ECE 398GG Prof. George Gross

Homework 4 Solution

1. Consider an *EV* battery pack made up of 108 prismatic can *Li-ion* cells connected in series. Each cell has the characteristics given in the table below. **Determine** both the cell and pack power, given that the fully charged pack is short circuited with a resistance equal to the pack resistance, *i.e.*, assume that the voltage is halved.

feature	value and unit
rated discharge capacity	140 *Ah*
maximum voltage at full charge	4.2 *V*
nominal discharge voltage	3.7 *V*
nominal discharge resistance	0.5 *mohm*
cell mass	2.11 *kg*
cell dimensions (*t* x *w* x *h*)	31 *mm* x 230 *mm* x 91 *mm*
cell specific heat capacity	1 *kJ/kg*K*

Solution

We use the assumption that $V_{min} = V_{max}/2 = 4.2\ V/2 = 2.1\ V$

$$P_{cell} = 2.1\ V \times (4.2 - 2.1)\ V / [0.5\ mohm/1{,}000\ mohm/1\ ohm) = 8{,}820\ W = \mathbf{8.82\ kW}$$

The series connection implies the voltages are additive and all cells have the same current. Thus,

$$P_{pack} = 108 \times 8.82\ kW = \mathbf{953\ kW}$$

2. **Evaluate** the discharge current for the pack under the assumption that a 10-*s* discharge is underway. **Determine** the equivalent *C-rate.*

Solution

We use the relationship

$P_{cell} = V_{cell} \times I_{cell}$

cell: 8820 W/2.1 V = **4,200 *A***

C-rate = 4200 A/140 Ah = **30 *C***

3. **Calculate** the heating power generated by that cell, under the assumption above.

Solution

$P_{heat} = [(4200\ A)^2 * 0.5\ mohm]\ 1\ ohm/1{,}000\ mohm$ = **8,820 *W* or 8.82 *kW***

4. **Compute** the amount of heat energy generated in one cell in 10s under the assumption of a constant current during that time period.

Solution

$E_{heat} = P_{heat} * t = 8{,}820\ W * 10\ s = 88{,}200\ J$ = **88.2 *kJ***

5. **Estimate** the temperature rise that occurs in the cell under adiabatic conditions

Solution

$T_{rise} = 88.2\ kJ/1\ \text{kJ}/\ kg * K/2.11\ kg$ = **41.8 *K***

6. Consider a discharge with a start temperature of 35 °C, which was determined from the pulse temperature at the end of the discharge. **Identify** the likely cause of the cell failure.

Solution

We evaluate the cell temperature to be

$T_{cell} = 35\ °C + 41.8\ °C\ (K) = \sim$ **77 °*C***

and conclude that some electrolyte decomposition occurred but that it presented no hazard.

7. **Repeat** for the case the cell is short circuited to 0.9 *V*. **Compute** the heat generation and expected temperature rise of the cell. **Determine** the cause of the cell failure.

Solution

P_{cell} = [0.9 *V* * (4.2 – 0.9 *V*)/(0.5 *mohm*)] * (1000 *mohm*/*ohm*)

= 5,940 *W* or 5.94 *kW*

cell current: 5,940 *W* / 0.9 *V* = 6,600 *A*

P_{heat} = (6,600 *A*)^2 * 0.5 *mohm* * (1 *ohm*/1000 *mohm*)= **21, 780 *W* or 21.78 *kW***

E_{heat} = P_{heat} * *t* = 21,780 W * 10 *s* = 217,800 *J* = **217.8 *J***

T_{rise} = 217.8 *kJ* * (*kg* * *K*/2.11kg) / 1 *kJ* = **103 K**

T_{cell} = 35 °*C* + 103 °*C* (*K*) = ~ **138 °*C***

The high temperature indicates separator melting which is associated with internal short circuit risk. The possible onset of cathode decomposition entails release of oxygen and additional heat energy.

8. We are told that a 140-*Ah* cell combusts. **Determine** the maximum additional amount of energy expected to be released from the anode alone.

Solution

140 *Ah* cell has the following attributes

cell energy is: 140 *Ah* x 3.7 *V* = 518 *Wh*

518 *Wh* x 3600 *J*/*Wh* = 1,864 *kJ*

1,864 *kJ* cell / 4.9 *kJ* = 380 *g anode*

63.6*kJ*/*g anode combustion* x 380 *g anode* = 24,193 *kJ combustion energy*

9. Assume the cell skin reaches a maximum temperature of 600 °*C*. The two major cell faces (91mm x 230mm) are protected with a 2 *mm* thick piece of aerogel. **Calculate** the temperature at the end of 10 *s* seen by these two adjacent cells.

Solution

The heat flux per side of aerogel is

$(600\ K * 0.01 W/m * K * 230\ mm * 91 mm/(1000\ mm/\mathrm{m})^2\ )/\ (2\ mm/1000\ mm/m)\ )$

$= 63\ W$ per side

In 10 s this becomes 63 W * 10 s = 630 J

Adjacent cell temperature rise is given by

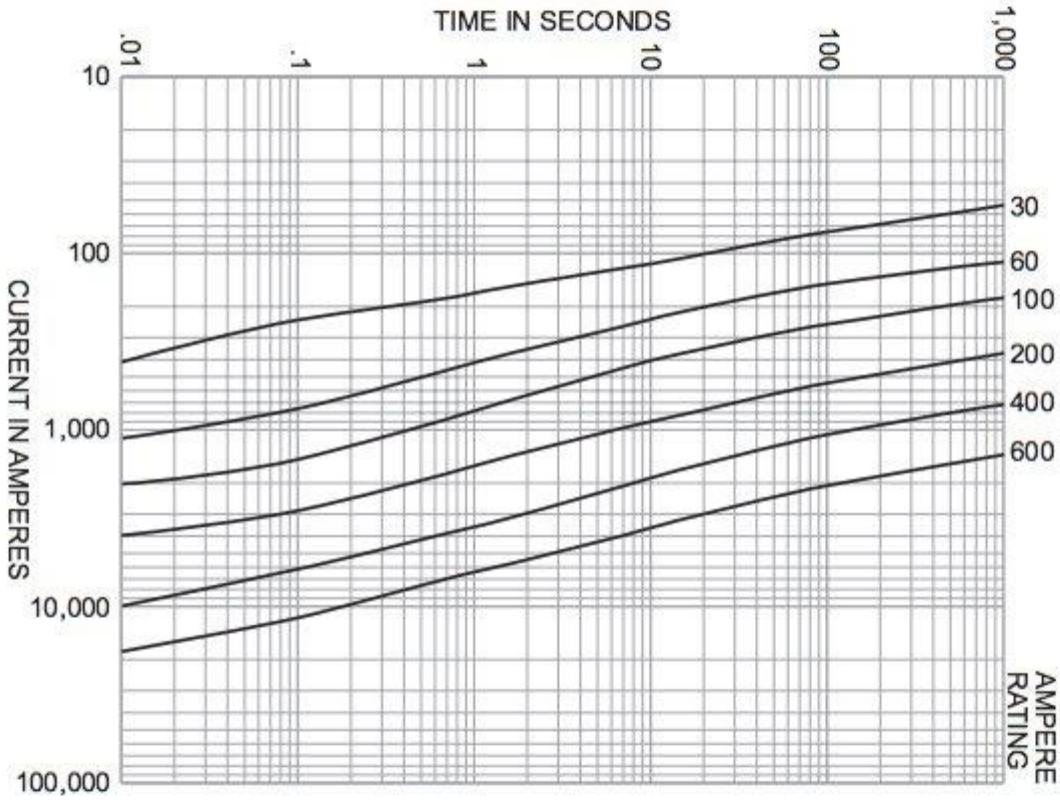
$630 J/\ (1000\mathrm{J}/kJ)\ /\ 1\ kJ/\ kg * K/2.11\ kg = 0.3\ °C$

10. Assume the pack had been engineered to use a 600-A-rated thermal fuse. Use the plot below to **determine** whether the fuse would have activated within the 10 s, 2.1-V short circuit event and at what time. An additional bonus question is to **determine** the pack safe discharge power limit, given the 600-A fuse, so that the fuse would not activate over the life of the pack.

Solution

A 4,200-A fuse would have activated in approximately 2 s.

$$P_{cell} = [3.7\ V - (600\ A * 0.5\ mohm)\ (1\ ohm/1{,}000\ mohm)] * 600\ A$$
$$= \mathbf{2{,}040\ W}$$
$$P_{pack} = 108\ cells * 2{,}040\ W/cell = 220{,}320\ \mathrm{W} = \mathbf{220\ kW}$$



Oliver Gross from Stellantis has also included a few comments of advice he wishes to share with each student.

Some words of advice / comments to the students on the topic of learning objectives:

- The student needs to recognize that the cell is capable of being safe, even at conditions well beyond those specified for the pack.
- The student needs to get a sense of how much energy can be released by a battery, under abusive conditions.
- The student needs to be aware of the benefits a prudent pack design offers in terms of energy management.