TRIBHUVAN UNIVERSITY
INSTITUTE OF ENGINEERING
PULCHOWK CAMPUS

A PROJECT PROPOSAL

ON

TOPOLOGY OPTIMIZATION OF COLD PLATE FOR BATTERY THERMAL MANAGEMENT SYSTEM

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ABSTRACT

Cooling plates are an essential element used in active liquid cooled BTMS to keep the battery temperature within an operating range of 15 -35 °C. While employing liquid cooling using cold plates, the problems regarding temperature uniformity and pressure drop need to be addressed. Topology optimization obtains a channel structure in the cold plate that provides better cooling performance creating a trade-off between the objective functions. It does so by varying the material phase density between 0 and 1 where '0' represents fluid and '1' represents solid. This project aims to optimize the topology of cooling plate, and compare the optimized geometry with the conventional geometry in the first phase. In the second phase, a cost-effective and reliable fabrication technique will be used to produce conventional and optimized cold plates. In the third and final phase, an experimental setup will validate the results from simulation.

KEYWORDS : Battery, BTMS, Cold plate, Topology Optimization

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LIST OF ABBREVIATIONS

TO	Topology Optimization
BTMS	Battery Thermal Management System
EVs	Electric Vehicles
li-ion	Lithium-ion
PCM	Phase Change Material
RCP	Rectangular channel Cold Plate
SCP	Serpentine channel Cold Plate
TCP	Topology optimized Cold Plate
CNC	Computer Numeric Control
DC	Direct Current
CAGR	Compound Annual Growth Rate
SOC	State of Charge
FEM	Finite Element Method
CAD	Computer-Aided Design

CHAPTER 1: INTRODUCTION

1.1 Background

The availability of the conventional non-renewable energy sources is limited. Recent data indicates that the world's proven petroleum reserves stand at approximately 1.55 trillion barrels [2]. The global demand for crude oil in 2023 amounted to 102.21 million barrels per day. This prolonged dependence on the conventional sources of energy has concerned consumers for so long. Moreover, these resources are fossil based organic fuels which on combustion emit carbon residue which raises serious concern for their replacement. The recent trend has shown that the electric power can be considered as optimum source of power due to its feasibility and multiple ways of its generation. The only medium to store the generated energy is the battery which stores the energy in the form of chemical potential. There is huge classification in batteries. Lithium ion based batteries(Lithium-O2, Lithium cobalt oxide(LiCoO2), Lithium manganese oxide, Lithium iron phosphate battery(LiFePO4),Lithium titanate battery, Li sulfur battery, Li-iodine battery), Nickel-based batteries(Nickel cadmium battery, Nickel-metal-hydride battery, Nickel-iron battery, Nickel-zinc battery, Nickel-hydrogen battery), Metal-air batteries(Zinc-air battery, Iron-air battery), Lead-acid batteries, Sodium-sulfur batteries, Aluminum-ion batteries, Copper-zinc batteries, Flow batteries(Redox flow battery, Vanadium-based flow battery, Membrane-less flow battery, Dual-liquid redox battery)[3]

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The energy transition scenario has also impacted on Automobile industry. The International Energy Agency (IEA) provided detailed analysis and statistics on global EV sales, highlighting the record-breaking increase of 55 % in 2022, with over 10 million electric cars sold globally.The global electric vehicle market size is projected to increase from 538.8 biilion U.S. dollars to estimated market size of 906.7 billion dollars between 2022 and 2028[4]. The essential part of the EV is its battery which cost almost around 30-40 % of the vehicle and is a very essential component in modern day EV. Li-ion batteries are the dominant battery material used in this industry.

A lithium-ion battery (Li-ion) uses lithium ions as the primary component of its electrolyte. Lithium has the largest electrochemical potential of 3.04 V which means lithium has a very high tendency of losing electrons making it at the top of the elctrochemical series. It has several advantages over other high-quality rechargeable battery technologies. They offer one of the highest energy densities, reaching up to 300 watt-hours per kilogram (Wh/kg), compared to about 75 Wh/kg for other types. Furthermore, Li-ion cells can deliver up to 3.6 volts, which is 1.5-3 times the voltage of alternatives, making them ideal for high-power applications such as transportation (Clean Energy Institute).

While charging, the voltage from the external source in the battery generates the lithium ion in cathode(typically a lithium metal oxide) and forces it to travel towards anode(usually graphite) through an electrolyte. This phenomenon works as the accumulation of energy in the form of charge. While discharging, the polarity is reversed and now the opposite directional travel of the ion provides power to operate any devices connected with the battery. During both of these phenomenon heat generation in the battery is seen.[5]. This generation of heat causes in the reduction of the performance and reduction of life-cycle. Operating environment can also lead to the generation of unwanted heat as well. This generation of heat is to be eliminated with the proper application of the appropriate battery thermal management system(BTMS).

Appropriate thermal management system need to be applied to maintain the LIB pack. The BTMS is categorized as; Air cooled(Natural convection and Forced air cooling), Liquid Cooled(Direct cooling and Indirect cooling), Phase change materials(Organic and inorganic material), Thermoelectric element based and Hybrid cooling. Application of each of the cooling methods depends on the working condition and the performance requirement.

Air cooling is traditional approach of cooling. Natural convection offers the entry of air into the system governed with natural phenomenon without the application of the mechanical energy. In forced air cooling, fans are used to flow the air into the system ensuring cooling.

The phase change materials(PCM) have high latent heat capacity that allows them to use as coolant. This property allows them to absorb large amount of heat from the battery packs, allowing them to stay in working condition. PCM should have high latent heat capacity, higher thermal conductivity, non-toxicity, better chemical stability, and suitable temperature range for its melting. The benefit of using PCM as cooling technology is reduction in active mechanical components such as fans and pumps from the module. Organic based PCMs are carbon based compounds, typically paraffins and fatty acids which has desired thermal properties. Inorganic based PCMs are salts hydrides, metals which offers better thermal conductivity and has higher latent heat.

In immersion liquid cooling, the battery pack is completely or partially submerged into the coolant to absorb heat from the pack. Battery cells are allowed to make direct contacts with the non-conductive dielectric fluid. Hydrocarbon oils, silicone oils and fluorinated hydrocarbons are widely researched cooling fluids.

Indirect cooling applications are preferred over the immersion due to safety reasons and weight distribution issues. Using channelled aluminium cold plate, distinct tubing or pipes surrounding each module, using external cooling jackets, cooling can be done with distinct layouts and configurations[6][7]. The pump is required to circulate the coolant into the closed system, carries out the heat and releases through the radiator and the coolant is pumped again. For high temperature heat extraction, additional fans are used in the radiator to increase its performance[8]. For the maximum reduction in the operating temperature the study in the design of the cold plate is being carried on. This paper will also focus on optimizing the cooling plate based on existing computational technique in order to improve liquid cooling performance.

1.2 Problem Statement

The major problems in cold plate cooling of the battery is average temperature rise,pressure drop and lack of temperature uniformity.
Due to the widespread use of electric vehicles across various geographic regions, seasons, and times of year, the operating temperature environment for lithium-ion power batteries also varies significantly(Jaguemont, Boulon, & Dubé, 2016)[9].
Considering the discharge efficiency and cycle life, the optimal operating temperature range for a lithium-ion battery is typically 20°C to 50°C(Lv et al., 2021)[10].Also, the temperature variation among all cells should not exceed 5°C (Zhao et al. 2019)[11].
The following conditions can cause the battery temperature to rise significantly:
1.The cause and effect loop between the reaction heat and temperature rise leads to thermal runaways leading to the risk of fire or explosion.
2.The increase in total heat because of ohmic , reaction and reversible heat during the end of charging and discharging affects battery life.

While employing the BTMS for this problem using the liquid cooling there arises another significant problem of pressure drop in the channel of cold plate.The pressure difference betweeen inlet and outlet in rectangular channel cooling plate is 66.6 Pa (Mo et al., 2021)[12]. Because of this, considerable amount of energy is required to circulate the coolant in the cold plate.

The challenge of maintaining uniform temperature in battery cold plates is a critical concern in the thermal management of lithium-ion batteries. This issue stems from the uneven heat distribution within the battery, resulting in hotspots that can compromise performance and longevity. Additionally, this temperature non-uniformity is often exacerbated by pressure inconsistencies within the cooling system. Uneven pressure distribution can lead to variable coolant flow rates, further contributing to thermal imbalances and reducing the overall efficiency of the thermal management system.

1.3 Objectives

1.3.1 Main Objective

The main objective of the project is to optimize the topology of cold plate used in Battery Thermal Management System using multi-objective functions.

1.3.2 Specific Objectives

i) To design and optimize the topology of cold plate using variable density method.

ii) To analyse and compare average temperature, temperature uniformity, pressure drop of optimized geometry and traditional geometry through simulation models.

iii) To fabricate the cold plate and validate the results obtained from FEM simulation with experimental analysis.

1.4 Limitations of the projects

The following are the limitations of the project :-

1)The purity and physical properties of the aluminium(Al 6061) is not exactly of the aluminium(ALSiMg10) used in literature but very similar.

2)The manufacturing process(CNC milling) will leave some errors in the geometry.

3)The testing setup will not use the battery but the equivalent uniform heat source will be provided to the cold plate.

CHAPTER 2: LITERATURE REVIEW

2.1 Lithium ion battery

Most of the electric vehicles today use lithium ion batteries, but the chemical composition may vary. Nickel metal hydride batteries are used in computer electronics and medical equipment and hybrid EVs as well. But their high cost, high self discharge rate, high heat generation in high temperatures makes them less favourable for electric vehicles. Lead-acid batteries are reliable, recyclable, and can power high output, but their application in the field of commercial electric vehicle is restricted due to low specific energy, poor cold operation and shorter life cycle [13]. The lithium ion battery has a high voltage ,high energy density and compactness making it the ideal option for being used in EVs. Automotive lithium-ion (Li-ion) battery demand increased by about 65% to 550 GWh in 2022, from about 330 GWh in 2021, as a result of growth in EV passenger car sales, with new registrations increasing by 55% from 2021 to 2022 [14].

2.2 Heat generation in Batteries

According to Peng et al., (2020) there are four main sources of heat production in battery, reaction heat (RH),side reaction heat (SRH), joule heat (JH) and polarization heat (PH).The total heat in battery is equivalent to equation [15].

$P_{total} = P_{rh} + P_{srh} + P_{jh} + P_{ph}$

Saw et al.,(2013) investigated the main heat source during charging and discharging of a Lithium Phosphate cell and found out reaction heat was responsible for 80-85% of the total heat generation [16].According to Ma et al.,(2019) reaction heat accelerates thermal ageing and shortens the life of the battery. The cause and effect between heat generated and temperature increment leads to thermal runaway in batteries [17].Olabi et al.,(2022) mentioned a 5% variation in battery temperature can reduce its power capabilities by 10% and battery pack capacity by 1.5-2% [6].The cycle life of Lithium ion batteries decreased by 68% from 45°C to 60°C (Tete et al., 2021) [18].Many studies have been conducted to limit the battery temperature to the operating range of 15 to 35°C using Battery Thermal Management Systems (BTMS).

2.3 Need of BTMS using cold plate liquid cooling

The EV battery pack cooling system market was valued at \$2.93 billion in 2023, and it is expected to grow at a CAGR of 15.39% and reach \$12.28 billion by 2033 [19] Different cooling techniques have been employed over time to efficiently cool the battery module. Liu et al., (2017) reviewed about active and passive cooling and discussed about different looking techniques like air cooling, liquid cooling, phase change material (PCM) cooling, heat pipe based cooling with their merits and demerits [20].Air Cooling is the most traditional approach. It can tackle heat generation issues in battery packs inside tiny spaces in between the cells where other technology limits itself[21].Natural convection air cooling technology, also called as conventional cooling totally depends upon the natural flow of air inside the battery pack. Limited room for research can be seen in such an arrangement, as it is constrained by many factors such as natural flow velocity, air temperature etc[21].In active cooling, air supplied from the fan or other devices into the BP. It is much preferred technology than passive cooling as it can work in the larger range of temperature[20]. Sabbah et al., (2008) found out in her work, air cooling is not an appropriate cooling technique at high discharge rates and high operating temperature without spending significant fan power due to its low thermal conductivity and low specific heat capacity [22].Because of the high complexity of heat pipe based cooling and low thermal conductivity of PCM based cooling, liquid cooling is a highly prominent and commercialised cooling system [20].Wang et al.,(2023) pointed out the importance of cold plate in liquid cooled systems. Through the cold plate, the coolant and battery surface are in indirect contact, reducing the possibility of coolant leakage and battery corrosion [23].

2.4 Rectangular and serpentine channels cooling plate

Huo et al., (2015) investigated the effects of number of channels, inlet mass flow rate, flow direction and ambient temperature on the cooling performance of a rectangular channel cold plate[24]. The maximum temperature of the plate decreased with the increase in the number of channels and mass flow rate. In addition to the effects of these parameters on the cooling performance Qian et al., (2016) compared two different designs. Maximum temperature and temperature difference decreased by 13% and 43% respectively in the design with an extra cold plate [25]. Jiaqiang et al., (2018) concluded in his work of RCP that number of channels and flow rate are primary factors and channel height and width are less important factors for temperature uniformity [26]. Amalesh et al., (2019) compared seven different configurations of the channel that are better than RCP . The zigzag and one with circular slot were found to be better configurations [27]. Other than RCP, serpentine channel cold plate are extensively studied and used. In a SCP, The temperature difference and cell maximum temperature rise are not significantly affected by increasing the LCP channel width; on the other hand, the power consumption ratio falls significantly as the LCP channel width increases (Sheng et al.,2019) [28].

2.5 Concept of optimization

These studies have focused on enhancing the heat transfer rate but have ignored the flow resistance of the coolant. Higher flow of the coolant increases the energy required to run the pump. Further studies have been conducted taking into account the minimisation of flow resistance [1]. Tan et al,. (2018) proposed a multi-objective optimization including average temperature, pressure drop and temperature difference [29]. Chen et al,. (2019) and Li et,al.(2019) also performed multi-objective optimization with the similar objectives and developed a cooling system with lower temperature and lower energy consumption [30][] [31]. Zhao, et al. (2021) designed the cold plate with optimal pin-fins diameter using genetic algorithms.The results showed 29.8% ,29% and 17.4% decrement in power consumption, weight and temperature standard deviation [32]. The aforementioned studies set the shape and structure of the plate in advance which limits further improvements in cooling plate's performance.Additionally, the optimization process generates a large number of surrogate models, which results in a large number of iterations, increasing the complexity and time required [12][33]. Topology optimization can get rid of this limitation and achieve higher design freedom.

2.6 Topology Optimization

It was first introduced by Bendsøe and Kikuchi (1988) in their work that focused on optimal design of mechanical components that can withstand certain loads. It is a computational technique used to determine the most efficient material layout within a given design space, subject to specific constraints and performance requirements. Topology is concerned with the connectivity of domain and shape, features and location of holes in domain (Bendsoe and Sigmund, 2013). Topology Optimization falls under structural optimization and most of the times it is confused with shape and size optimization. Bendsoe and Sigmund, (2013) in their book made a clear distinction between the three.

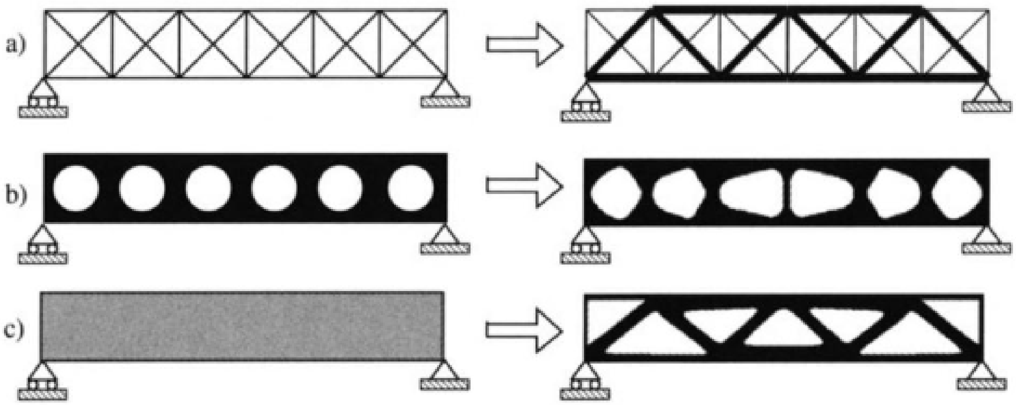

Figure 2.1: a) Size optimization b) Shape optimization c) Topology Optimization [34]

In topology optimization, there is no requirement for predefined structure of cooling channels, as new cooling channels can be formed automatically based on objective functions [12]. The concept was limited to structural design, later Borrvall and Petersson (2002) added a resistance term in Stokes equation to penalize fluid velocity and optimize runner topology making TO prominent in the field of fluid dynamics, thermal conductivity and convective heat dissipation of heat sinks [35]. Hansen et al.,(2005) used the Brinkman penalty model in TO considering the steady, incompressible flows at low to moderate Reynolds number [36]. Olesen et al., (2006) implemented nonlinear topology optimization in commercial software package called FEMLAB which used high level programming language [37]. Dede (2009) implemented Navier Stokes fluid topology optimization in COMSOL Multiphysics software and since then COM-

SOL has been widely used for TO [38].Koga et al., (2013) performed multi-objective topology optimization in a heat sink considering the thermal and flow effects.Finite Element Method is combined with Sequential Linear Programming to perform TO [39]. In heat sink analysis, the use of weighting coefficients w1 and w2 with the objective functions allowed the control over the bias enhancing thermal or flow performance. Many studies used this approach for topology optimization. Subramaniam et al., (2019) also used this to produce a single minimization function considering, w1 + w2 = 1 [40].

2.7 Topology Optimization in cooling plates for BTMS

Variable density method, alternatively known as Solid Isotropic Material with Penalization(SIMP) is generally employed for TO of cooling plates in BTMS. The idea behind this method is to vary the material density between [0,1]. '0' represents fluid and '1' represents solid [41]. Material density is allowed to be a continuous value between 0 and 1 for numeric stability but with the help of penalty parameters they are steered back to the integer value. This way a black and white design is achievable [42].

Mo et al., (2021) used multiobjective topology optimization of the cooling plates for the Battery Thermal Management System. The pressure drop and maximum temperature of the optimized cooling plate were respectively 2 °C and 47 % lower than those of the traditional cooling plate. Simulation results were also supported by the experiments [12]. Chen et al., (2022) compared the optimized geometry compared with rectangular and serpentine geometry of the channels and found out TCPs are more effective in cooling the battery at the same inlet pressure because of higher heat transfer coefficient and Nusselt number. Increasing the flow domain volume fraction makes the optimized geometry more complex, and objective function values are also higher. The maximum temperature of the battery using topology-optimized cold plates was found to be reduced by 0.27 % and 1.08 %, respectively, at an inlet pressure of 150 Pa, compared with conventional cold plates, and the temperature difference was reduced by 19 % and 41 %, respectively [43]. Guo et al., (2022) designed the cold plate with multiple inlets and outlets to improve temperature uniformity and cooling performance for a pouch type $LiFePO_4$ battery.It was mentioned that the ideal choice for cooling a 20 Ah pouch type $LiFePO_4$ battery is the topology mini-channel, with four staggered inlets, a flow depth of 4 mm, an inlet width of 6 mm, and a mass flow rate of $3*10^{-3}$ kg/s [33]. Four objective functions : maximum heat exchange, maximum outlet enthalpy, minimum solid domain temperature, and multi-objective function were investigated for better topology optimization results and maximum outlet enthalpy was found to be the ideal function. However, multiobjective function is more prevalent and important because it also considers the flow resistance parameter (Wang et al., 2023) [23]. Liu et al., (2024) in his work compared two novel cold plates with different weighting coefficients for a high capacity battery. The cold plate with optimized geometry was found to have better heat transfer capacity, rational flow path, uniform temperature distribution and lower flow resistance [1].

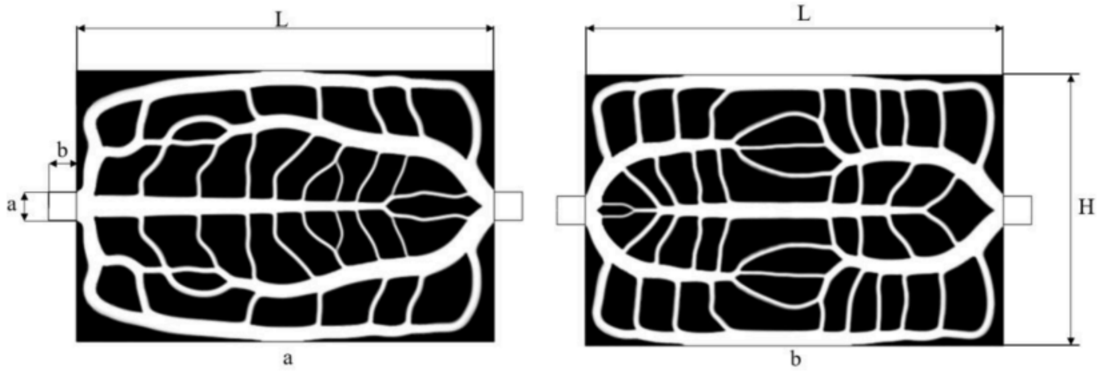

Figure 2.2: Optimized topology of cold plate [1]

2.8 Optimization Objective

The optimization objecive of TO is to minimize the average temperature of the cold plate and power dissipation of the coolant flow. The expressions for Φ_T and Φ_f are given by [12]:

$$\Phi_T = \frac{\int_{\Gamma_\mathrm{Q}} T d\Gamma_\mathrm{Q}}{\int_{\Gamma_Q} 1 d\Gamma_\mathrm{Q}}$$

$$\Phi_\mathrm{f} = \mu \int_\Omega \nabla\mathbf{u} \cdot \nabla\mathbf{u} d\Omega + \int_\Omega \alpha(\gamma)\mathbf{u} \cdot \mathbf{u} d\Omega$$

The magnitudes of these objective functions might differ so they are normalized.

$$\overline{\Phi_T} = \frac{\Phi_T}{\Phi_T^0}, \overline{\Phi_\mathrm{f}} = \frac{\Phi_\mathrm{f}}{\Phi_\mathrm{f}^0}$$

The objective functions are combined with the help of weighting coefficients to obtain the single objective function [12].

$$\Phi = w_T \overline{\Phi_T} + w_\mathrm{f} \overline{\Phi_\mathrm{f}}$$

where w_T and w_f are the weighting coefficients of Φ_T and Φ_f respectively. The sum of w_T and w_f is 1.

The TO can be represented [44] as :

find γ

$\min \Phi = w_T \overline{\Phi_T} + w_\mathrm{f} \overline{\Phi_\mathrm{f}}$

Constraints:

$$0 \leq \frac{\int_\Omega \gamma d\Omega}{\int_\Omega 1 d\Omega} \leq \varphi_\mathrm{f}$$

$$0 \leq \gamma \leq 1$$

$$w_T + w_\mathrm{f} = 1$$

2.9 Research Gap

The research gaps found during literature review are:

1. According to Zhao et al., (2019), the temperature curve of the battery when it is charged and discharged at different rates will be the accurate and reliable input data source for the CFD simulation instead of constant heat flux but all the existing literature have used heatflux in their work [11].

2. According to Mo et al., (2021) there have been studies about topology optimization by level set method, homogenization method and Evolutional Structural Optimization (ESO) [12]. Among these variable density method is the most widely used topology optimization technique used for cold plates in BTMS. Other techniques have not been implemented for TO of cold plate in Battery Thermal Management System.

3. According to Guo et al., (2022) impact of topology on battery electrical performance ,changes of lithium-ion concentration, battery capacity and battery SOC are yet to be studied [33].

4. According to Chen et al., (2022) increasing the flow domain volume fraction makes the optimized geometry more complex [43]. Higher volume fraction improves the cooling performance but manufacturability is tougher. The trade-off between manufacturability, cost and performance have not been researched yet.

5. According to Wang et al., (2023) ”maximum outlet enthalpy” as the objective function gives the best cooling performance but it ignores the flow term [23]. Recent studies [12][33][43][1] have used ”maximum heat transfer” and ”minimum flow resistance” as the objective functions. This signifies that better cooling performace might be obtained if TO is based on ”maximum outlet enthalpy” and ”minimum flow resistance”.

6. According to Adhikari et al., (2024) ethylene glycol at 30% concentration is the best coolant for indirect liquid cooling [45] . The recent studies [12][33][43][23] [1]used only water as the coolant in analysing optimized topology of the cold plate. The comparative study of glycol as coolant in optimized topology is yet to be explored.

CHAPTER 3: METHODOLOGY

3.1 Overall Framework

This study will focus on designing, simulating, fabrication of the optimized cooling plate and validating the outcomes. A general work flow of the research is presented below.

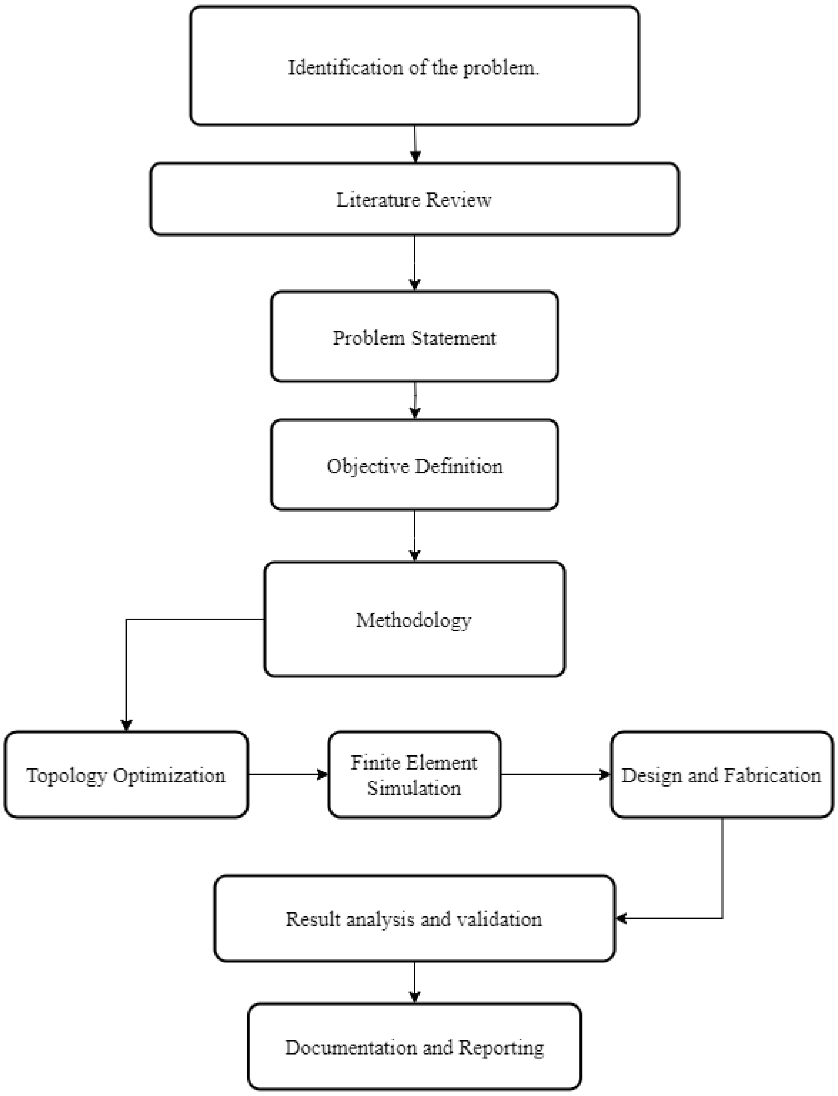

Figure 3.1: Overall flowchart

Phase I :Topology Optimization

A CAD model is designed in Solidworks with proper dimensions and properties and will be transported to COMSOL Multiphysics where TO will be carried out in the following steps:

1) Define the Design Problem:

a)Design Space: Specify the geometric boundaries within which the material can be distributed.

b)Objective Function: Determine the goal of the optimization (e.g., minimize weight, maximize stiffness, improve thermal performance).

c)Constraints: Set the constraints.

2) Create Initial Model: Develop an initial finite element model of the design space. This model includes the material properties, boundary conditions, and loading conditions.

3)Set Up Optimization Problem: Formulate the optimization problem by defining the objective function, constraints, and design variables (typically the density or presence of material in each element)

4)Apply the method of optimisation(eg. variable density method) for obtaining the optimised topology.

5)Iterate Optimization: Adjusting material layout iteratively to improve performance.

6)Finalize Design: Refine the optimized design for practical use and manufacturability.

Phase II : Simulation and Analysis

The average temperature, pressure drop , temperature uniformity and the effect of parameters like inlet velocity, flow rate, number of channels in both optimised geometry and equivalent conventional geometry will be visualized and compared via Ansys simulations.

Phase III : Fabrication and Experimentation

Aluminium 6061 and the manufacturing tools required for the fabrication will be acquired and setup. The conventional cold plate designed in Solidworks and the cold plate optimized in COMSOL Multiphysics will be fabricated by CNC milling. The scaled up product will be manufactured if necessary. Both the produced cold plates are tested with the help of an experimental setup for BTMS to validate the simulation results.

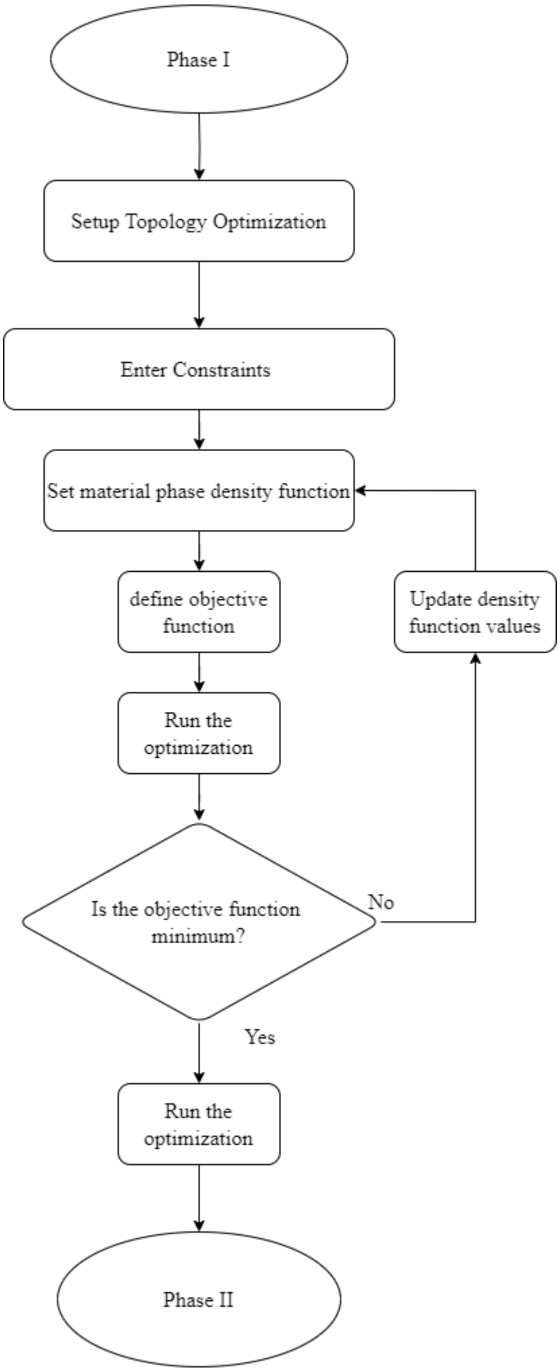

Figure 3.2: Phase I

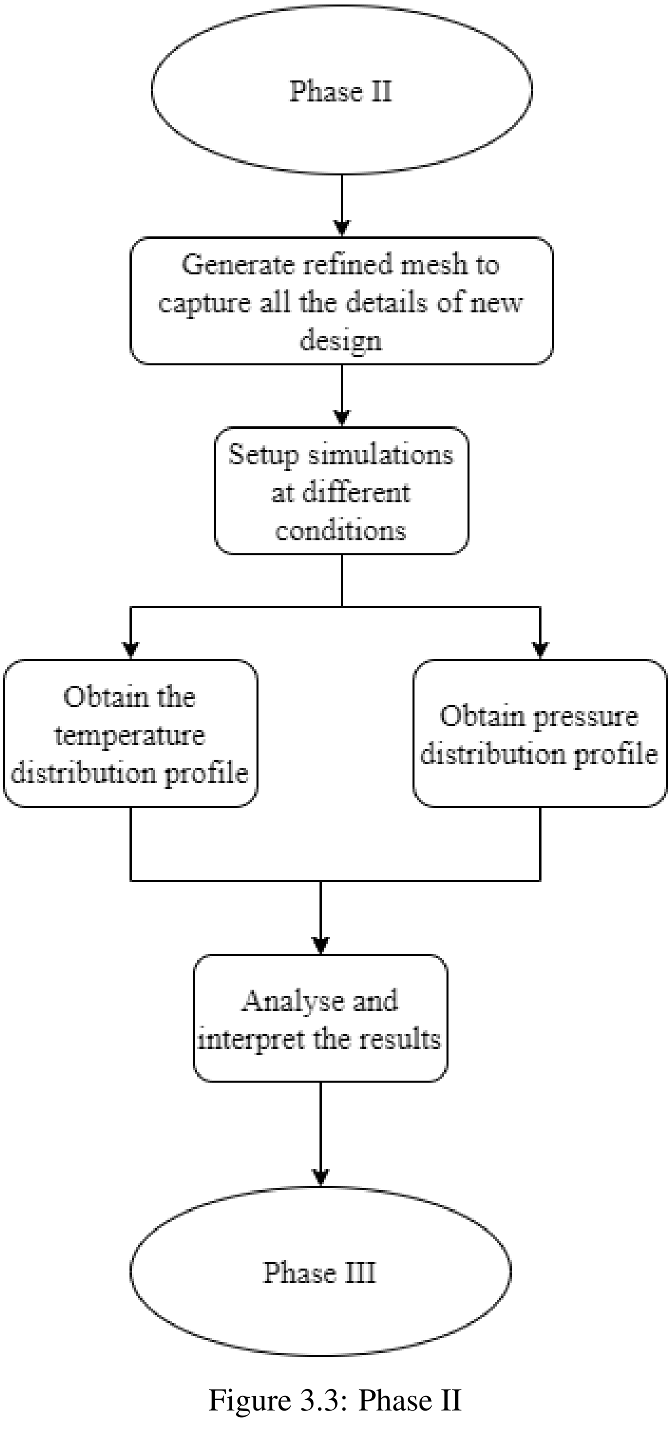

Figure 3.3: Phase II

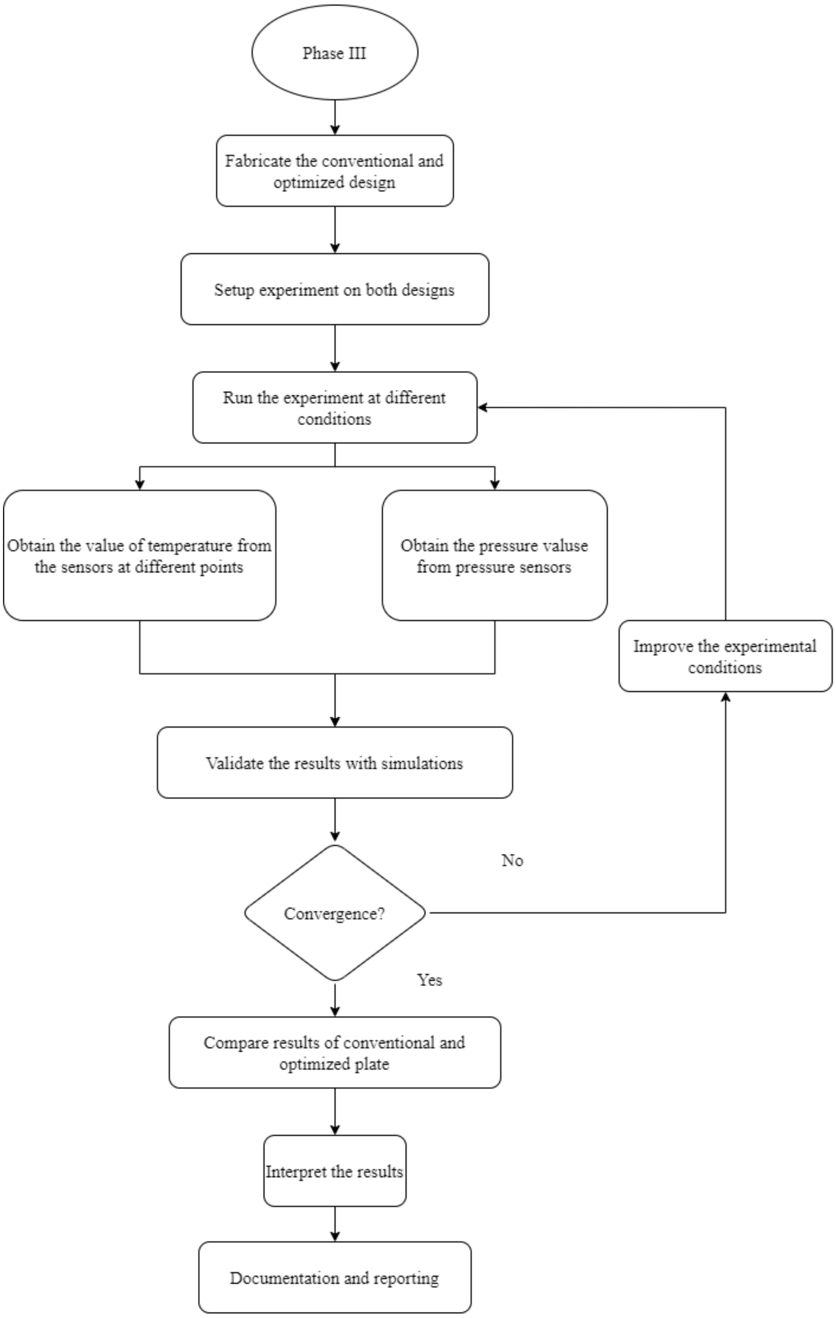

Figure 3.4: Phase III

CHAPTER 4: EXPECTED OUTCOMES

After the completion of this project,following outcomes are expected :-

- A novel design of the cold plate optimized using the variable density method, demonstrating improved performance over traditional designs.

- Comprehensive analysis and comparison of the optimized cold plate and traditional cold plate, highlighting improvements in average temperature, temperature uniformity, and pressure drop based on simulation models.

- Fabricated cold plates made from reliable and readily available materials, showcasing practical application and feasibility.

- Experimental validation of the cooling performance of the optimized cold plate, confirming the accuracy and effectiveness of the numerical and simulation results.

CHAPTER 5: EXPERIMENTAL SETUP AND VALIDATION

After the optimised geometry is obtained for the cold plate by the use of topology optimisation using COMSOL Multiphysics or ANSYS, the obtained geometry will be manufactured and also the conventional cold plate will also be manufactured.
For the validation and verification following things will be done:

5.1 Experimental setup

One of the surest way to ensure the validity of the obtained result by simulation is to verify experimentally .So the experimental set up will be prepared and the optimised cold plate as well as conventional cold plate will be tested under the set up . Some errors are expected to be obtained due to manufacturing and environmental constraints which are to be accepted if they fall in a reasonable range. The unavailability of materials like pure aluminium alloy, standardized testing equipments might produce errors more than expected.

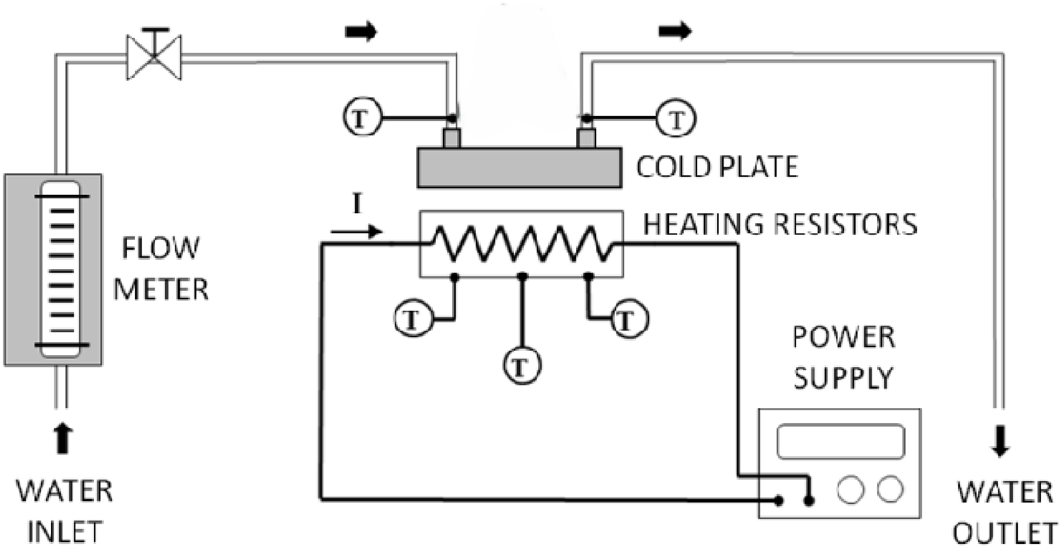

Figure 5.1: Proposed Schematic Diagram of the Experimental Setup[46]

After the testing of the Cold plates in the experimental setup is done .The datas will be noted and the results obtained will be compared with the results obtained through the simulation.The comparitive analysis will provide the validation for the FEM simulation and the topology optimization.

CHAPTER 6: BUDGET ESTIMATION

The following table shows the cost analysis for the project :-

S.N	Description	Amount
1	Computational Cost	15,000
2	Aluminium block cost	5,000
3	Manufacturing Cost	20,000
4	Experimental Setup Cost	30,000
5	Miscellaneous	10,000
6	Total	80,000

Table 6.1: Cost estimation

S.N	Description	Amount
1	Flow meter	8,000
2	Pump	1,000
3	Water Tubes	1,000
4	Sensors	5,000
5	Heating Element	1,000
6	Insulator (Acrylic)	3,000
7	Thermal Paste	500
8	Arduino Uno	2,500
9	Wires	500
10	Miscellaneous	7,500
11	Total	30,000

Table 6.2: Experimental set up cost Details

CHAPTER 7: PROJECT SCHEDULE

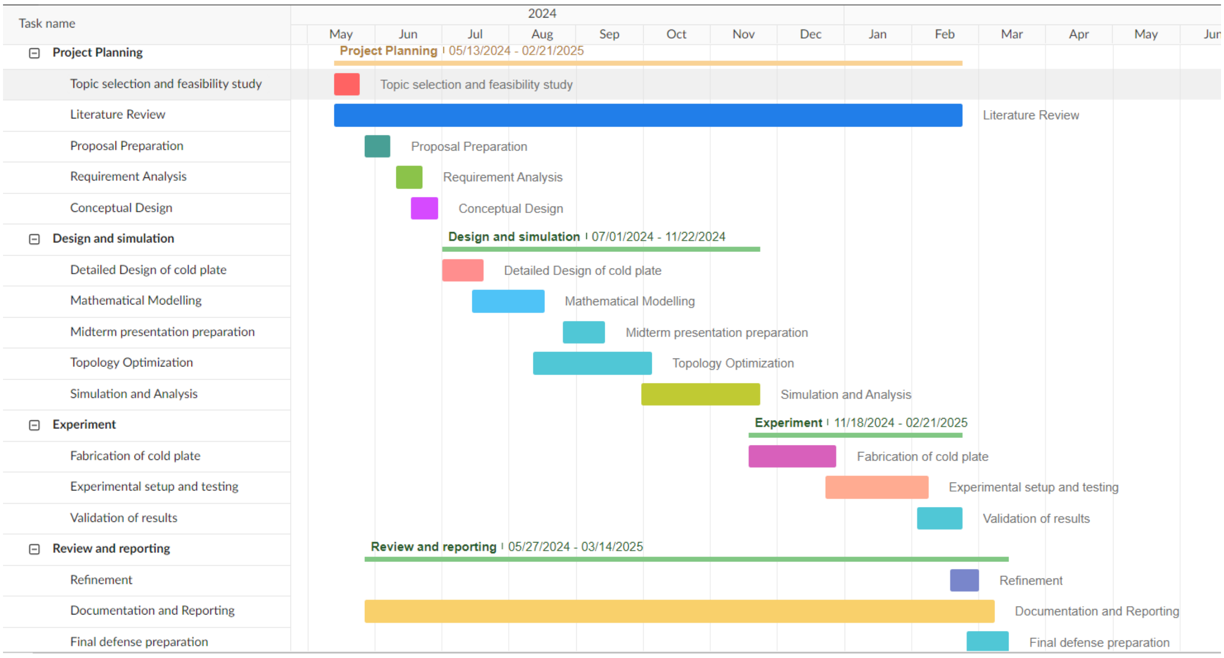

Figure 7.1: Gantt Chart

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