

Battery Recyclability Assessment System and Method

Technical Field

5 The present application relates to battery recycling technology. In particular, the present application relates to a battery recyclability assessment system and method for grading batteries.

Background

10 Batteries such as lithium rechargeable batteries have becoming one of the most widely used mobile energy sources in many industrial and daily life applications. With the usage of rechargeable batteries greatly increasing, aged and discarded batteries have become a major issue of environmental concern and sustainability of social developments.
15 Industrial players have been endeavoured with continuous efforts in developing effective and practical solutions for rechargeable battery recycling for the purposes of possible environmental pollution reduction and the better reuse of the precise metals and other materials from the recycled battery parts.

20 Known battery recycling technologies process used and retired batteries by mixing batteries of various types, models and grades together. As the electrochemical status such as the state of charge, health status and remaining power of used and retired batteries vary in any given batch, conventional battery recycling processes face problems of long treatment time, high power consumption and low level of efficiency. Further, broken or
25 defective batteries may also give rise to safety concerns.

 It is therefore desirable to provide a solution to improve the battery recycling efficiency.

30 Summary

 According to one aspect, the present invention provides a battery recycling assessment method. In one embodiment, a battery recycling assessment method comprises

identifying a volume variation of a battery-under-test; identifying an external surface degradation of the battery-under-test upon the volume variation being determined not exceeding a predetermined volume variation threshold, and obtaining electrical characteristics of the battery-under-test to determine a recyclability of the battery-under-test upon the external surface degradation being determined not exceeding a predetermined surface degradation threshold. Determining a volume variation of a battery-under-test comprises hermetically sealing the battery-under-test in a chamber; filling the chamber with a volume of test air until an air pressure in the chamber reaching a predetermined level; comparing the volume of test air with a volume of reference air corresponding to a reference battery. The reference battery has a specification the same as the battery-under-test. The volume variation of the battery-under-test is determined by a difference between the volume of reference air and the volume of test air.

According to another aspect, the present invention provides a battery recyclability assessment system. In one embodiment, a battery recycling assessment system comprises a first apparatus configured for determining a volume variation of a battery-under-test, a second apparatus for determining an external surface degradation of the battery-under-test, a third apparatus configured for determining electrical characteristics of the battery-under-test, and a data storage module in data connection with the first apparatus, the second apparatus and the third apparatus. The first apparatus, the second apparatus and the third apparatus are respectively configured for determining a volume variation of a battery-under-test according to a method as defined and described above.

Brief Description of Drawings

The technical solutions and corresponding technical features of the embodiments will be more comprehensively understood in conjunction with the accompanying drawings, in which:

Fig. 1 is a flow chart showing a battery recyclability assessment method according to one embodiment of the present invention;

Fig. 2 is a flow chart showing further steps of the method shown in Fig. 1;

Fig. 3 is a flow chart showing further steps of the method shown in Fig. 1;

Fig. 4 is a flow chart showing further steps of the method shown in Fig. 1;
Fig. 5 is a flow chart showing further steps of the method shown in Fig. 1;
Fig. 6 is a flow chart showing further steps of the method shown in Fig. 1;
Fig. 7 is a block diagram showing a battery recyclability assessment system
5 according to one embodiment of the present invention;

Fig. 8 is a block diagram showing the battery recyclability assessment system as shown in Fig. 7 and with additional modules;

Fig. 9 is a block diagram showing additional modules of the battery recyclability assessment system as shown in Fig. 8;

10 Fig. 10 is a block diagram showing additional modules of the battery recyclability assessment system as shown in Fig. 8;

Fig. 11 is a block diagram showing additional modules of the battery recyclability assessment system as shown in Fig. 8;

15 Fig. 12 is a block diagram showing additional modules of the battery recyclability assessment system as shown in Fig. 8.

Detailed Description

20 The present invention provides a method and system for battery recyclability assessment, for the purposes of pre-selecting waste and/retired batteries for recycling. Batteries satisfying the predetermined pre-selection criteria are sent for recycling processing, and batteries dissatisfying the pre-selection criteria are determined to be unsuitable for recycling, and are abandoned and disposed off without sending for recycling processing so that the recycling facilities and resources are optimized and recycling
25 efficiency improved.

As shown in Figs. 1 to 5, according to one embodiment, a battery recyclability assessment method 100 comprises, at step 110, identifying a volume variation of a battery-under-test, as compared with a new battery having the same specification. In the context,
30 a volume variation of a battery refers to situations where, due to the quality, the actual usage and/or the working environment, a change or variation of the shape and/or volume of the battery which is identified as one of the criteria to determine the actual situation of the battery for recyclability. For example, a battery may become partially or locally

collapsed and/or embossed as may be taken place on the external surfaces of the battery. A battery recyclability assessment method according to the present invention is able to determine the recyclability of the battery by assessing the nature and level of such defects, as illustrated in further detail below.

5

As shown in Fig. 2, in one embodiment, the step 110 of identifying a volume variation of a battery-under-test may further comprise a step 112 of hermetically sealing the battery-under-test in a chamber and thereafter, at step 114, filling the chamber with air until an air pressure in the chamber reaches a predetermined level, and the volume of air filled into the chamber is recorded and denoted as M1, and referred in the context as the volume of test air. The air as filled in the chamber thus occupies the inner space of the chamber and surrounds the external surface of the battery-under-test.

The volume of test air M1 is then compared, at step 116, with a volume of reference air M0. The volume of reference air M0 is one pre-stored in a database or a lookup table, i.e. the volume of air filled in the same chamber, or a chamber with the same internal volume, after a reference battery is hermetically sealed in the chamber. The reference battery is one having the same specification and model as the battery-under test, and has a volume according to the specification without surface defect, deformation or change of volume. The reference battery may be a brand-new battery, or one the external shape, volume and surface situation have passed a quality check and in this regard, the reference battery is referred to as a defect-free battery.

Alternatively, in cases where such a database or a lookup table it not available, the method 100 may comprise a step 120 of establishing a volume of reference air corresponding to a reference battery. For example, as shown in Fig. 3, the step 120 of establishing a volume of reference air corresponding to a reference battery may comprise, at step 122, hermetically sealing the reference battery in the chamber and at step 124, filling the chamber with the volume of refence air M0 until an air pressure in the chamber reaching the predetermined level. In cases where a database or a look up table is available, as illustrated above, the reference battery is one having the same specification and model as the battery-under test, and has a volume according to the specification without surface defect, deformation or change of volume. The reference battery may be a

brand-new battery, or one the external shape, volume and surface situation of which have passed a quality check and in this regard, the reference battery is referred to as a defect-free battery. The volume of refence air M0 so established will then be used for comparison with the volume of test air M1. Upon comparison, as shown in Fig. 2, a volume variation w may be derived by subtracting the volume of test air M1 from the volume of reference air M0.

Preferably, the chamber has a first temperature when filled with the volume of reference air, the chamber has a second temperature when filled with the volume of test air, and the second temperature is the same as the first temperature. Setting at the same temperature in the chamber is advantageous of simplifying the measurement comparison of the air volume of test air and the volume of reference air. Alternatively, the second temperature needs not be the same as the first temperature, and the volume of test air and the volume of reference air may be measured and compared by taken the air temperature into consideration, according to the ideal gas equation of state.

As shown in Figs. 1 and 2.the method 100 then determines, at step 130, a difference w between the volume of reference air M0 and the volume of test air M1. If $w > 0$, the method 100 determines that the volume of test air occupies a space in the chamber less than the space occupied by the volume of refence air, which indicates that the battery-under-test is expanded / inflated as compared to the reference battery. In cases where the value of w exceeds a predetermined threshold w_0 , the method 100 determines that the battery-under-test is over-expanded / over-inflated to a situation or level unsuitable for recycling i.e. the battery-under-test is non-recyclable.

Likewise, if $w < 0$, the method 100 determines that the volume of test air occupies a space in the chamber greater than the space occupied by the volume of refence air, which indicates that the battery-under-test is shrunk or collapsed as compared to the reference battery. In cases where the absolute value of w exceeds a predetermined threshold, i.e. $|w| > w_0$, the method 100 determines that the battery-under-test is shrunk or collapsed to a situation unsuitable for recycling i.e. the battery-under-test is non-recyclable.

In any event, the variation of value w may be taken in an absolute form $|w|$, as depicted in Fig. 2, in which, the method 100 determines that the battery-under-test is non-recyclable when the absolute value of w exceed a predetermined threshold w_0 , i.e. $|w| > w_0$, which collectively corresponds to a situation where the battery-under test is either over-expanded / over-inflated or severely shrunk / collapsed. A battery-under-test so determined is then rejected from further processing and maybe disposed off at step 131.

As shown in Fig. 1, a battery-under-test thus processed and not rejected after the above-illustrated step 130 is then processed under step 150, at which, the method 100 identifies an external surface degradation of the battery-under-test. In the context, the term “surface degradation” refers to predetermined defects identifiable on the external surfaces of a battery-under-test. Such defects may include, e.g. scratches, dents and/or embossments on the external surface(s) of a battery-under-test, and the scratches, dents and/or embossments on the external surface(s) are not present in a brand-new battery or any battery which is identified to meet quality standard.

As shown in Fig. 4, the step 150 of identifying an external surface degradation of the battery-under-test may comprise, at step 152, capturing an image of the external surface of the battery-under-test and at step 154, identifying surface defects of the battery-under-test from the image. The step 152 of capturing an image of the external surface of the battery-under-test maybe implemented by an imaging device, and through a telecentric lens. A telecentric lens is advantageous in capturing high-resolution images of objects within a certain object distance at a same level of image magnification. The surface defects refer to and include at least one of a scratch, a dent and an embossment on the external surface of the battery-under-test, and the predetermined surface degradation threshold includes a predetermined dimension threshold.

At step 156, the method 100 compares the surface defect with the predetermined surface degradation threshold. Upon a physical dimension of the at least one of a scratch, a dent and a bump exceeding the predetermined dimension threshold, the method 100 determines, at step 170, that the battery-under-test is non-recyclable, i.e. the battery-under-test as determined is unsuitable for recycling due the surface defect identified. A battery-

under-test so determined is then rejected from further processing and maybe disposed off at step 171.

As an alternative of step 150 and 170, the method 100 comprises at step 160, after a battery-under-test being not rejected due to exceeding a volume variation threshold at step 130, of determining the recyclability of a battery-under-test with respect to a nature of surface defects on the battery-under test. As shown in Fig. 5, the step 160 comprises a step 162 of capturing an image of the external surface of the battery-under-test, a step 164 of identifying a surface defect of the battery-under-test from the image and followed by a step 166, to determine whether the battery-under-test is recyclable based on a nature of surface defects on the battery-under test. If the surface defect includes a recessed portion and a raised portion, the battery-under-test is determined to be non-recyclable, and rejected at step 167.

Steps 162, 164 and 166 may be implemented in situations where a battery-under-test passes step 130 for further processing, i.e. a battery-under-test is determined to have no volume variation, or with a volume variation within the predetermined volume variation threshold, but may still have a volume variation exceeding the predetermined volume variation threshold. For example, such situation may exist in batteries-under-test where there is a negative volume variation e.g. a recessed or collapsed portion and a positive volume variation e.g. a raised portion, under which, the volume variation determined may not reflect the actual situation due the possibilities of the raised portion and the recessed portion offsetting the overall battery volume variation against each other. Under this scenario, steps 162, 164 and 166 may be executed to nonetheless determine a battery-under-test having a recess portion and a raised portion as non-recyclable.

For batteries-under-test passing the above-illustrated steps of volume variation determination and surface degradation determination, as shown in Fig. 6 and in conjunction with Fig. 1, the method 100 comprises a step 190 of obtaining electrical characteristics of the battery-under test. The electrical characteristics of the battery-under-test includes a state of charge, a health status and a remaining power of the battery-under test, and step 190 comprises a step 192 of obtaining electrical characteristics of the battery-under-test by assessing the state of charge, the health status and the remaining

power of the battery-under test, by a multimodal evaluation module, an electrochemical model module, an equivalent circuit model module and a neural network model module.

According to another aspect, the present invention provides a battery recyclability assessment system. In one embodiment, as shown in Figs. 7 to 12, a battery recyclability assessment system 200 comprises a first apparatus 210 configured for identifying a volume variation of a battery-under-test, a second apparatus 220 configured for identifying an external surface degradation of the battery-under-test, a third apparatus 230 configured for obtaining electrical characteristics of the battery-under-test, and a database module 280 coupled to and in data communication with the first, second and third apparatus 210, 220 and 230.

The first apparatus 210 comprises a hermetically sealable chamber 212, an air supply device 214 connected to the chamber 212 for filling air into the chamber, and a measurement device 216 coupled to the chamber for determining a volume, a temperature and a pressure of air filled into the chamber 212. The measurement device 210 is in data communication with the data storage module 280 for transferring data related to the volume, the temperature and the pressure of air filled into the chamber with the data storage module 280.

The second apparatus 220 comprises an imaging device 222 with a telecentric lens 224 coupled to the imaging device 222 for capturing an image of a battery 40, and an image processor 226 coupled to the imaging device 222 for receiving and processing images captured by the imaging device, and the image processor 226 is in data communication with the data storage device 280 for transferring data with the data storage device 280.

As shown in Fig. 8, the system 200 may further comprises a data acquisition module 230, a data pre-processing module 240, a multimodal evaluation module 250, a comprehensive evaluation module 260 and a transfer learning module 270 coupled to the data storage module 280.

As shown in Fig. 9, the data acquisition module 230 may further comprises a battery data acquisition module 232 and an environment data acquisition module 234.

As shown in Fig. 10, the multimodal evaluation module 250 may further comprises an electrochemical model evaluation module 252, equivalent circuit model module 254, a neural network model module 256 and an electrothermal coupling model module 258.

As shown in Fig. 11, the comprehensive evaluation module 260 may further comprises a state of charge evaluation module 262, a battery health status evaluation module 264 and a remaining power evaluation module 266.

As shown in Fig.12, the data storage module 280 may further comprises a battery standard specification database 282, a model database 284, an evaluation result database 286 and a system database 288.

When used for battery recyclability assessment and in line with the method and steps as illustrated above and in conjunction with Fig. 7, a battery-under test 40 is placed and hermetically sealed in the chamber 212. Air is then filled into the chamber 212 from the air supply device 214. The temperature, pressure and air volume filled into the chamber 212 are measured by the measurement device 216. The volume of the battery-under-test can then be determined according to the method illustrated above and in conjunction with Figs. 1 to 6.

The result of assessment of a state of charge, a health status and a remaining power of the battery-under test may be collected and stored in a data storage device for further processing e.g. comprehensive evaluation. The comprehensive evaluation may be implemented using algorithms such as Weighted Averages, Kalman filter and/or Bayesian fusion. The result of comprehensive evaluation and corresponding battery basic data may be used for subsequent model training to obtain comprehensive battery evaluation model for evaluation efficiency improvements.

Embodiments of the present invention are presented above for purposes of illustration and description of the technical solutions and relevant technical features

therein, but is not intended to be understood to be exhaustive or limiting. Modifications and/or variations will become apparent to those of ordinary skilled in the art to contemplate and implemented based on the inventive concept and technical solutions disclosed herein. The example embodiments are chosen and described to explain principles and practical application of the present invention, and to enable those of ordinary skilled in the art to understand the disclosure for various embodiments with various modifications as are suited to the particular technical solution contemplated and described. Further, while some technical details may be omitted from the description and drawings, for the purpose of clarity and conciseness, such omissions are not meant to be understood that the omitted features are necessarily absent or missing in the relevant structures, parts, processes and/or steps, as described herein, for understanding and practicing the invention.

Thus, although illustrative example embodiments have been described herein with reference to the accompanying drawings, it is to be understood that this description is not limiting and that various other changes and modifications may be effected therein by one skilled in the art without departing from the scope or spirit of the disclosure as sets out and defined the claims appended hereto.

CLAIMS

1. A battery recyclability assessment method comprising:
identifying a volume variation of a battery-under-test;
5 upon the volume variation being determined not exceeding a predetermined
volume variation threshold, identifying an external surface degradation of the
battery-under-test, and
upon the external surface degradation being determined not exceeding a
predetermined surface degradation threshold, obtaining electrical
10 characteristics of the battery-under-test to determine a recyclability of the
battery-under-test.
2. The method as recited in claim 1, wherein identifying a volume variation of a
battery-under-test comprises:
15 hermetically sealing the battery-under-test in a chamber;
filling the chamber with a volume of test air until an air pressure in the chamber
reaching a predetermined level;
comparing the volume of test air with a volume of reference air corresponding to
a reference battery, wherein the reference battery having a specification the
20 same as the battery-under-test,
wherein the volume variation of the battery-under-test is determined by a
difference between the volume of reference air and the volume of test air.
3. The method as recited in claim 2, further comprising, prior to comparing the volume
25 of test air with a volume of reference air corresponding to a reference battery,
establishing the volume of reference air corresponding to the reference battery.
4. The method as recited in claim 3, wherein establishing the volume of reference air
corresponding to the reference battery comprises:
30 hermetically sealing the reference battery in the chamber;
filling the chamber with the volume of reference air until an air pressure in the
chamber reaching the predetermined level.

5. The method as recited in claim 2, wherein the chamber has a first temperature when filled with the volume of reference air, the chamber has a second temperature when filled with the volume of test air, wherein the second temperature is the same as the first temperature.

5

6. The method as recited in claim 2, wherein the battery-under-test is determined to be non-recyclable upon the volume variation of a battery-under-test exceeding the predetermined volume variation threshold.

- 10 7. The method as recited in claim 6, wherein identifying an external surface degradation of the battery-under-test comprises:
capturing an image of the external surface of the battery-under-test, and
identifying a surface defect of the battery-under-test from the image,
wherein the battery-under-test is determined to be non-recyclable upon the surface
15 defect being identified to include a recessed portion and a raised portion.

8. The method as recited in claim 1, wherein identifying an external surface degradation of the battery-under-test comprises:
capturing an image of the external surface of the battery-under-test;
20 identifying a surface defect of the battery-under-test from the image, and
comparing the surface defect with a predetermined surface degradation threshold,
wherein the battery-under-test is determined to be non-recyclable upon the surface
defect exceeding a predetermined surface degradation threshold.

- 25 9. The method as recited in claim 7, wherein the surface defect includes one of a scratch, a dent, and a bump on the external surface of the battery-under-test, the predetermined surface degradation threshold includes a predetermined dimension threshold, the battery-under-test is determined to be non-recyclable upon a physical dimension of the one of a scratch, a dent, and a bump exceeding the predetermined
30 dimension threshold.

10. The method as recited in claim 7 or claim 8, wherein capturing an image of the external surface of the battery-under-test is implemented by an imaging device through a telecentric lens.

11. The method as recited in claim 1, wherein the electrical characteristics of the battery-under-test includes a state of charge, a health status and a remaining power of the battery-under test, wherein obtaining electrical characteristics of the battery-under-test comprises assessing the state of charge, the health status and the remaining power of the battery-under-test by a multimodal evaluation module, an electrochemical model module, an equivalent circuit model module and a neural network model module.

12. A battery recyclability assessment system comprising:
a first apparatus configured for identifying a volume variation of a battery-under-test according to a method as recited in any one of claims 1 to 6;
a second apparatus configured for identifying an external surface degradation of the battery-under-test according to a method as recited in any one of claims 1 and 7 to 10;
a third apparatus configured for obtaining electrical characteristics of the battery-under-test according to a method as recited in any one of claims 1 and 11, and
a data storage module in data communication with the first apparatus, the second apparatus and the third apparatus.

13. The system as recited in claim 12, wherein the first apparatus comprises a hermetically sealable chamber for receiving a batter therein, an air supply device connected to the chamber for filling air into the chamber, and a measurement device coupled to the chamber for determining a volume, a temperature and a pressure of air filled into the chamber, and the measurement device is in data communication with the data storage module for transferring data related to the volume, the temperature and the pressure of air filled into the chamber with the data storage module.

14. The system as recited in claim 12, wherein the second apparatus comprises an imaging device and a telecentric lens coupled to the imaging device for capturing an

image of a battery, and an image processor coupled to the imaging device for receiving and processing images captured by the imaging device, and the image processor being in data communication with the data storage device for transferring image data with the data storage device.

5

15. The system as recited in claim 12, further comprising a battery data acquisition module and an environment data acquisition module coupled to the data storage device for obtaining data from the battery-under-test and data from an environment within which the battery-under-test is disposed.

10

16. The system as recited in claim 12, further comprising an electrochemical model module, an equivalent circuit model module, a neural network model module and an electrothermal coupling model module coupled to the data storage module for assessing a state of charge, a health status and a remaining power of the battery-under test and transfer data of assessment result to the data storage module.

15

17. The system as recited in claim 12, further comprising a state of charge evaluation module, a battery health evaluation module and a battery remaining power module coupled to the data storage module for obtaining a state of charge, a health status and a remaining power of the battery-under-test and transferring corresponding data to the data storage module.

20

18. The system as recited in claim 12, wherein the data storage module further comprises a battery standard specification database, a modal database, an evaluation result database and system database coupled to the data storage module for transferring corresponding data to the data storage module.

25