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Thermal behavior of lithium-ion polymer batteries in the presence of phase-change materials

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ABSTRACT

A battery unit is the main power source for under water vehicles such as torpedoes launched against enemy targets. Generally, magnesium sea water activated batteries are employed in these vehicles. The advent of lithium-ion battery technology offers a great promise to develop a suitable battery unit for these vehicles. However, the major drawback of the lithium batteries is their thermal runaway characteristic. A close review of literature reveals that phase change materials (PCM) are used in many applications to contain temperature within limits. In this regard, investigations have been carried out experimentally to study the suitability of different PCMs for a lithium ion polymer (LiPo) battery obtained from trade. Three PCMs viz., OM35, OM37 and OM46 have been used in the present investigations. Preliminary experiments have been carried out to test whether they behave accordingly or not. The LiPo cell was casted on both sides with computed amounts of different PCMs and the temperature variation of the entire cell, its anode and cathode were studied at different discharge rates. It was found that the use of PCM will definitely hold the temperature within the limits during the mission time.

KEYWORDS

Lithium battery;
LiPo cell;
Phase change material;
PCM;
Thermal runaway.

INTRODUCTION

Numerous applications require energy in the stored form. The batteries usually store energy in the chemical form. Among many batteries available in the market, lithium batteries gained much attention in the recent times. Generally, lithium batteries are available as primary batteries and secondary batteries. The secondary batteries are also categorized as Li-ion batteries and Li-ion polymer batteries. The lithium batteries have the advantage of light weight, high voltage, high electrochemical equivalence, good conductivity and can be shaped in various geometries with very high aspect ratios. The disadvantages are thermal runaway, short circuit, explosion when overcharged etc. Their range applications vary from very small button cells used in watches to very large batteries used in torpedoes and other military applications[1].

Several reviews appear in the literature relevant to the present study. The development of batteries in various aspects in the last 50 years has been thoroughly reviewed by Dell[2]. A detailed review on lithium batteries, their present status, prospects and future has been covered thoroughly by Scrosati and Garche[3]. Ritchie and Howard[4] presented a review on recent development and the likely advances achieved in lithium-ion batteries. The conduction phenomena in Li-ion batteries has been comprehensively reviewed by Park et al[5]. The status of Lithium ion batteries and the lithium ion polymer secondary batteries has been reviewed by Blomgren[6].

Gitzendanner et al[7] investigated the suitability of high power and high energy lithium-ion batteries for under water applications because the lithium-ion batteries had been successful due to their excellent energy density, reliability, and life in commercial applications. Pendergast et al[8] explored the suitability of a rechargeable lithium-ion battery module for underwater use. Zhang et al[9] analyzed the thermal modeling and cooling of high-power lithium ion cells. Lithium ion polymer batteries using microporous polyvinylidenefluoride PVdF filled by the liquid electrolyte as polymer electrolyte have been investigated by Saunier et al[10]. It was found that the conductivity depended only on PVdF porosity. This battery performance showed its potential applications. New designs for safe lithium-ion gel polymer battery were proposed by Sato et al[11]. Several solutions against thermal runaway have been proposed by Zeng et al[12].

Satyavani et al[13] investigated the electrical and thermal behaviors of Li-Po cells, the effect of self discharge, the effect of charge stand period, normal cycling, quick Cycling etc were studied. The temperature profiles during discharge were also obtained. Srilaxmi[14] developed correlations for temperature rise of anode and cathode of a LiPo cell in terms of discharge rate and time duration.

Farads et al[15] comprehensively reviewed the phase change materials as latent energy storage materials. The PCMs were classified into three categories viz., organic, inorganic and eutectic. Selecting a suitable PCM is dependent on thermal, physical, kinetic and chemical properties along with cost effectiveness. Kumar et al[16] have provided the current technology status of PCMs along with their potential applications for defence purpose.

A close inspection of the literature revealed that several works[17-22] have been reported on thermal management of Li-ion batteries. Also the Li-ion polymer batteries offer a good promise to use in under water military and other applications. But the basic disadvantage is their thermal runaway nature. This is more likely to lead to explosion when big battery units are employed in confined spaces. There is also a good possibility of employing suitable PCMs with lithium ion polymer batteries especially used for under water applications[23]. An inspection of the literature revealed that work in this direction is scarce. In view of this the present work has been attempted. The range of variables covered in the present study is compiled in TABLE 1.

TABLE 1 : Experimental conditions used in the present experiment

Parameters studied		Values/Range of parameters
Discharging rate		
C-rate	Current	Duration
1-C	40 A	60 min
2-C	80 A	30 min
3-C	120 A	20 min

EXPERIMENTAL

A single cell module of the Lithium Ion Polymer (LiPo) battery was chosen for the present work along with PCMs. Its specifications were compiled in TABLE.2. The apparatus and equipment employed to carry out the discharge studies of the single cell module in the present study essentially consisted of an elec-

TABLE 2 : Specifications of Lithium-Ion Polymer battery (Cell & Single Cell module)

S.No.	Parameter	Description
1	Length of cell	220 ± 2 mm
2	Weight	1081 g
3	Capacity of each cell	40 Ah
4	Open Circuit Voltage (OCV)	4.2 V
5	Nominal Cell Voltage	3.7 V
6	Discharge current	40 A
7	Discharge cutoff voltage	2.7
8	Discharge time period	Not less than 54 min at 40 A (approx. per hour)
9	Peak Current	120 A for one second
10	Cycle life	Not less than 200 cycles at 90% discharge on duty (DOD) at 1-C rate
11	Shelf life	More than 5 years at a storage temperature of 25-40°C
12	Operating temperature	15 to 60°C

tronic load bank, and thermocouple based temperature sensors connected in a discharge circuit. The experiments were also conducted to obtain the temperature rise during discharge of LiPo cell without PCM. Experiments were also conducted to compute the heat output during discharge at specified C-rate. Appropriate quantity of PCM was melted and casted over both sides of LiPo cell. Experiments were conducted by taking the cell combined with computed quantity of PCM. Three different PCMs viz., OM35, OM37 and OM46 were used in the experimentation. The catalogue number OM35 means Organic Material having a melting point of 35°C. These PCMs were obtained from trade.

RESULTS AND DISCUSSION

Experiments were conducted to measure the variation of temperature for a given heat input to the PCMs without LiPo cell. These experiments are essential to make out whether the PCMs serve the required purpose or not. The data obtained from the preliminary experiments have been analyzed and presented in section 3.1. The data obtained from discharging the Li-ion polymer cell casted with the PCM were analyzed in section 3.2.

Studies with PCM

One liter of water was taken in an insulated vessel and a constant input of 100 W was supplied to water which was the system under consideration. The change in the temperature of the water was measured and was shown as plot A in Figure 1. In another similar chamber, 200g of OM35 was also added to the system. The temperature measured in this case was shown as plot B in Figure 1. A close inspection of these plots revealed that the temperature difference to a maximum of 15°C could be noticed at a point where the OM35 was undergoing melting process which was seen at about 1500 s. With further increase in time, the difference in the temperatures got decreased which could be attributed to the complete melting of the PCM.

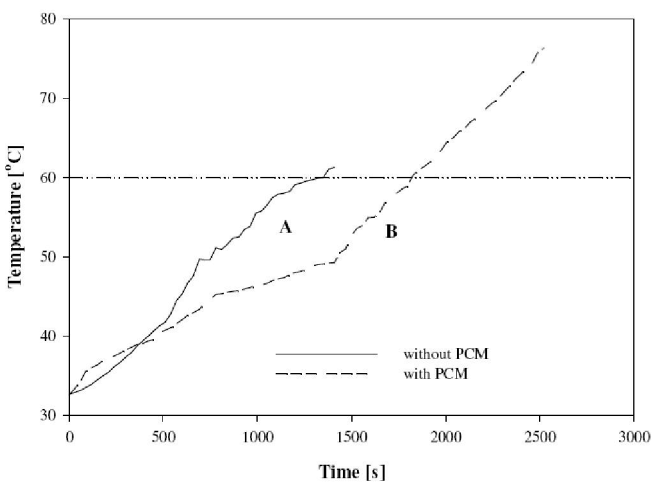

Fig.1: Temperature of the system with PCM OM35 (200g) when the input is 100 W.

Effect of weight of PCM

Experiments conducted in similar fashion by employing OM46 as the PCM. Different quantities of PCM were taken in the present case. The temperature of the system obtained for these situations was shown in Figure 2. Plot A corresponds to the case of no PCM, plot B with 50 g of OM46, plot C with 100 g OM46 and plot D with 200 g of OM46. It could be observed from these plots that addition of PCM to the system was definitely advantageous as it brought significant cooling effect by maintaining the temperature of the system less than the acceptable temperature limit of 60°C for a period upto 2500 s i.e., 41 minutes. Therefore, the PCMs are definitely useful to contain the temperature well below the acceptable limits.

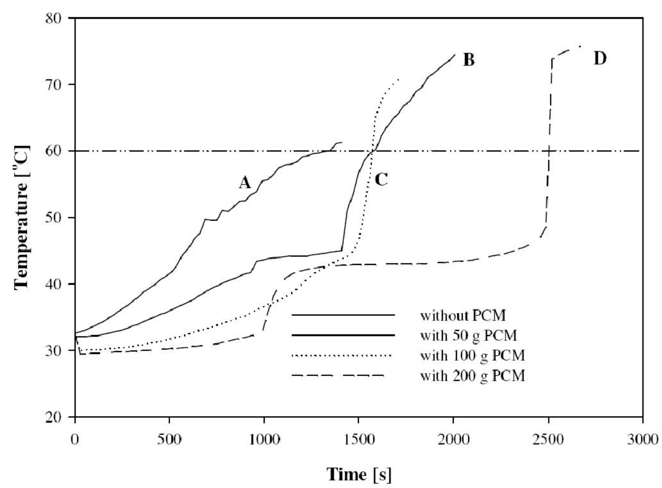

Fig.2: Effect of weight of PCM (OM46)

Comparison of different PCMs

Temperature data obtained in the similar conditions for the cases of no PCM, 100 g each of OM35, OM37 and OM46 were drawn against time and shown in Figure 3. These data were shown respectively by means of plots A, B, C and D. It is clear from these plots that the addition of PCM has helped in realizing low tem-

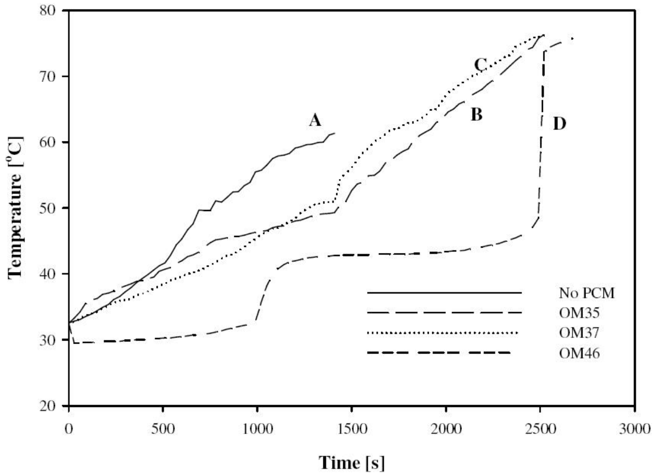

Fig.3: Comparison of different PCMs of 200 g

peratures. Also the duration of obtaining the temperature limit of 60°C was increased with increase in the melting point of the PCM.

Studies on lithium batteries with PCMs

The Lithium polymer battery was casted on both sides with computed weights of different PCMs used in the present experimentation. The weight of the PCM used was computed from the heat output data measured under discharge of different C rates. The cathode and anode temperatures were measured in these experiments.

Reproducibility of electrode temperature

Variation of cathode temperature of the lithium ion polymer battery has been obtained in the presence of 159 g of OM35 for a constant discharge rate of 1C i.e., 40 A. To check the reproducibility of the data, the experiments were repeated for three times. The cathode temperature data obtained in these three experiments have been shown in Figure 4. for a discharge rate of 1C. The plots of the Figure showed good reproducibility of the cathode temperature. Similarly, anode temperature reproducibility has also been shown in Figure 5 for 1C discharge rate. Likewise, the temperature data were obtained for all combinations at discharge rates of 2C and 3C. All such data exhibited good reproducibility.

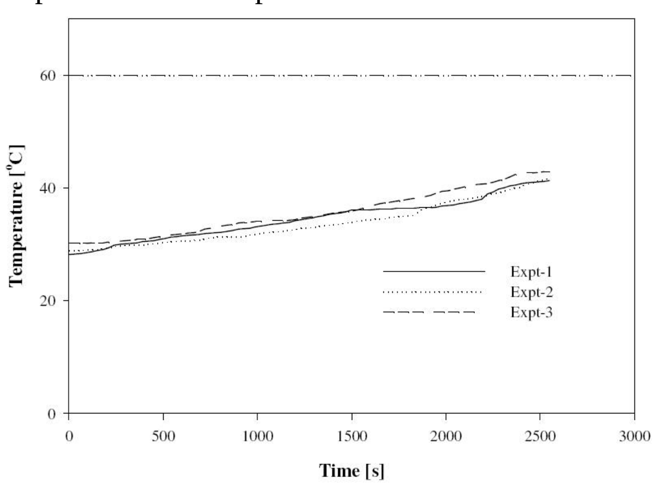

Fig.4: Variation of cathode temperature in different experiments with PCM (OM35) at 1C rate

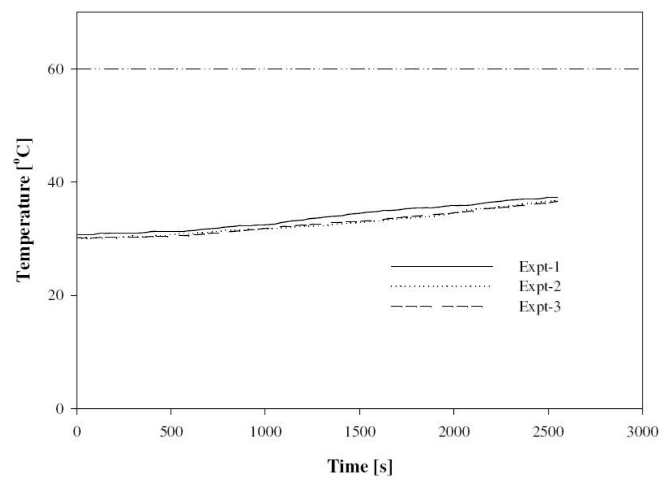

Fig.5: Variation of anode temperature in different experiments with PCM (OM46) with 1C rate

Effect of PCM type on electrode temperature

Variation of cathode temperature of the lithium ion polymer battery has been obtained in the presence of different PCMs viz., OM35 (159 g), OM37 (144 g) and OM46 (125 g) for a discharge rate of 1C. The cathode temperature has been plotted against time for all these cases and shown in Figure 6. A close inspection of the plots of this Figure revealed that the tem-

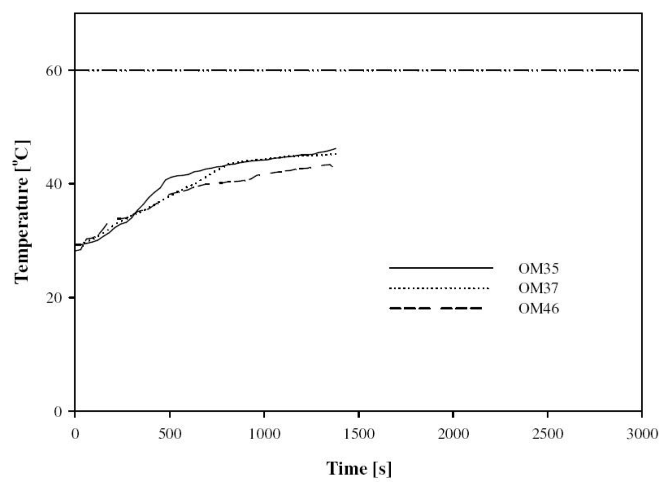

Fig.6: Variation of cathode temperature for different PCMs at 2C rate

perature of the cathode is more or less same in the presence of these PCMs. Similar results were observed from Figure 7 drawn for anode temperature at the same discharge rate of 1C.

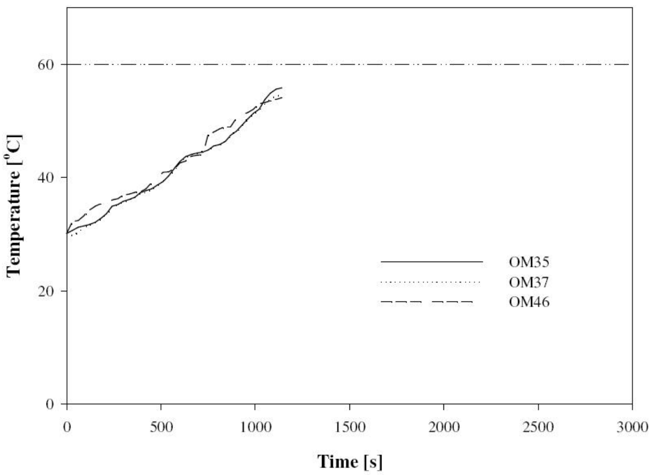

Fig.7: Variation of cathode temperature for different PCMs at 3C rate

CONCLUSIONS

Based on the studies and experiments presented in the preceding section the following conclusions are drawn:

Rise in temperatures at cathode and anode of a 40 Ah lithium-ion polymer cell at different rates of discharge are studied.

Method of control of temperature of cell is established through use of Phase Change Materials.

Type and quantity of PCMs to be used for a 40 Ah capacity LiPo cell to keep the temperature under control during different rates of discharge have been determined.

Use of PCMs is one effective method for thermal management in a LiPo battery.

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