21st Century Locomotive Technology: Quarterly Technical Status Report 23 DOE/AL68284-TSR23

This is the quarterly status report for the 21st Century Locomotive Technology project, DOE Award DE-FC04-2002AL68284. This report covers activities performed July 2008 to September 2008.

Task 3: Hybrid Energy Storage

Electrical tests were performed on a subscale sodium metal halide battery to develop thermal heat release parameters that can be used for analysis of a full-size battery system deployed on the hybrid locomotive. Many charge and discharge cycles were applied to the battery and the thermal response was measured, such as illustrated in Fig. 1 below:

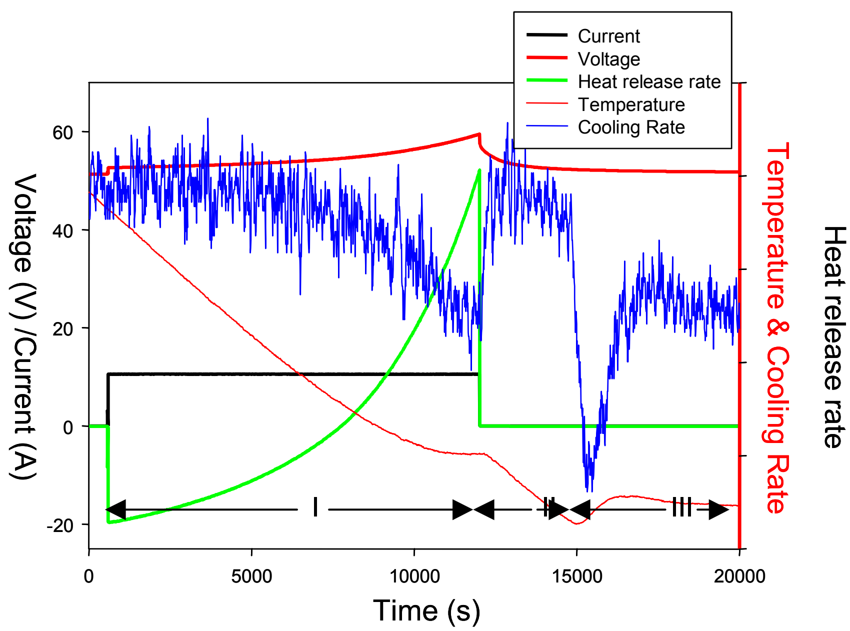

Fig. 1: 10A charge of subscale sodium metal halide battery.

The figure shows the applied current and terminal voltage, temperature, cooling rate and heat release rate (due to applied current). In Phase 1, a constant 10A charging current is applied. The terminal voltage rises with time due to changing inernal resistance as function of state-of-charge. The temperature falls at a rate that reduces with time. At the end of phase 1, the cooling rate is close to zero. The theoretical heat release rate (due to internal resistance combined with the heat of the electrical reaction) is also indicated. In Phase II, the current is removed, and the temperature cooling rate returns to its initial rate. Finally in Phase III, the temperature starts to increase, overshoots before stabilizing at the thermal controller setpoint. In Phase I, the temperature starts out falling due to heat leak through the battery thermal insulation. As the charge period proceeds, the battery internal resistance increases and thus internal heating rate increases. Clearly when the current is turned off at the end of Phase I, the internal heating component stops and the cooling rate returns to the pre-test case heat leak. At the end of Phase II the battery thermal control kicks in to turn on heaters to control the quiescent battery temperature, as seen in Phase III.

The thermal tests were performed over a wide range of charging and discharging currents. In order to avoid errors due to non-equilibrium battery internal temperatures, high current tests were performed to a pulsed protocol. Multiple tests were analyzed to determine the heat capacity and the charging endothermic heat absorption/discharging exothermic heat evolution. These valiudated thermal parameters were incorporated into the battery thermal model, to be used to evaluate battery thermal integration into the hybrid locomotive. Example results from a battery thermal analysis are shown in Fig 2, which covers one hour of operation.

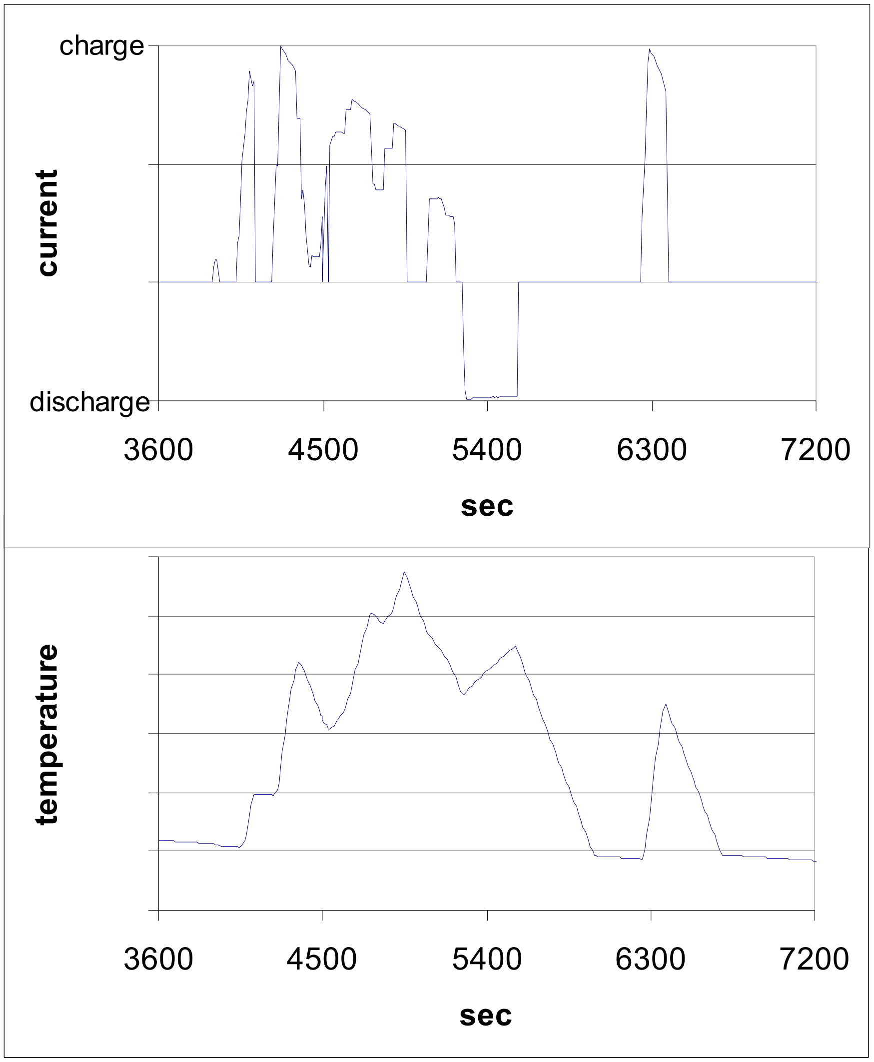

Fig. 2: Battery thermal model transient behavior.

We see that the battery is initially charged at varying current levels, leading to heating and the resulting risa in temperature, which peaks at approx. 5000 sec. At 5000 sec, the charging is interrupted for about 100 sec, at which time the temperature is falling. The temperature rises 5300-5500 sec, corresponding to a battery discharge phase. Subsequently the temperature continues falling until 5900 sec, at which time the cooling air is turned off and the cooling rate becomes much slower. The battery is charged from 6300 to 6400 sec with a resulting increase in temperature, and resumption of forced air cooling. The appropriate heat release and heat capacity parameter values are required to relate battery current to the resulting rise in temperature.

The next steps in the battery thermal analysis will be to update the cooling rate parameters to enable study of cooling control parameters necessary for a full-size hybrid battery bank operating on the hybrid locomotive.