1. To show the importance of an effective thermal management system to maintain operational temperatures within safe limits for performance and longevity, consider a lithium-ion battery pack consisting of 20 battery units connected in series. Each battery unit has the following specifications:

   - **Dimensions**: 16 cm wide, 23 cm tall and 25 cm depth
   - **Batttery Capacity**: 42 Ah
   - **Discharge Rate**: $5C$ (where C is the capacity of the battery)
   - **Heat Generation**: The internal heat generation rate per unit volume can be modeled as: where R_i is the internal equivalent resistance (assumed to be $0.05\,\Omega$) and I is the discharge current.

   (a) Calculate the battery discharge current

   (b) Calculate the total heat generation for the battery pack. Note: $Q_{\text{total}} = \text{n} \times q_{\text{unit}}$ where n is the number of battery unit in the pack.

   (c) Calculate the volume of one unit battery

   (d) By assuming a density ($\rho = 2500$ kg/m^3), calculate the total mass of battery pack.

   (e) By assuming that all generated heat is absorbed by the battery pack without any heat loss (for simplification). Use specific heat capacity ($C_p = 1200\,\text{J/kg}\cdot\text{K}$) of the battery material to calculate the temprature rise (ΔT) by using the following heat transfer equation:

$$Q_{\text{total}} = m_{\text{total}} C_p \Delta T$$

2. In order to compare the maximum heat dissipation capabilities of base versus side plate cooling for a 40650 Li-ion cell, consider a 40650 Li-ion cell (cylindrical, 65 mm height, 40 mm diameter). Compare base vs side plate cooling for this cell based on maximum heat dissipation. Assume axial and radial thermal conductivities of 10 W/mK and 1 W/mK, respectively. Since the entire side surface of a cell cannot be utilized for cooling, assume a reasonable percentage of the side surface area for side cooling.

Cell Specifications

- **Type**: 40650 cylindrical Li-ion cell
- **Height**: $h = 65$ mm $= 0.065$ m
- **Diameter**: $d = 40$ mm $= 0.04$ m
- **Axial Thermal Conductivity**: $k_{\text{axial}} = 10\,\text{W/m}\cdot\text{K}$
- **Radial Thermal Conductivity**: $k_{\text{radial}} = 1\,\text{W/m}\cdot\text{K}$

(a) Calculate the base area

(b) Calculate the side area

(c) Calculate the usable side area assuming 70%

(d) Using Fourier's law of heat conduction, Calculate the heat transfer Q for both Base cooling method.

(e) Also calculate the heat transfer Q_{side} for side cooling

(f) Summarize the results in a table and make your conclusion

3. Based on the heat generation in Li-ion cells, explain the terms associated with heat generation and discuss their relative importance.

$$\dot{Q} = I \cdot V - I \cdot V_{oc} - I \cdot T_{ref} \cdot \frac{dV_{oc}}{dt}$$

where,

- $\dot{Q}$: Total Heat Generation Rate
  - Represents the overall rate at which heat is generated in the cell, typically measured in watts (W).
- I: Current
  - The current flowing through the cell during operation, measured in amperes (A). It plays a crucial role in determining heat generation due to resistive losses.
- V: Operating Voltage
  - The actual voltage across the cell during operation, measured in volts (V). This value can fluctuate based on the state of charge (SoC), temperature, and load conditions.
- V_{oc}: Open-Circuit Voltage
  - The voltage of the cell when it is not connected to any load (i.e., no current is flowing). This value represents the maximum potential of the cell based on its chemistry and state of charge.
- T_{ref}: Reference Temperature
  - A reference temperature that can be related to ambient conditions or specific operating conditions. It serves as a baseline for evaluating thermal effects on voltage changes.
- $\frac{dV_{oc}}{dt}$: Rate of Change of Open-Circuit Voltage
  - Indicates how quickly the open-circuit voltage changes over time, influenced by factors such as temperature and state of charge. A high rate of change may indicate rapid electrochemical reactions occurring within the cell.