# ChE 311- Heat Transfer Operations

## Thermal Management of Battery Pack Using Different Cooling Flow Pattern


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## 1. Introduction

The increasing demand for high-performance electric vehicles and portable electronic devices has intensified the need for efficient Battery Thermal Management Systems (BTMS). Maintaining the battery cell temperature within an optimal range (298–320 K) is crucial to ensure high performance, long cycle life, and operational safety.

In this study, a Computational Fluid Dynamics (CFD) simulation was performed using ANSYS Fluent to analyze the transient heat transfer performance of three different cooling channel configurations for a lithium-ion battery pack:

- Rectangular Flow Channel
- Immersed (Flooded) Cooling Configuration
- Serpentine Flow Channel

The main objective of this work is to evaluate and compare the temperature distribution, coolant flow behavior, and overall cooling efficiency of each configuration when water is used as the working fluid.

## 2. Geometry and Meshing

### 2.1 Geometry Details

Each model consists of a rectangular battery module enclosed within an aluminum casing containing nickel-based internal components. The coolant (water) flows either across or around the battery domain to absorb the generated heat.

| Configuration | Description | Flow Path | Key Feature |
|---|---|---|---|
| Rectangular Channel | A straight coolant path directly beneath the battery surface. | Linear, parallel to cells | Uniform cooling with low pressure drop |
| Immersed (Flooded) | The entire battery pack is fully submerged in the coolant (water). | Unrestricted flow across all surfaces | Maximum surface contact but lower flow uniformity |
| Serpentine Channel | A meandering or zig-zag flow passage. | Sequential passes through narrow bends | High surface area and enhanced heat removal |

### 2.2 Meshing

All models were meshed using ANSYS Meshing with tetrahedral cells. Fine mesh inflation layers were applied near the battery walls to capture boundary layer effects. Mesh independence was ensured by monitoring surface temperature variations between successive refinements (less than 2% variation).

## 3. Physical Models and Boundary Conditions

### 3.1 Models Used

- Solver Type: Transient, 3D
- Flow Model: Laminar
- Energy Equation: Enabled
- Gravity: Neglected (forced convection dominant)

### 3.2 Material Properties

| Material | Density ($kg/m^3$) | Cp (J/kg·K) | Thermal Conductivity (W/m·K) |
|---|---|---|---|
| Water (Coolant) | 998.2 | 4182 | 0.6 |
| Aluminum (Casing) | 2700 | 900 | 205 |
| Nickel (Core) | 8900 | 445 | 90.7 |

### 3.3 Boundary Conditions

- Inlet velocity: 1 m/s (water at 290 K)
- Outlet: Pressure outlet (0 Pa gauge)
- Battery heat generation: Corresponding to ~5 K surface temperature rise
- Walls: No-slip, conjugate heat transfer enabled
- Simulation duration: 10 s (transient)

## 4.Comparative Summary

| **Configuration** | **T_wall, final difference(K)** | **Cooling Uniformity** | **Relative Heat Transfer Coefficient (h)** | **Remarks** |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| **Immersed** | ≈ 6k | Very High | Medium | Uniform and stable cooling performance |
| **Serpentine** | ≈ 9k | Moderate | High | Fastest cooling rate due to enhanced convection |
| **Rectangular** | ≈ 3k | Medium | Low | Gentle, energy-efficient, but slower cooling |

## 5. Conclusion

A transient CFD analysis was carried out for battery pack cooling using **water at 290 K** as the coolant and a constant **cell surface temperature of 333 K** to represent heat generation during operation. Three different coolant flow configurations — **Rectangular**, **immersed (Flooded)**, and **Serpentine** channels — were analysed to evaluate thermal behaviour and cooling effectiveness.

1. **Immersed Cooling Configuration**
   The area-weighted temperature plot shows a gradual and smooth reduction in the average cell-wall temperature as the coolant removes heat uniformly from all sides. The flow pattern allows multidirectional convective heat transfer and minimal temperature gradient across the pack.
   **Best thermal uniformity** and **stable temperature field**, ideal for research setups or stationary battery systems.

2. **Serpentine Flow Channel**
   The transient temperature curve indicates a rapid drop from the initial wall temperature toward equilibrium within ~0.6 s, after which the temperature stabilizes. This demonstrates **strong convective heat transfer** due to flow acceleration and boundary-layer disruption in each bend of the serpentine path.
   → **Highest effective heat-transfer coefficient**, fastest cooling response, but slightly less uniform temperature distribution because of velocity variations at turns.

3. **3.Rectangular Flow Channel**

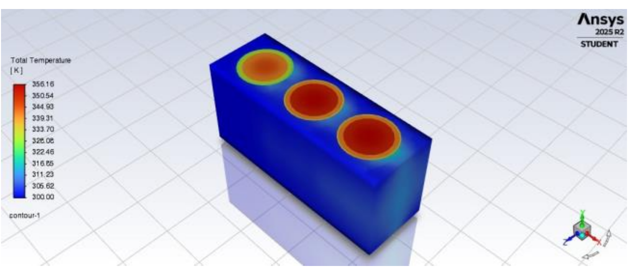
 The temperature decay would be the **slowest** among the three. The straight, uniform path ensures stable cooling with a low pressure drop, but the overall convective surface area is limited.

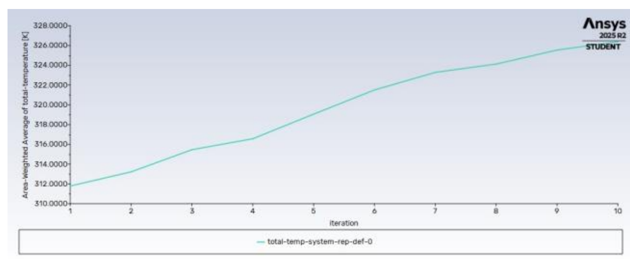
 → **Lowest h-value**, smooth but slower cooling rate — suited for compact systems or low heat-flux modules

## 6.Contribution of Members

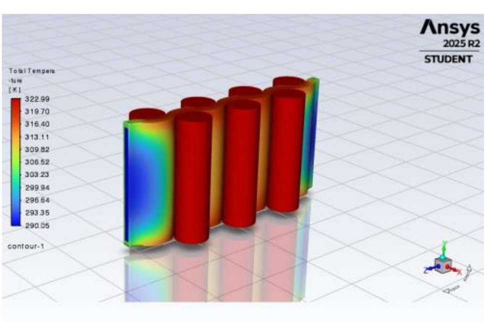
 The project was carried out by three members, all of whom contributed equally across the three configurations. Each member worked on different aspects of the study — including geometry creation, meshing, and Fluent setup — to ensure balanced participation. While one handled the geometry and meshing for a particular model, others performed solver setup and post-processing, and the roles were rotated for the remaining cases. All members jointly analysed results and prepared the final report.

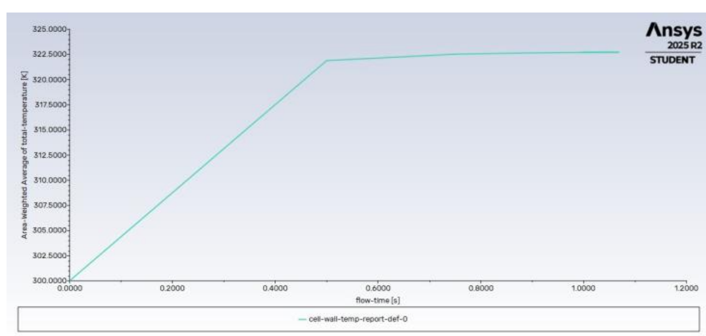
## 7.Contours And Plots



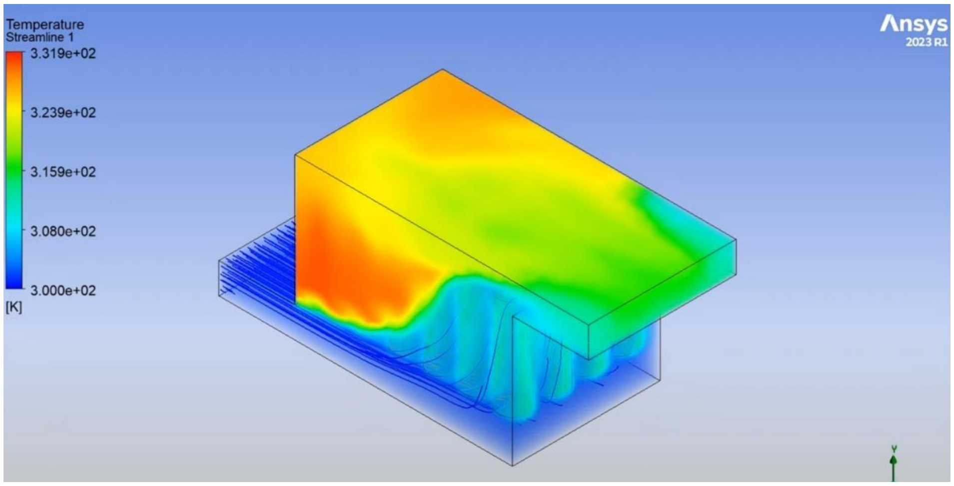




Immersed cooling system




Serpentine Cooling system



Rectangular Cooling System