Thermal Phenomena, Performance and Management of Electric Vehicles
MIE 1135H - Course Content

This course describes the thermal phenomena in Electric Vehicles (EVs), including the main cooling/heating circuits associated with the power train, cabin, and battery. The major focus is on thermal performance and thermal management of batteries, power electronics and electric motors, and it also includes thermal issues related to cabin electronic systems. Emphasis is on Lithium-ion batteries (LIB), which are expected to continue to be the most widely used battery for EVs in the next decade. This course will cover LIB cells and their fundamentals; principles of operation; electrochemical and heat transfer formulation, modelling and simulation; thermal-related effects on LIB performance and longevity, including aging, degradation, safety, and thermal runaway; thermal modelling of EV system- and component-level, LIB, electric drivetrain, cabin, and fast charger.

Students in this course are expected to have a basic understanding of electrochemistry terminologies and undergraduate-level fundamental knowledge of fluid mechanics, thermodynamics, heat transfer and numerical methods.

Course Content:

1. **Introduction of EV Fundamentals**
    - Thermal-related effects on battery performance and longevity, including driving range, battery capacity, degradation, safety, SEI, lithium plating, and thermal runaway
    - Thermal modelling of system- and component-level, electric drivetrain, cabin, fast charger, and battery

2. **Hierarchical Multiscale Thermal Modeling of EVs and Lithium-Ion Batteries**
    - Battery cells: fundamentals, nanoscale modelling (MD, DFT, ML), 2D materials
    - Component-level and Computational Fluid Dynamics (CFD) modeling
    - System-level thermal modelling and reduced-order (RO) modelling, digital twins, simulation software
    - Trade-off between model computation time, robustness, and fidelity

3. **Battery Cells**
    - Overview of lithium-ion battery (LIB) cells, principles of operation, internal structure, battery cell types, chemistries, and form factors
    - Sources of heat generation in LIB cells, their dependence on charging/discharging rates, and their effect on battery performance

- Electrochemical governing equations and modelling: single-particle zero-dimensional model, one-dimensional model (1D), pseudo two-dimensional model (P2D), and detailed three-dimensional model (3D)
- Coupled electrochemical-heat transfer processes in LIB cells: from physical regions to computational domains
- Characterization and prediction of cell thermophysical properties (e.g., thermal conductivities, heat generation) for cylindrical, prismatic and pouch cells
- Inverse heat transfer modeling

4. **Battery Thermal Management Systems (BTMS)**
    - BTMS overview and requirement
    - System design perspective, including introduction to electrical design, cell series and parallel arrangements, modules and packs
    - BTMS types and their applications: active (air and liquid); passive (e.g., phase change materials); hybrid
    - Techniques for cooling/heating and pre-conditioning EV batteries; pack- and module-level thermal management, including cooling approaches, coolant delivery modes, and pack architectures

5. **Aging, Lifetime and Degradation of Li-ion Batteries**
    - Aging indicators, calendar and cycling modes, mechanisms, impact of cell chemistry on aging, cell-to-cell variation
    - Predicting aging: data-based models, equivalent circuit models, electrochemical models, electrochemical impedance spectroscopy and incremental capacity
    - Aging and fast charging
    - Mitigating aging

6. **Thermal Management of EV Autopilot & Cabin Electronic Systems**
    - Overview of thermal management of autopilot and cabin electronic systems

7. **Thermal Management of EV Power Electronics and Electric Powertrains**
    - Introduction to EV power electronics and electric machines
    - Thermo-mechanical aspects of power electronics, thermal management of EV electric motors, and integrated drive systems

Support Material:

Course material will be based on several textbooks, industry material and scientific publications. Course notes and public references will be posted in Quercus.

Learning Outcomes:

Students will gain a deep understanding of the concepts and challenges related to thermal performance and thermal management of EV batteries, power electronics and electric motors. The course is designed to equip students with the fundamental knowledge and tools needed to pursue the thermo-electrochemical analysis of lithium-ion batteries and their thermal performance, including that associated with aging, degradation, safety and thermal runaway.

After active participation and completion of the course, students will have demonstrated the ability to:

- Understand and predict thermal-related effects on battery performance, degradation and longevity
- Describe and become familiar with EV battery terminology and thermal challenges
- Understand the operation of different EV components
- Augment individual knowledge through teamwork and self-guided learning
- Formulate and model electrochemical and heat transfer processes in lithium-ion battery cells
- Formulate multiscale hierarchical models from cell electrodes to battery modules to system-level electric vehicles
- Evaluate the performance of Battery Thermal Management Systems (BTMS)
- Design BTMS for specific applications, applying the fundamental concepts and considering competing design constraints and trade-off