The reservoir is attached to the back of the steel plate using bolts. The connection between the copper tube and the pump is made using soft plastic hose. A clamp is provided at the top to hold the battery in place with the battery compartment.

9.3 CIRCUIT CONNECTIONS AND CODING

9.3.1 CIRCUIT CONNECTIONS

A LM35 temperature is placed on the battery cover to constantly measure the temperature of it, so whenever the temperature rises above 35°C the Arduino sends signal to one-way relay making it closed circuit, this will make the pump circulate the

coolant required to cool the battery cover. Thus, reducing the amount of heat transferred from battery cover to the battery.

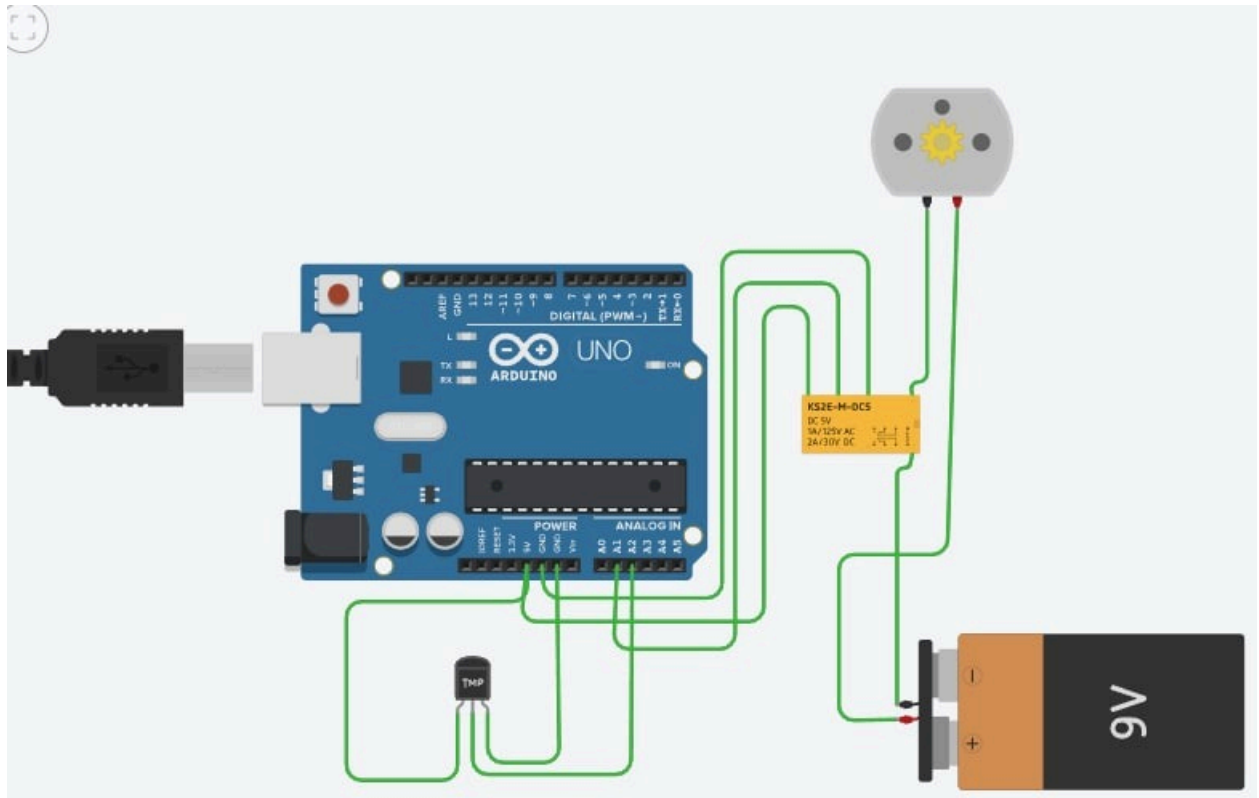


Figure 9.3 Circuit connection of LM35 sensor and pump

9.3.2 ARDUINO CODING

```
int temppin=A2;

const int RELAY=A5;

void setup() {

  pinMode(RELAY,OUTPUT);

  pinMode(temppin,INPUT);

  Serial.begin(9600);

}
```

```
void loop() {  
  float val=analogRead(temppin);  
  float mv=(val/1024.0)*5000;  
  float t=mv/10-2.85;  
  delay(2000);  
  Serial.println(t);  
  if(t>35){  
    digitalWrite(RELAY,LOW);  
  }  
  else{  
    digitalWrite(RELAY,HIGH);  
  }  
}
```


CHAPTER 10

RESULTS AND CONCLUSION

10.1 READINGS AFTER COOLING SYSTEM INSTALLED

At the beginning of the experiment, we made sure that the battery was 40 °C and measured the time required by the designed cooling system to cool down battery to 35°C. We have chosen the peak temperature time, that is 1:30 pm and 2:00 pm and tested it.



Figure 10.1 a) Battery cover with cooling system – top view



Figure 10.1 b) Battery cover with cooling system – side view

Test taken at 1:30 pm:

Time	Temperature reduction by cooling system on 1:30 pm
1min	38.46
2min	37.95
3min	36.79
4min	35.32
5min	34.03

Table 10.1 Readings taken on 1:30 pm with fabrication installed on the battery

Test taken at 2:00 pm:

Time	Temperature reduction by cooling system on 2:00 pm
1min	38.96
2min	38.32
3min	36.89
4min	35.69
5min	34.78

Table 10.2 Readings taken on 2:00 pm with fabrication installed on the battery

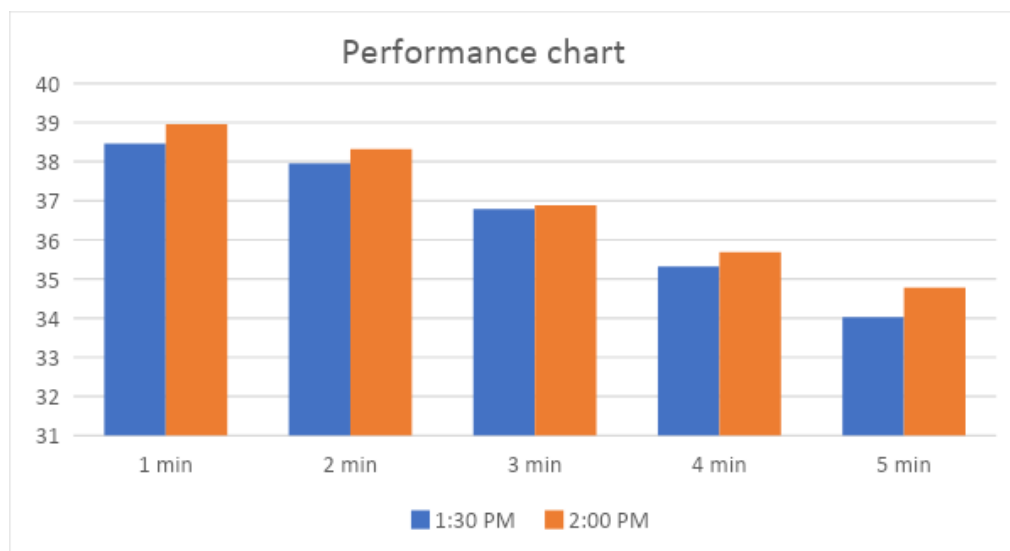


Figure 10.2 Graph of temperature readings with fabrication installed on battery

10.2 RESULTS AND DISCUSSION

As the temperature of the ethylene glycol and water mixture is also increased slightly due to the convective heat transfer from the copper tube and atmosphere, the time to operate pump for reducing the temperature of the battery cover to 35 °C is increased. This may not affect the cooling system operation since the temperature of the atmosphere and battery pack is reduced after 2:00 pm.

10.3 CONCLUSION:

In the current investigation, the temperature of the battery and the battery cover is reduced under optimum temperature of the battery with the help of the cooling system. Addition of Arduino system for the efficient working of the pump observed to be a good strategy to reduce temperature of the battery when parked under sun.

- Our system effectively reduces the temperature rise in battery due to heat transfer from the vehicle frame and battery cover, when parked under direct sun.
- By keeping the temperature within a narrow optimum level, it helps to lengthen the battery pack lifetime.
- Pump is operated using solar power, so no additional energy is drawn from the vehicle battery to circulate coolant through the channels.
- By keeping the battery under 35°C, performance and the safety of the battery is increased.

10.4 FUTURE SCOPE

- This cooling system can be used in drone to keep the battery under ideal temperature by doing some modifications in channel design.
- The same cooling system can be used in electric vehicles while vehicle is in running condition by adding radiator.
- Efficiency of the cooling system can be changed by varying the coolant and materials used in the channel.

- Weight of the cooling system can be reduced by using proper phase changing material. So, there will be no need for solar panel, reservoir, secondary battery, pump.
- This project can be implemented in all the electric vehicles by changing the channel design with respect to the vehicle battery.
- Further work will focus on the optimization of the cooling channel and its operating conditions

10.5 COST REPORT

Serial No.	Material	Cost (INR)
1	Copper tube (4 meters)	3000
2	Pump	350
3	Reservoir tank	300
4	Ethylene glycol	240
5	Solar plate	900
6	Arduino UNO	500
7	Relay	100
8	Steel plate	1000
9	LM35	560
10	Battery	850
11	Other charges	3000
Total		10720

Table 10.3 Cost report

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