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RECONDITIONING OF Li-ION RECHARGEABLE BATTERIES, A POSSIBLE SOLUTION FOR BATTERIES CIRCULAR ECONOMY

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This paper presents the results achieved for the reconditioning of some lithium-ion batteries that were considered inappropriate for usage in their applications. In order to evaluate the efficiency of the reconditioning procedure, one has calculated a reconditioning degree (g_r), which indicates the percentage of the rechargeable battery recovered capacity versus its nominal capacity. This procedure shows promising results for structural sound intact batteries and one may see that after the reconditioning process, the recovered capacity of the lithium-ion batteries may reach up to 95% of its initial capacity stated in the technical specifications. The results obtained indicate that the recondition of lithium-ion is a procedure which may be introduced as an alternative way for recycling, this procedure allowing the reintroduction of these batteries to their originally intended use decreasing the amount of rechargeable lithium-ions batteries that end up to recycling, as well as decreasing the market demand and saving valuable metals used for their manufacture.

Keywords: Lithium-ion batteries; reconditioning procedure; degree of reconditioning; energy consumption

1. Introduction

Batteries are electrochemical energy storage devices widely used for various purposes. Among batteries, secondary batteries or rechargeable batteries such as nickel-metal hydride (Ni-MH) and lithium-ion batteries are preferred as mobile power sources for cell phones, portable computers and electric vehicles as they have a high capacity, a high energy density and present a potential for recovery or recycling [1, 2].

Lithium-ion batteries have numerous applications in portable electronic products, with wide applications in miniaturised gadgets, laptops, electric vehicles and for aerospace purposes. This is mainly due to their inherent properties such as higher energy density and slow discharge rate in idle mode. However, this type of batteries has a short lifespan and contains potentially toxic components, such as

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metals (e.g. copper, nickel, lead, cobalt) and organic compounds (toxic and flammable electrolytes containing $LiClO_4$, $LiBF_4$ and $LiPF_6$). These compounds may have adverse effects on the environment if a proper disposal or recycling of these batteries should not be performed [1-3].

Another issue that should be taken into consideration when dealing with lithium-ion batteries is the availability of lithium, as the number of lithium-ion batteries put on the market is increasing. In this regard, the recycling of lithium from spent batteries could provide additional lithium supply; however, the recycling of lithium from spent batteries is a niche market and at present time the recycled material is not reused for batteries production. Although concerns regarding the availability of lithium in conjunction with the growing market of electric vehicles exist, few reports are available on this matter and in most cases, the recovery of lithium from spent batteries is treated together with the recovery of other metals of concern [4].

The global market for electric vehicles is increasing and over 3.1 million units were put on market in 2017, of which 1.9 million units of battery electric vehicles and 1.2 million units of plug-in hybrid electric vehicles. The amount of spent batteries was estimated to be around 0.8 million metric tons by 2027, considering an average lifespan of the vehicles of 10 years [5]. The recycling of spent batteries is one the most promising options as it may reduce the environmental impact of batteries whilst recovering the useful components, such as metals (copper, cobalt, nickel, lithium) and facilitates their further reuse in battery production [5-7].

Lithium-ion batteries use a wider variety of materials compared to other types of batteries, such as lead-acid or NiMH, and have 100 or more individually cells packed into modules [6, 7]. A current practice when dealing with spent lithium-ion batteries is the recycling of useful components, mainly metals such as copper, nickel, cobalt and lithium, and their reuse in various purposes [2].

A key aspect in the recycling of lithium-ion batteries is their varied composition and chemistry, which confers complexity to the recycling processes. Also, the recycling is profitable only when large amounts of spent batteries are processed. Another factor that influences the recycling process is the value of the recovered compounds. In the case of lithium-ion batteries, metals such as copper, cobalt, nickel and lithium are recovered [8]. In the context of more and more efforts regarding the extension of batteries lifetime, a procedure consisting of reconditioning has been developed and tested, as a possible way for the battery circular economy [9, 10].

This paper presents the results obtained during the testing of the reconditioning procedure for spent lithium-ions batteries and provides a cost analysis of the energy consumption necessary for the reconditioning.

2. Experimental part

One has applied the reconditioning procedure on 20 Li-ion batteries (US18650G3 with a capacity mentioned in the technical specification of 1800mAh and St14650 with a capacity of 1200mAh), that were employed in various applications. One has labeled the St14650 batteries with numbers from 1 to 18 and the US18650G3 with 19 and 20. The reconditioning procedure applied was previously tested on different lithium-polymer batteries [9, 10].

This procedure was preceded by an evaluation stage in order to see the state of the batteries. The evaluation of the batteries has two steps, one of a visual evaluation in order to identify any deformations of the outer casing and one of battery testing. The testing consisted of a measurement of the electromotive force and a charging/discharging cycle in order to identify the actual battery capacity. Both the evaluation and the reconditioning procedure were performed with a professional PRO-PEAK Prodigy II digital charger/discharger, connected to a power source at a constant voltage of 12V. The charging step of the reconditioning was performed at a constant current of 1A, and for the discharging step, the current was set to 0.6A for the St14650 batteries and to 0.9A for the US18650G3 ones. The end of the discharging step represents the moment that the voltage of the battery reaches a terminal voltage of 3V, in order to prevent any damaging of the battery. For each step, one has recorded the charging capacity and the discharging capacity. When the reconditioning procedure was over, one has evaluated the performances of the lithium-ion batteries, in order to determine the reconditioning degree of each sample.

3. Results and discussions

The most relevant information about the state of the lithium-ion batteries is the discharging capacity, since this is the main parameter which is representative for their usage. The values of the discharging capacity of the investigated lithium-ion batteries before and after applying the reconditioning procedure are presented in Fig. 1.

In order to see more clearly the effect of the reconditioning procedure, one has calculated a reconditioning degree (equation 1), which may be defined as the amount of restored capacity reported to the one mentioned in the technical specifications.

$$g_r = \frac{Q_r}{Q_i} \cdot 100, \% \qquad (1)$$

where g_r = reconditioning degree, %

Q_r = the discharge capacity after the reconditioning procedure, mAh

Q_i = the capacity specified in the technical specification for each type of battery (1200mAh, respectively 1800mAh)

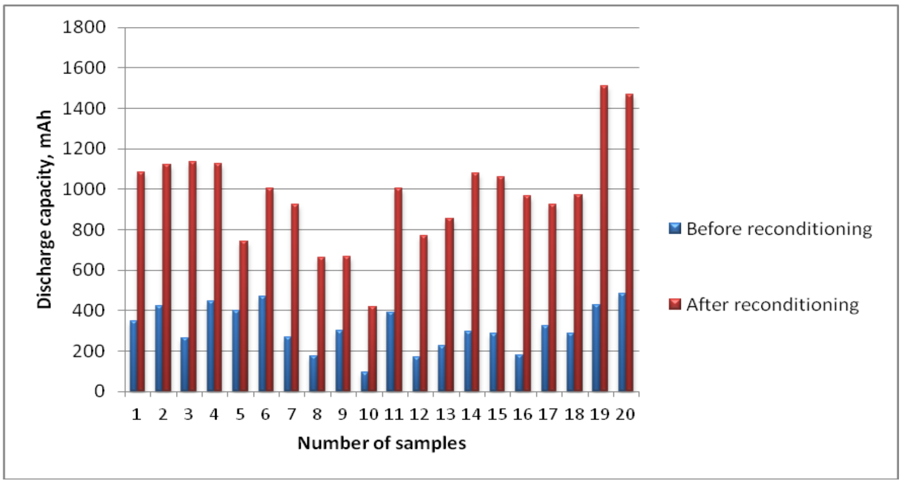

Fig. 1. The values of the discharging capacity of the investigated lihium-ion batteries before and after applying the reconditioning procedure.

The values of the reconditioning degree were calculated and are depicted in Fig. 2.

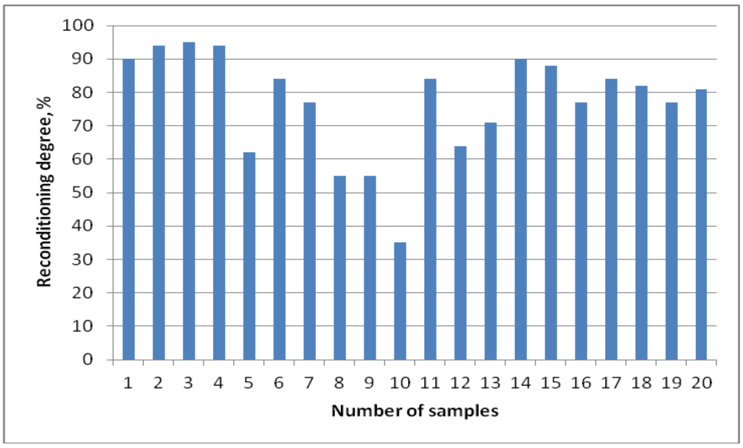

Fig.2. The values of the reconditioning degree for the tested lithium-ions batteries

In order to consider successful the reconditioning of a lithium-ion battery, a reconditioning degree higher than 60% should be achieved. From the representation of the reconditioning degree in Fig. 2., it is observed that 3 out of 20 lithium-ion batteries have a reconditioning degree lower than 60%, hence these samples are considered prone to recycling. The most important observation is that 5 out of 20 samples have been restored up to 90% and higher, which is an important recovery of the capacity.

Moreover, using the results obtained, one may calculate the amount of energy necessary for the reconditioning procedure, and therefore the cost of the energy involved in the process. The total amount of energy consumed in the reconditioning process is the sum of the energies for the initial evaluation (E_i), the energies for the five charging/discharging steps ($\sum_{n=1}^{5} E_r$) and one consumed in the final evaluation of the lithium-ion battery (E_f) (equation 2).

$$E = E_i + E_f + \sum_{n=1}^{5} E_r \quad (2)$$

Since the voltage is constant at a 12V value, one may easily calculate the energy as follows (equation 3):

$$E = 12(Q_e + Q_f + \sum_{n=1}^{5} Q_{r,n}) \quad (3)$$

where: Q_e = the sum of the charging and discharging capacity for the preliminary evaluation step, Ah

Q_f = the sum of the charging and discharging capacity for the final evaluation of the batteries, Ah

$Q_{r,n}$ = the sum of the charging and discharging capacity for each step of the reconditioning process, Ah. For example, in Table 1 is presented the energy consumed for the reconditioning of three samples, which represent the maximum, a medium and the lowest samples regarding the consumption of energy.

Table 1

The energy consumption of the reconditioning of three lithium-ions batteries

Sample number	Q_e, Ah	Q_f, Ah	Q_r, Ah	Energy (E), kWh	Price, Euro
3	0.60	2.40	5.4	0.1008	0.0083
10	0.19	0.85	2.8	0.0460	0.0038
12	0.34	1.70	4.8	0.0820	0.0068

Also, taking into account that in Romania, the value of a kWh is 0.0821euros/kWh (VAT excluded), one may calculate the cost of the energy consumed during the reconditioning of the lithium-ion batteries.

4. Conclusions

The reconditioning procedure has been applied on a batch of 20 lithium-ion batteries that were considered inappropriate for any more usage. From the tested batteries, it was possible to successfully recondition a number of 17 batteries (85% of the batch of batteries). The recovery state of the lithium ions was identified by calculation a reconditioning degree. An example of a calculus for the energy consumption of the reconditioning process was presented.

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R E F E R E N C E S

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