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Electrochemical energy storage in sustainable modern society

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Abstract: This paper shows the momentum of the development in the use of alternative energy, as well as the needs of modern users for storage of excess energy, mobility, etc. and in connection with that, the modern development and use of electrochemical energy sources, especially in the light of ecological needs.

Keywords: alternative energy, electrochemical energy sources, battery

1. Introduction

Energy is present all around us in various forms and in a philosophical sense it can be said that there is an equivalence of energy and life. Today, energy is the most represented, along with the economy and the environment, in discussions about the strategic directions of the development of each society. These three pillars of society are in such a sensitive cooperation that any progress must rest on the optimal management of all three segments, which is achieved by promoting energy efficiency, establishing free investment, avoiding trade restrictive measures, encouraging research, development and application of energy-efficient technologies, forcing international cooperation in the development of innovative technologies, encouraging mutual recognition of energy labels and standards, and finally, imposing rigorous and reliable measures in the field of environmental protection.

According to the first low of thermodynamics, during an interaction between a system and its surroundings, the amount of energy gained by the system must be exactly equal to the amount of energy lost by the surroundings. A closed system it can change from one form to another, i.e. the amount of energy is always constant, which is known as the principle of conservation of energy.

The transition of chemical energy into heat and other forms of energy is found, for example, when burning fossil fuels in the form of heat that is converted into the kinetic energy of water vapor to start turbines and produce electricity in thermal power plants, or the released thermal energy is used to heat a fluid. which indirectly heats another system. Kinetic energy is recognized in wind and sea waves, while magnetic field energy and electrical energy are encountered in everyday life in many forms. Different energy sources have different energy values. Although we are surrounded by energy, we cannot always simply use it. We generally need it in a specific form and quantity at a specific place and at a specific time, which results in the need for energy to be stored in a portable form, ready for use. Electrical energy can be stored in the form of an electric or magnetic field, mechanical energy in devices such as a flywheel, and thermal energy in isolated solids or fluids, but their stored quantities are relatively small, and their conversion methods are complicated. A much larger amount of energy can be stored in the form of chemical energy that can be converted into electrical, mechanical, thermal or light energy at the moment of need. Most often, this energy is converted into thermal and mechanical energy by means of thermal power plants and internal combustion engines, but the modern way of life with the use of new technologies gives increasing importance to the conversion of chemical energy into electricity by means of electrochemical converters, electrochemical power sources (EPS). The biggest advantage of electrochemical converters is that they work isothermally, they are not limited by the so-called Carnot cycle, which achieves a much higher coefficient of useful conversion effect. In electrochemical converters, chemical energy is converted into electrical energy in the form of low-voltage direct current through the overall chemical reaction, which is a set of electrochemical reactions at the phase boundaries between electrodes and electrolyte, or vice versa, electrical energy is converted into chemical energy (energy conversion).

Recently, a huge increase in activities in the field of research and development of electrochemical power sources has been noticed. There are several reasons for this, and the foremost among them is the environmental reason. This is confirmed by numerous conventions, whose goal is to reduce global warming, signed on the basis of the Kyoto Protocol, which, along with the United Nations Framework Convention on Climate Change, is a basic international agreement aimed at reducing the emission of carbon dioxide and other gases that affect the destruction of the ozone layer.

There is no doubt that the burning of fossil fuels releases gases whose accumulation leads to global warming, which can be seen from the data that in 2011 the atmospheric concentration of carbon dioxide was 391 ppm, while the concentration of carbon dioxide was measured in old ice deposits whose origin was dated to 1750 a year, i.e. pre-industrial era, 278 ppm. To this should be added industrial pollution of the environment as well as the appearance of atmospheric smog in urban areas as a result of the huge increase in the number of cars with internal combustion. The use of internal combustion engines is strictly prohibited in enclosed spaces due to toxic exhaust gases. All these facts have contributed to the accelerated development of electric cars that use electrochemical energy sources. Their development, focused on obtaining a reliable source with high values of specific energy and working life, becomes imperative. Such an electrochemical source must enable the electric car to be competitive with existing internal combustion engines, from the point of view of performance as well as financially. That competitiveness has not yet been realized, so this intermediate space has been filled by the development of hybrid cars. In addition, in the automotive industry, there is a noticeable increase in the needs related to interior comfort in terms of installing electric motors for opening and closing windows, adjusting mirrors and seats, then for the use of higher power sound systems and small electrical accessories in the car cabin, which requires that the starter batteries in recently, they will switch from the current 12 V to 36 V. This requirement cannot be achieved only by simply connecting the existing starter EPSs in series due to their limited specific characteristics, but the replacement of the most commonly used lead acid batteries today with completely new electrochemical systems is being considered (Симичић, 2020).

2. Needs of the contemporary world for alternative energy

An important reason for the great increase in interest in the development of new electrochemical systems lies in the increased awareness of the limited resources of fossil fuels, which encouraged the development and use of alternative sources of electricity, such as solar energy, wind and wave energy. From 2009 to 2018 alone, the produced capacities from wind generators increased from about 150 to 564 GW, while the capacities of using solar energy increased from about 23 GW in 2009 to 486 GW in 2018 (IRENA, 2019). It is a well-known fact that the application of alternative sources is not uniform over time, their availability and use depend both on the time of day and the season. Precisely because of this, the development of efficient reversible electrochemical systems for the storage of excess alternative energy and its leveling have become a strong driving force for financing new projects in this area.

When considering the reasons for the increase in interest in the development of EPS, we should not leave out the dizzying growth in the sale of small electronic devices such as computers, tablets, mobile phones, cameras, wireless power tools and devices where energy density, their specific power and life span are of crucial importance for the consumer.

And finally, we should mention the application of EPS for backup power in cases of termination of the primary power supply of electrical consumers such as large computer systems, networks, telephone exchanges, lighting power, electric motors for powering elevators, etc.

The feeling of the importance of EPS research and development led to an absurd situation that Germany, with a once traditionally emphasized social-market economy, in its "National Industrial Strategy to 2030", accepted, in February 2019, that state interventionism is justified in innovative industries if it is in the interest of the competitiveness of the national economy and calls on politicians to constantly improve the framework conditions for the competitiveness of industrial production in important sectors, among other things, through research and technological innovation. Based on this strategy, a German-French initiative was created to create a consortium that would deal with the development and production of EPS for powering electric cars with a budget of 1,700,000,000 euros with the aim of catching up with Asian competitors.

3. Overview of the characteristics of secondary electrochemical sources of electricity

Secondary electrochemical power sources (accumulators) represent a very dynamic area that is difficult to present in one time section. We are witnessing the continuous improvement of existing systems, research and development of new systems, which results in constant changes in their characteristics, construction, application methods and market prices. In addition to the traditionally well-known starter batteries (for starting engines in vehicles) and industrial (traction) batteries for powering electric vehicles for internal, most often, factory transport and stationary batteries for auxiliary (reserve) power supply, there is a huge market of propulsion batteries of smaller sizes for powering portable devices such as tools, laptop computers, cameras, mobile phones, and for a long time, batteries for powering electric and hybrid vehicles have been winning an increasingly important market.

The dynamism of this area can best be seen from Figure 1, which shows the global battery market in the period from 1990 to 2015 (Pillot, 2016).

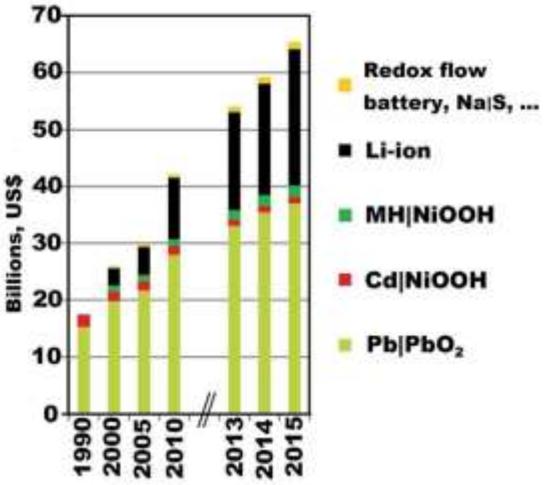

Figure 1. Global battery market in the period from 1990 to 2015.

According to estimates by the Bloomberg New Energy Finance agency, the total global battery production capacity will reach nearly 280 GW in 2021. Globe Newswire's latest forecast in the "Battery Market - Growth, Trends, and Forecast (2020-2025)" report provides a tentative estimate that the global battery market will grow at a compound annual growth rate (CAGR) of 12.31% between 2019 and 2024. The main drivers of this growth will be the decline in the price of lithium-ion batteries, which has fallen by almost 90% since 2010 from 1183 $/kWh to 156 $/kWh in 2019, then the growth in the production of electric and hybrid vehicles, the growing renewable energy sectors and portable electrical devices. This report also predicts that the mismatch between the raw material and battery manufacturing markets could potentially hinder this projected growth.

Table 1. Characteristics of some of the most common accumulators on the market.

<table>
<tr><th colspan="2"></th><th>Cd|NiOOH</th><th>MH|NiOOH</th><th>Pb|PbO_2 (vented)</th><th>Pb|PbO_2 (VRLA)</th><th>Zn|MnO_2</th><th>Na|S</th></tr>
<tr><td colspan="2">Specific energy, Wh/kg</td><td>45-80</td><td>60-120</td><td>30-50</td><td>30-50</td><td>80</td><td>120-150</td></tr>
<tr><td colspan="2">Internal resistance, mΩ</td><td>100-200 (6V batt.)</td><td>200-300 (6V batt.)</td><td><100 (12V batt.)</td><td><50 (12V batt.)</td><td>200-2000 (6 V batt.)</td><td></td></tr>
<tr><td colspan="2">Service life, number of cycles (80% of discharge)</td><td>1500</td><td>500</td><td>200-300</td><td>300-600</td><td>50 (до 50%)</td><td>>2500</td></tr>
<tr><td colspan="2">Charging time, h</td><td>1-2</td><td>2-4</td><td>8-16</td><td><1</td><td>2-3</td><td></td></tr>
<tr><td colspan="2">Overcharge tolerance</td><td>moderate</td><td>low</td><td>high</td><td>very high</td><td>moderate</td><td></td></tr>
<tr><td colspan="2">Self-discharge, %/month at room temperature</td><td>20</td><td>30</td><td>5</td><td>1-3</td><td>0.3</td><td>low</td></tr>
<tr><td colspan="2">Nominal cell voltage, V</td><td>1.25</td><td>1.25</td><td>2</td><td>2</td><td>1.5</td><td>2.08</td></tr>
<tr><td colspan="2">Charging efficiency, %</td><td>70-90</td><td>65-80</td><td>50-92</td><td>98</td><td></td><td>85</td></tr>
<tr><td rowspan="2">Discharge mode</td><td>peak</td><td>20 C</td><td>5 C</td><td>5 C</td><td></td><td>0.5 C</td><td></td></tr>
<tr><td>standard</td><td>1 C</td><td><0.5 C</td><td>0.2 C</td><td></td><td>0.2 C</td><td></td></tr>
<tr><td colspan="2">Operating temperature, °C (discharge)</td><td>from -40 to 60</td><td>from -20 to 60</td><td>from -20 to 60</td><td>from -40 to 0</td><td>from 0 to 65</td><td>from 280 to 350</td></tr>
<tr><td colspan="2">Maintenance</td><td>moderately</td><td>moderately</td><td>moderately</td><td>not required</td><td>not required</td><td>moderately</td></tr>
<tr><td colspan="2">Environmental impact</td><td>very high</td><td>low</td><td>high</td><td>high</td><td>moderate</td><td>low</td></tr>
<tr><td colspan="2">In use since</td><td>1950</td><td>1989</td><td>the end of the 19th century</td><td>1985</td><td>1992</td><td>1960</td></tr>
</table>

Table 1. (continued) Characteristics of some of the most common accumulators on the market.

<table>
<tr><th colspan="2"></th><th>Li-ion (cathode $LiCoO_2$)</th><th>Li-ion (cathode $LiMn_2O_4$)</th><th>Li-ion (cathode $LiFePO_4$)</th><th>Li-ion (polymer)</th><th>Na|$NiCl_2$ (ZEBRA)</th></tr>
<tr><td colspan="2">Specific energy, Wh/kg</td><td>150-250</td><td>100-150</td><td>90-120</td><td>150-250</td><td>100-120</td></tr>
<tr><td colspan="2">Internal resistance, mΩ</td><td colspan="3">150-250 (6.6/7.2 V batt.)</td><td>200-300 (7.2 V batt.)</td><td></td></tr>
<tr><td colspan="2">Service life, number of cycles (80% of discharge)</td><td>500-1000</td><td>500-1000</td><td>1000-2000</td><td>300-500</td><td>3500</td></tr>
<tr><td colspan="2">Charging time, h</td><td>2-4</td><td>1-2</td><td>1-2</td><td>2-4</td><td></td></tr>
<tr><td colspan="2">Overcharge tolerance</td><td>low</td><td>low</td><td>very low</td><td>low</td><td></td></tr>
<tr><td colspan="2">Self-discharge, %/month at room temperature</td><td colspan="3"><5</td><td>~5</td><td>no</td></tr>
<tr><td colspan="2">Nominal cell voltage, V</td><td>3.6</td><td>3.7</td><td>3.2-3.3</td><td>3.6</td><td>2.58</td></tr>
<tr><td colspan="2">Charging efficiency, %</td><td colspan="3">80-90</td><td>>90</td><td>>90</td></tr>
<tr><td rowspan="2">Discharge mode</td><td>peak</td><td>2 C</td><td>>30 C</td><td>>30 C</td><td>>2 C</td><td></td></tr>
<tr><td>standard</td><td>< 1 C</td><td><10 C</td><td><10 C</td><td>≤ 1 C</td><td></td></tr>
<tr><td colspan="2">Operating temperature, °C (discharge)</td><td colspan="3">from -20 to 60</td><td>from 0 to 60</td><td>from 270 to 350</td></tr>
<tr><td colspan="2">Maintenance</td><td colspan="3">not required</td><td>not required</td><td></td></tr>
<tr><td colspan="2">Environmental impact</td><td colspan="3">low</td><td>low</td><td>low</td></tr>
</table>

In use since	1990	1996	1999	1999	2001

The characteristics of the batteries that are most common on the market are shown in Table 1. Data from the table should be taken with caution, as an orientation indicator of different electrochemical systems because they are collected from literature based on the characteristics of standard batteries of various commercial manufacturers. The characteristics of an electrochemical system depend on many parameters, construction, composition and structure of active materials, separators, technological procedures, charging and discharging modes, and therefore it is very ungrateful to reduce them only to the characteristics shown in Table 1. Therefore, any serious approach to this complex matter requires a deeper and a more comprehensive analysis both from the electrochemical and technological aspects as well as regarding the categorization of batteries of the same electrochemical system and its basic purpose.

Figure 2. Gravimetric energy (Wh/kg) and volumetric energy density (Wh/dm^3) for most secondary EPSs Plot.

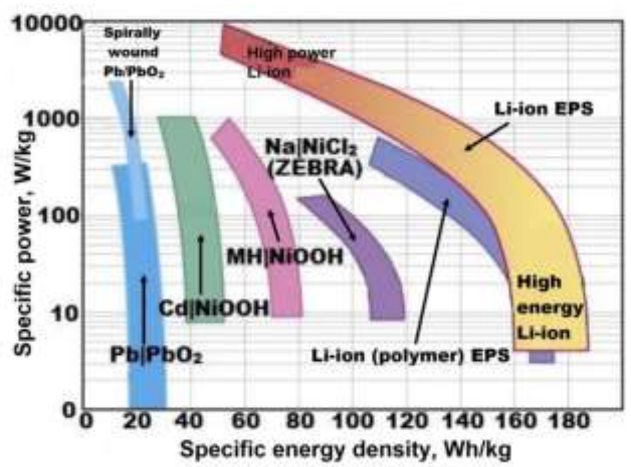

Figure 3. Ragone plot as a comparative representation of most secondary EPSs.

A comparative representation of the dependence of gravimetric (kW/kg) and volumetric (kW/dm^3) energy density and Ragone's comparison plot for most accumulators are shown in Figures 2 and 3 respectively. Discharge curves in the discharge current regime of approximately C/5 of different batteries are shown in Figure 4, while the effects of temperature on the specific energy of different systems at the same regime of approximately C/5 are shown in Figure 5 (Reddy & Linden, 2011).

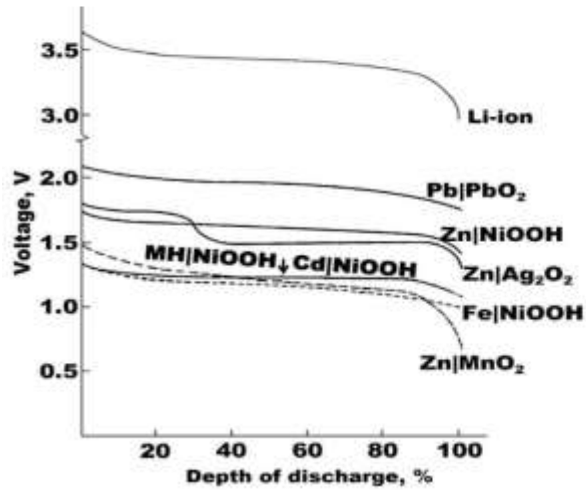

Figure 4. Discharge curves in the discharge regime of approximately C/5.

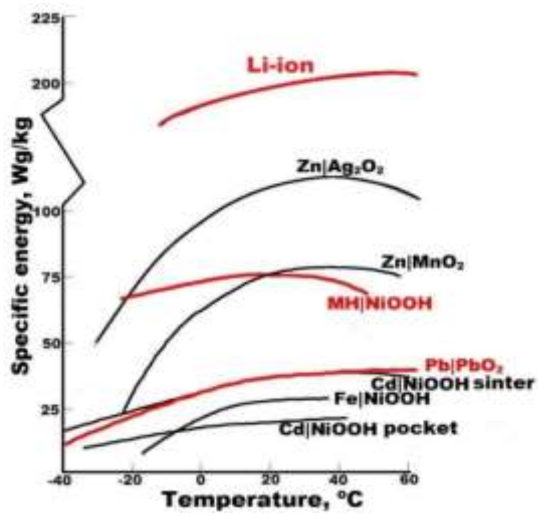

Figure 5. Temperature effects on the specific energy of EPSs at a regime of approximately C/5.

4. Conclusion

At the end of the second decade of the twenty-first century, we are witnessing an extremely intense development and production of electrochemical energy sources. They are becoming an essential part of a large number of modern devices in the most modern technologies, and the huge interest in them stems from the increased ecological awareness. Apart from the presented modern electrochemical energy sources, in the near future it is possible to expect the appearance of possible electrochemical sources such as lithium|air, zinc|air, lithium|sulfur, sodium-ion and other systems that are still far from commercial use at the moment.

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Elektrohemijsko skladištenje energije u održivom modernom društvu

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Apstrakt: U ovom radu prikazan je trenutni razvoj u korišćenju alternativne energije, kao i potrebe savremenih korisnika za skladištenjem viška energije, mobilnosti i sl. i s tim u vezi savremeni razvoj i korišćenje elektrohemijskih izvora energije, posebno u svetlu ekoloških potreba.
Ključne reči: alternativna energija, elektrohemijski izvori energije, baterija