XPLORLABS | UL Research Institutes

The Science of Thermal Runaway: Engineering Safe Solutions

Engineering Design Challenge

Student Guide

Safety Engineering to Meet Standards

In the Science of Thermal Runaway pathway, you identified significant risks to lithium-ion batteries. Excessive heat, physical damage, and mismatched chargers can all lead to thermal runaway. Safety engineers must consider all the risks when designing safe battery enclosures, but this engineering design challenge will focus specifically on thermal design requirements to protect the battery and the device from excessive heat.

In this engineering design challenge you will select, test, and choose material(s) to use in a battery enclosure to manage thermal energy that could lead to thermal runaway. You will test your design to meet thermal performance criteria just like safety engineers test e-mobility devices to meet Standard UL 2272.

If your team's enclosure design meets the standards criteria, then it will pass the safety test! If your team's enclosure design does not meet these criteria, then your group must analyze other group data to identify the best characteristics of each that can be combined into a new solution. Once adjustments are made, run the tests again.

This is the process of safety engineering.

Your Safety Standard Criteria and Constraints:

Design Criteria	**Constraints**	
Minimize risks associated with change in temperature.	The **internal** temperature of battery enclosure **cannot** increase **more than 5ºF (2.8ºC)**	The **external** temperature of the battery enclosure **cannot** increase **more than 7ºF (3.9ºC)**

Roles

The Stuff Supervisor

Gather and clean up materials.

The Experiment Exec

Ensure reliability of test data

The Director of Documents

Help with recording data

The Presenter

Share the group's work with the class

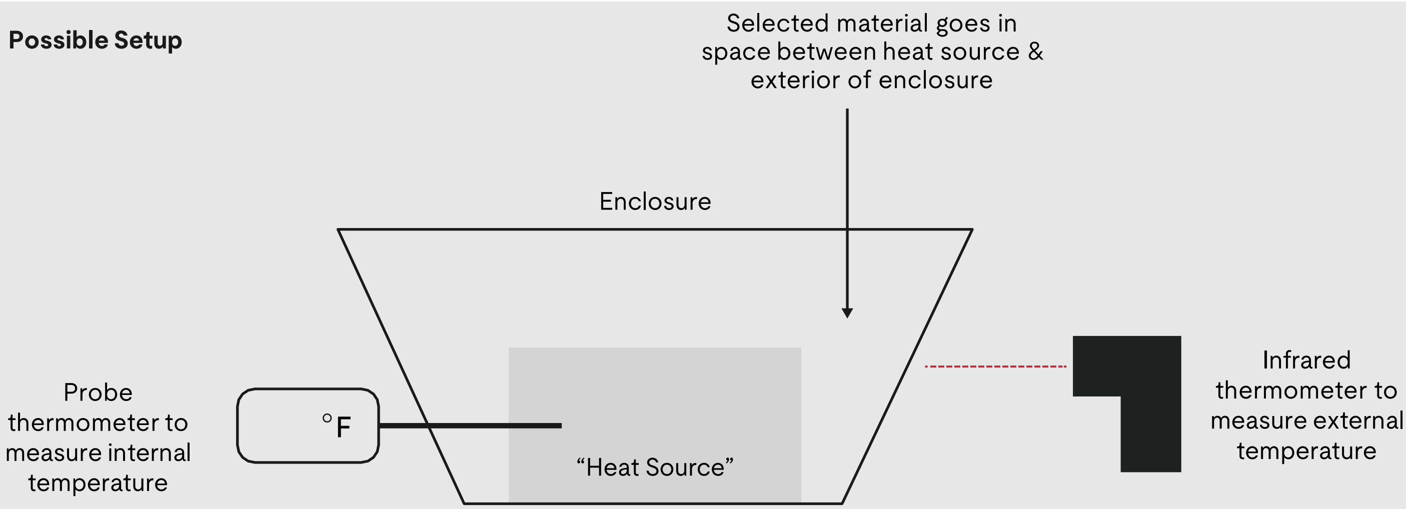
Materials

- Prototype of battery enclosure for e-mobility device (see *possible setup* below)
- 2 handwarmers to simulate the heat of batteries
- Meat thermometer or temperature probe to record the internal temperature of enclosure
- Infrared thermometer or other surface thermometer that reads over 140ºF (0 C) to record the external temperature
- Various materials to be tested for thermal performance between the source of heat (battery /handwarmers) and the outside of the device (see *possible materials* below)

Preparing your enclosure

*The provided enclosure is a scaled-down version of a portable electric powered device. It is simplified for testing purposes. Its purpose is to simulate the exterior of a portable electric powered device, like a hoverboard. Therefore, ensure that the enclosure that you use has a space between the heat source (battery) and exterior. This space allows you to place the materials you will test between the heat source (handwarmers) and outside of the enclosure.

Possible Setup



Possible Materials

Material	Specific Heat Capacity (J/g °C)	Thermal Conductivity (k)(W/mK)
Water	4.179	0.60[1]
Air	1.01	0.026[1]
Glass	0.753	0.81[3]
Paper	1.336	0.5
#6 plastics (polystyrene) *e.g. packing peanuts, some egg cartons*	13-15	0.3
#5 plastics (polypropylene) *e.g. Tupperware, dairy containers*	1.920	0.1-0.22
Soil *Depends on whether soil is dry (lower) or wet (higher)*	0.8-1.48	0.5-1
Wood *Birch, commonly used in popsicle sticks*	1.9	~0.15[1] -0.19[1]
Clay	0.92	0.6
Cork	2.0	0.43
Copper	0.385	401.0[1]
Steel	0.490	60.5[1]
Cotton	1.34	.035

Individual Engineering Design Ideation

Performance task: Design an enclosure that manages the heat from a "battery pack." The enclosure design must protect the device from excessive heat that could cause combustion.

Thermal Performance Standards

- The internal temperature of your battery enclosure cannot exceed a **5⁰F (2.8⁰C)** increase
- The external temperature of your enclosure cannot exceed a **7⁰F (3.9⁰C)** increase

1. Before meeting as a team, on your own **write down** everything you know about thermal performance:

2. Based on what you already know about the interactions of specific types of matter and thermal energy, generate a **list of reasonable materials** that might meet the safety standards. Include **justification** for your thinking. An example idea is provided below.

Possible reasonable material	Justification
Example: Water	High specific heat, but maybe not reasonable for other safety considerations; water close to battery leads to electrocution?

3. Connect your knowledge about thermal performance and your material ideas to develop an **initial model** of how the enclosure might be constructed to meet the thermal performance standard. This can be a simple sketch. Include labels!

4. Prepare to share your ideas with teammates to develop a plan collaboratively.

Team Engineering Design Ideation

1. Discuss and brainstorm (ideate) as a team what materials could be used to manage the heat from the battery. **Listen** to each team member's ideas. Concentrate your feedback and discussion on **materials to consider** for the enclosure to allow it to meet the thermal performance standards.

Thermal Performance Standards

- The internal temperature of your battery enclosure cannot exceed a **5^{o}F (2.8^{o}C)** increase
- The external temperature of your enclosure cannot exceed a **7^{o}F (3.9^{o}C) i**ncrease

Sketch a model of your team's enclosure design. Include the following labels:

- Materials
- Features of your enclosure
- Justifications for your choices

Team develop solutions

Prepare a data table for testing

1. Open the hand warmers and shake them vigorously so they can begin heating up. **It takes about 20 minutes for the handwarmers to reach about 120°F (48.9°C).** This is the ideal temperature to begin testing.

2. Arrange your handwarmers to resemble a battery pack (pouch or cylinder). Use rubber bands to secure them in that shape. Set them aside for now.

3. Consider what you are testing and how you are maintaining a reliable dataset.
   - **Control variables:** ______________________________
   - **Independent variable:** ______________________________
   - **Dependent variable:** ______________________________

4. Consider all data to be collected in this test for material choice. Brainstorm and agree on a data table to use during the test. (see sample data table)
   - **Note 1:** This test is to be run a minimum of 2 times. Therefore, modifications to the suggested table are necessary for accurate record keeping.
   - **Note 2:** You will be using an infrared thermometer to measure external temperature and a meat thermometer to measure internal temperature. What are some things to consider in your test execution to ensure your data is consistent and reliable?

Thermometers:

Probe thermometer measures internal temperature

Infrared thermometer measures external temperature

Sample data table:

Material Tested	Time	Internal Temperature (°F/°C)	External Temperature (F/C)
	0 minutes		
	5 minutes		
	10 minutes		
	Change in Temperature		
Pass or Fail		Change in temp < 5°F (2.8°C) = PASS Change in temp > 5°F (2.8°C) = FAIL	Change in temp < 7°F (3.9°C) = PASS Change in temp > 7°F (3.9°C) = FAIL

5. Collect **control data** on your **enclosure without any modification**. Record it in your data table below.
   a. Use the infrared thermometer to record the external temperature (°F or °C) of the enclosure. Record this external temperature in your data table at 0 minutes.
   b. Arrange the activated hand warmers in the space that represents the "battery pack."
   c. Safely position the meat thermometer between the "batteries" (hand warmers). Read and record the internal temperature (°F or °C) of the "battery pack" at 0 minutes. (see sample data table)
   d. Record both internal and external temperatures after 5 minutes and 10 minutes in your data table.
   2. **Note 3:** Do not bundle the handwarmers too tight. Do not pierce the handwarmers with the thermometer. Use the same unit for temperature (°F or °C) throughout your tests.

Thermal Performance Data Table – Control Data:

Test team ideas against standards

Receive approval for your procedure and material choices from your teacher. Then, your team will **test several possible solutions** you have developed together.

1. Create an experimental data table in the space below.
2. Make sure your hand warmers have been activated for 20 minutes before beginning testing.
3. Use the infrared thermometer to read and record the external temperature (°F or °C) of the enclosure. Record this temperature in your data table as your temperature at 0 minutes.
4. Arrange the activated hand warmers in the space that represents the "battery pack."
5. Use the meat thermometer to read and record the internal temperature (°F or °C) of the "battery pack." Record this in your data table as your temperature at 0 minutes.
6. Set a timer for 5 minutes. Read and record both internal and external temperatures after 5 minutes and 10 minutes in your data table.
7. Test the thermal performance of your designed enclosure three times.
8. Repeat procedure based on the number of materials needed to test.

Thermal Performance Data Table – Experimental Data:

Team reflection

Analyze thermal performance data

Analyze the thermal performance data that you collected:

1. Use the space below to:
    a. Analyze the data for an average (mean) change in temperature.
    b. Determine whether the design passes the criteria from the safety standards.
    c. Consider a way to present your team's data analysis. An example of how you could present your data is shown to the right.

Data Analysis for ______			
Material	Minimum Temperature (internal)	Maximum Temperature (internal)	Mean Change in Temperature (internal)

Sample data analysis table. Consider how you can adjust this to make it your team's own!

Data Analysis

Make sense of your team's outcomes:

2. Which **materials** in your team's designed enclosure passed the thermal performance test?

3. What **properties** of the materials your team chose worked well?

4. Explain the potential impacts of **thermal conductivity**, **insulators** and **conductors**, and **specific heat capacity** on your team's test outcomes:

5. **Share your team's outcomes with other teams.** What characteristics of other teams' solutions worked well?

6. Describe how the different materials and enclosure designs transferred thermal energy.

Consider adding other teams' data to your data analysis. Consider incorporating 1-2 ideas from another team to optimize your team's design.

Plan to Optimize Design Solutions

1. Consider all the data on thermal properties as well as the data collected in class. Develop an **optimized** (improved) **model for materials and design** to manage heat in your "device." Include a **caption** with an explanation for your material choices supported by **evidence** from your testing data and your communication with other teams.

Caption:

2. **Predict** how you think your new enclosure design will perform in comparison to your previous designs.

3. **Justify** your material(s) choice using:

- Relevant data consistent with the constraints of the thermal performance standards
- Properties of the materials (thermal conductivity, insulators and conductors or specific heat capacity) that were evident in the data

Team construct and test

Optimize Your Design

As a team, you will test and collect data for your optimized enclosure design.

Procedure:

1. Consider the benefits of your previous data table, the most important data for you to collect, and the number of tests you will run. Prepare your data table.
2. Prepare your redesigned enclosure by placing the handwarmers the same way you did in previous tests and use your new material selection and design.
3. Record the internal and external temperature at 0 minutes, 5 minutes, and 10 minutes. Record your data.
4. Repeat this test three times.

Thermal Performance Data Table:

Analyze Thermal Performance:

Now you will analyze the Thermal Performance Data. Use the space below to:

- Analyze the data for an average change in temperature.
- Determine whether the material selected for your enclosure passes the criteria in the safety standards.
- Consider a way to present the team data analysis.

Make Sense of Outcomes:

1. Did your optimized design pass the criteria for thermal performance?
2. What characteristics of your team solution worked well?
3. What characteristics of other team solutions worked well?

Make a Recommendation

1. Restate the problem you were attempting to solve in this engineering design challenge.

2. Make a **claim** about what material(s) are the best choice to use as material in your enclosure design. Remember to consider the thermal performance standard, your stakeholders, and the criteria and constraints facing a lithium-ion battery powered device. Include a model with labels of all materials and components of your design.

   Note: *You do not have to actually construct this design.*

   Claim:

   Model:

3. Provide **evidence** utilizing your data. This can be raw data from tests represented in table format, or a scatterplot showing relationships between solutions (independent variable) and thermal performance (dependent variable).

Language to Consider Applying in your Reasoning

Specific heat	High	Low	Insulator
Transfer	Energy	Conductor	Matter
Absorbs	Releases	Minimizes	Maximizes
Synthetic material	Natural material	Increase	Decrease

4. Include **reasoning** for why your evidence is relevant. Reasoning should justify your proposed solution by making connections to scientific knowledge. Consider using some of the terms listed above.