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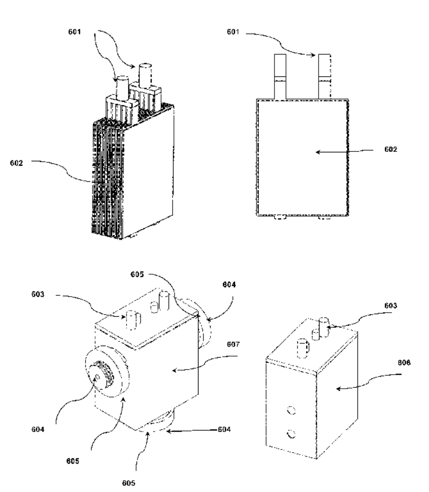
(54) Title: METHODS AND SYSTEM OF ACOUSTICALLY ASSISTED BATTERY OPERATION

FIGURE 6



(57) Abstract: Battery operation with an auxiliary form of input energy other than electricity is demonstrated to effectively lengthen the battery's use lifespan. The non-invasive in-operando reconfiguring of the pore-pressure distribution over the cross section of the porous electrodes immersed in a fluid electrolyte extends the cycle life of the battery cell. A secondary input of sound energy with a distributed transducer configuration embedded on the battery case directs bulk longitudinal waves through the electrolyte that induces a beneficial reconfiguration of pore-pressure distribution. The reconfigured pore-pressure distribution facilitates the penetration of electroactive ions to the porous electrode matrix, consequently arresting the buildup of discharge byproducts that cause capacity fade. Lastly, a secondary input of sound energy assists in charge balancing all battery cells by estimating each cell's state of health. The balanced recharging can maintain the battery's overall state of health, consequently extending its use lifespan.

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AMENDED CLAIMS
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Claims

[Claim 1] [Amended] A method of assisted battery operation by the non-invasive reconfiguring of the pore pressure distribution of the porous components to prevent or delay the formation of sulfate deposits from the beginning of operation, by improving electroactive-ion transmission through a diffusion layer developing on the electrode surface during discharge, in at least one battery cell through the input of energy in at least one other form distinct from electrical energy.

[Claim 2] [Amended] The method of claim 1, wherein the input of energy in at least one other form distinct from electrical energy is done simultaneously or overlapping in time with the input of electrical energy to generate a timely, uninterrupted reconfiguring of pore pressure distribution of the porous components that enable the deeper penetration of electroactive ions from the electrolyte into the bulk portion of the electrode past a diffusion layer on the electrode surface.

[Claim 3] [Amended] The method of claim 1, wherein the porous components in at least one battery cell consist of at least one electrode and at least one separator material that undergo poroacoustic interactions with the electrolyte mixing patterns, generating low-pressure regions akin to cyclonic centers, which result in a reconfiguring of pore-pressure distribution allowing electroactive ions to shuttle through the low-pressure regions into the interior portions of the bulk electrode.

[Claim 4] [Amended] The method of claim 1, wherein the at least one battery cell is a standalone compartment consisting of a fluid electrolyte immersing the porous components of the battery cell to facilitate pore diffusion that is influenced by the reconfiguring of the pore pressure distribution that allows electroactive ions from the electrolyte to shuttle through the low-pressure regions into the interior portions of the bulk electrode.

[Claim 5] [Amended] The method of claim 1, wherein the pore pressure distribution is the pressure of the fluid electrolyte within each pore and varying over the entire cross section of each of the porous components of the at least one battery cell characterized by low-pressure regions, generated by the poroacoustic interaction of the porous materials with the energy input distinct from electrical energy, that facilitate the penetration of electroactive ions through the bulk electrode interior.

[Claim 6] [Amended] The method of claim 1, wherein the non-invasive reconfiguring of the pore pressure distribution is by way of pressure waves propagating through the fluid electrolyte of the at least one battery cell originating from the input of energy in at least one other form distinct from electrical energy, such that the pressure-wave amplitudes are below the atomization threshold of the fluid electrolyte material.

[Claim 7] [Amended] The method of claim 1, wherein the at least one other form distinct from electrical energy is sound energy of a frequency between 90 and 3600 kHz.

[Claim 8] [Amended] The method of claim 1, wherein the input of energy is done with the operation of at least one ultrasonic transducer driven at sufficiently low power that ensures the vibration amplitude is below the atomization threshold of the fluid electrolyte material.

[Claim 9] [Amended] A system of assisted battery operation by the non-invasive reconfiguring of the pore pressure distribution of the porous components to prevent or delay the formation of sulfate deposits from the beginning of operation by improving electroactive-ion transmission through a diffusion layer developing on the electrode surface during discharge, in at least one battery cell through the input of energy in at least one other form distinct from electrical energy.

[Claim 10] [Amended] The system of claim 9, wherein the input of energy in at least one other form distinct from electrical energy is done simultaneously or overlapping in time with the input of electrical energy to generate a timely, uninterrupted reconfiguring of pore-pressure distribution of the porous components that enable the deeper penetration of electroactive ions from the electrolyte into the bulk portion of the electrode past a diffusion layer on the electrode surface.

[Claim 11] [Amended] The system of claim 9, wherein the at least one other form distinct from electrical energy is sound energy of a frequency between 90 and 3600 kHz.

[Claim 12] [Amended] The system of claim 9, wherein the at least one battery cell is a standalone compartment consisting of a fluid electrolyte immersing the porous components of the battery cell to facilitate pore diffusion that is influenced by the reconfiguring of the pore pressure distribution that allows electroactive ions from the electrolyte to shuttle through the low-pressure regions into the interior portions of the bulk electrode.

[Claim 13] [Amended] The system of claim 9, wherein the at least one battery cell is contained within a standalone compartment with hermetic attachments that not only seals off the leakage of the fluid electrolyte out of the compartment, but also ensures the mechanical efficiency of the piezoelectric vibration of the ultrasonic transducers.

[Claim 14] [Amended] The system of claim 9, wherein the input of energy of at least one other form distinct from electrical energy is done with the operation of at least one ultrasonic transducer driven at sufficiently low power that ensures the vibration amplitude is below the atomization threshold of the fluid electrolyte material.

[Claim 15] [Amended] The system of claim 13, wherein the hermetic attachments may include threaded structures and sealants adjoining elements preventing the leakage of fluid electrolyte of the at least one battery cell and also mechanical components that enhance the efficiency of the input of energy of at least one other form distinct from electrical energy to reduce the heating caused by energy losses of the transducer vibration.

[Claim 16] [Amended] The system of claim 14, wherein the at least one ultrasonic transducer is made of a compound material containing lead, zirconium, titanium, potassium, sodium, and/or niobium, molded into a disc shape with a piezoelectric property that enables it to vibrate along a particular axis at a specific fundamental frequency with the input of electrical energy, and such that the selected compound material offers a suitable matching with the battery chemistry due to the exposure of at least one of the transducer's parts to the electrolyte, and especially considering the manufacturing costs.

[Claim 17] [Amended] The system of claim 14, wherein the operation of at least one ultrasonic transducer refers to a configuration of a plurality of transducers each vibrating as a sinusoid at a single or various frequencies within the range 90 and 3600 kHz and with a phase difference within the range of 0 to 180 degrees between each transducer, with the vibration portion of all transducers exposed to the fluid electrolyte of the battery cell.

[Claim 18] [Amended] A method of input of electrical energy to a battery cell controlled by the estimate of the state of health of the cell obtained through the non-invasive input of energy in at least one other form distinct from electrical energy and interpreting the propagated signal received at various positions relative to the source for the dispensing of suitable level of electric current via parallel charging.

[Claim 19] [Amended] The method of claim 18, wherein the input of electrical energy is done by supplying electrical current to the terminals of the battery cell and of the sources of one other form distinct from electrical energy to which the power input must be less than 10 mW/cm2 or 0.01 watt/cm2.

[Claim 20] [Amended] The method of claim 18, wherein the non-invasive input of energy in at least one other form distinct from electrical energy is sound energy of a frequency between 90 and 3600 kHz.

[Claim 21] [Amended] The method of claim 18, wherein the non-invasive input of energy in at least one other form distinct from electrical energy is generated by at least one ultrasonic transducer on the external enclosure of the battery cell with the possibility of exposing only one side of the transducer along the vibration axis to the fluid electrolyte.

[Claim 22] [Amended] The method of claim 18, wherein the propagated signal is the input of energy generated by at least one ultrasonic transducer and transmitted as pressure waves through the fluid electrolyte of the battery cell and scattered, reflected, or refracted by the porous components of the battery cell, such that the pressure-wave amplitudes are below the atomization threshold of the fluid electrolyte material.

[Claim 23] [Unchanged] The method of claim 18, wherein the propagated signal received at various positions relative to the source transducer is received by at least one ultrasonic receiver on the external enclosure of the battery cell.

[Claim 24] [Amended] The method of claim 18, wherein the interpreting the propagated signal received is done by a set of computer instructions to perform a series of calculations for classifying the set of signal received as belonging to a battery cell with a state of health above or below 80%, and using the classification result to control the magnitude of electrical current supplied to the battery cell on recharge via parallel, rather than series, cell-level charging.

[Claim 25] [Amended] The method of claim 24, wherein the series of calculations for classifying the set of signal received is an algorithm obtained from the machine learning of patterns from a set of known information pertaining the state of health of the battery cell units and the propagated signal.

[Claim 26] [Amended] The method of claim 24, wherein the set of computer instructions is stored in a non-transitory computer readable medium that takes as input the received signal from the at least one ultrasonic receiver and outputs a binary digit indicating whether the battery cell unit's state of health is below or above 80%.

[Claim 27] [Amended] The method of claim 25, wherein the machine learning is done with artificial neural networks, decision trees, Bayesian networks, support vector machines, or the like, including the combination of at least two of the foregoing, which uses available datasets to encode iteratively the relationships (hidden within the datasets) among the acoustic variables and the state of health of the battery cell unit, to generate an automated protocol for predicting an output binary digit from future input data taken as the received signal from the at least one ultrasonic receiver.

Statement under Article 19(1)

The amendments clarify three non-obvious features of the invention, from which multiple prior arts teach away. The first relates to the input of sound energy through piezoelectric vibration at sub-atomization amplitudes. The vibration frequency is deduced from two equations in the description as filed: Faraday wavelength (par. 500) and atomization threshold (par. 515). We reduced the input power to the transducer to keep it below what is required to induce atomization; hence, cavitation. At sub-atomization amplitudes, the invention minimizes the level of electrolyte misting while ruling out acoustic cavitation as the primary mechanism of enhanced mass transport. The second non-obvious feature is the facilitation of electroactive species transport into the electrode bulk through low, rather than high, pressures. While prior arts consider the burst of cavitation bubbles as a source of high pressures to push electroactive ions into the electrode, it is known to cause unwanted amounts of heat. The low-pressure alternative, which is the subject of the present invention, relies on negative pore pressures and is expected to keep the electrodes intact while increasing their capacity utilization. The third feature pertains to parallel cell-level charging, contrary to the series charging implemented by existing commercial and even prototypical batteries.

None of the amended claims impact the description, drawings, and abstract as filed.