Review and Analysis of Batteries for Electric Vehicles in the Central Asian Climate

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Abstract: This article discusses a review and analysis of batteries for electric vehicles in the dry and hot climate of Central Asia. Suitable battery types were selected for electric vehicles operating under these conditions.

1 INTRODUCTION

Recently, more and more cars are switching from hydrocarbon fuel (gasoline, diesel fuel, methane, propane-butane, alternative fuels of plant origin, etc.) to electric traction. Of course, the latter is still far from the classic internal combustion engines in terms of its characteristics, but progress does not stand still, and if gasoline and diesel engines still hold the palm, then very soon there will be a mass transition to more environmentally friendly and silent electric engines, that is, electric vehicles (Daminov et al., 2022; Daminov et al., 2022; Daminov et al., 2022; Daminov et al., 2022).

At the moment, the weak point of an electric car is the battery. Lithium-ion batteries are mainly used now. Such batteries, with their advantages associated with relatively small sizes, suffer more from the process of deterioration of characteristics over time. Most of these batteries cannot serve for more than five years. The number of charge-discharge cycles (short charge and discharge cycle time, the battery can withstand up to 2000 cycles) does not affect the resource as much as age. To achieve maximum battery life, it is necessary to use currents equal to half the capacity when charging. And it is undesirable to exceed the limit of one capacity, as this leads to a sharp reduction in service life (Uddin et al., 2016; De Dudley et al., 2017; Sutter et al., 2018; Lai et al., 2018; El Ghossein, et al., 2019; Fan et al., 2019; Fang et al., 2019; Han et al., 2019; Harting et al., 2019).

2 MATERIALS AND METHODS

A battery is already a set of many elements. Several cells are connected into a battery when the characteristics of one cell are not enough. If connected in series, the voltage increases according to the battery connection formula. If connected in parallel, the battery capacity increases. It can include not only battery elements, but also auxiliary control electronics.

Capacity is a battery characteristic measured in ampere-hours (A·h). For example, a capacity of 2 A·h means that the battery can deliver a current of 1 A for two hours and 2 A for one hour. Ampere-hour (A·h) is a non-systemic unit of measurement of electric charge, used mainly to characterize the capacity of electric batteries.

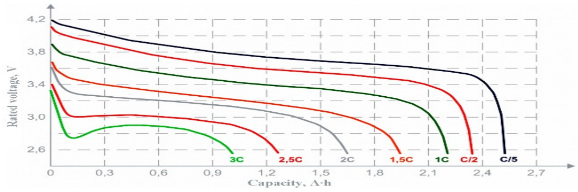

Figure 1: Voltage dependence on capacitance.

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A charged battery with a declared capacity of 1 A·h is theoretically capable of providing a current of 1 ampere for one hour (or, for example, 10 for 0.1 hour, or 0.1 A for 10 hours). In practice, too high a battery discharges current leads to less efficient power output, which non-linearly reduces its operating time with such a current and can lead to overheating.

The derived unit milliampere-hour (mA·h) is also often used, which is usually used to indicate the capacity of small batteries (Barcellona & Piegari, 2017; Abdullaev, 2022; Ismatov et al., 2023).

The value in ampere-hours can be converted to the system unit of charge measurement - coulomb. Since 1 C/s is equal to 1 A, then, converting hours to seconds, we get that one ampere-hour will be equal to 3600 C.

The battery capacity also depends on the discharge current. Usually, the higher it is, the smaller the capacity. Battery manufacturers usually indicate the capacity obtained during discharge with some measly current of 100 mA.

The graphic diagram shows the characteristics of a Li-ion battery, which is discharged at different current strengths. The higher the current, the lower the discharge curve (Tillaxodjayev & Juraboev, 2021; Tillyahodjaev & Mirzaev, 2022; Umerov et al., 2022; Umerov et al., 2024).

C is a letter of the Latin alphabet that measures the ratio of current strength to battery capacity, that is, how many times the current exceeds the capacity. If the battery has a capacity of 2 A·h and is discharged at a current of 4 A, then we can say that it is discharged at a current of 2 C. The thing is that the greater the capacity of the battery, the easier it is to give current to it, and therefore it is more convenient to use such a characteristic than just amperes.

Energy is a characteristic that allows you to compare batteries with different voltages. It is measured in watt-hours and is roughly calculated by multiplying the battery voltage by its capacity (Musabekov et al., 2023; Musabekov et al., 2023; Musabekov et al., 2023; Matmurodov et al., 2024). Often, battery manufacturers indicate only the stored charge in mAh (mA·h) in their technical specifications, while others indicate only the stored energy in W·h (W·h). Both characteristics can be called "capacity" (not to be confused with electrical capacity as a measure of a conductor's ability to accumulate charge, measured in farads). Calculating the stored energy from the stored charge is generally not easy: it requires integrating the instantaneous power supplied by the battery over the entire period of its discharge. If high accuracy is not required, then instead of integrating, you can use the average values of voltage and current consumption, using the formula that follows from the fact that

1 W = 1 V · 1 A:

1 W · h = 1 B · 1 A·h.

That is, the stored energy (in watt-hours) is approximately equal to the product of the stored charge (in ampere-hours) and the average voltage (in volts):

$E = q \cdot U.$

Example

The technical specification of the device states that the “capacity” (stored charge) of the battery is 2.2 A·h, the operating voltage is 3.7 V. Then the “capacity” (stored energy) is 2.2 A·h · 3.7 V = 8.14 W·h = 8.14 W · 3600 s = 29.304 kJ.

When identical batteries are connected in series, the "capacity" remains the same, when connected in parallel, it is added up. For example, for two batteries, each with a voltage of 3.7 V and a stored charge of 2200 mAh, a series connection will create a source with a voltage of 7.4 V and a stored charge of 2200 mAh, a parallel connection will create a source with a voltage of 3.7 V and a stored charge of 4400 mAh.

Internal resistance of batteries - Li-ion battery with a capacity of 2.2 A·h and a nominal voltage of 3.7 V. When fully charged, the battery has a voltage of approximately U = 4 V. What current I will flow through the battery if a resistor with a resistance of R = 1 Ohm is connected to it? Based on the formula I = U / R not 4 amperes, but slightly less - about 3.75 A.

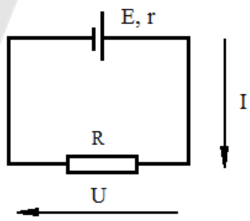

Figure 2: Battery resistance determination diagram.

Internal resistance of the battery if we measure the voltage on the battery to which the resistor is connected, we will see that it is approximately equal to 3.75 V - the voltage on the battery has dropped due to the fact that the diffusion rate of ions in the electrolyte is not infinitely high.

The battery is represented as a two-terminal network with EMF (electromotive force - voltage without load) E and internal resistance r. It is assumed that part of the battery EMF drops on the load, and the other part - on the internal resistance of the battery. In other words, it is assumed that the formula is correct:

$E = (R + r) \cdot I$

We can roughly determine the internal resistance of a 3.7V, 2.2Ah DC battery.

$r = (E - U) / I = (4B - 3{,}75V) / 2{,}2A = 0{,}11\ Om.$

Battery types

The electrical and operational characteristics of the battery depend on the material of the electrodes and the composition of the electrolyte. The following batteries are currently the most common:

Li-ion – lithium-ion. They have the highest energy capacity. They discharge quickly when used in the cold season.

Figure 3.

They deteriorate when discharged below 2.5 V.
They are explosive when overcharged above 4.2 V.

That is why many Li-ion batteries have a special board under the case that switches off the current when the voltage is below 2.5 V or above 4.2 V. Such batteries have the word "protected" in the name. Unprotected batteries without a special board cannot be used in the battery. For more information on protection - Li-ion batteries and their balancing, see below. They lose capacity over time, even from simply lying on a shelf. They lose capacity especially quickly at high temperatures (Barcellona & Piegari, 2017; Venugopal et al., 2019). The easiest way to avoid this problem is to use protected batteries. These are the ones bought for all kinds of LED flashlights. Protected batteries have a small board like this inside the case:

Figure 4.

A popular size for lithium-ion batteries is 18650 (18mm wide and 65mm long).

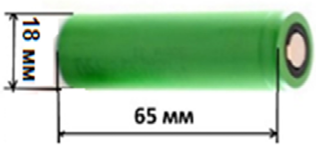

Figure 5.

These are the ones used in laptop batteries. They are located behind the plastic battery case. The same ones are used in the Tesla Roadster electric sports car.

A nickel-cadmium battery (NiCd) is a secondary chemical power source in which the cathode is nickel oxide hydrate Ni(OH)2 with graphite powder (about 5–8%), the electrolyte is potassium hydroxide KOH with a density of 1.19–1.21 with the addition of lithium hydroxide LiOH (to form lithium nickelates and increase capacity by 21–25%), and the anode is cadmium oxide hydrate Cd(OH)2 or metallic cadmium Cd (in powder form). The EMF of a nickel-cadmium battery is about 1.37 V, and the specific energy is about 45–65 Wh/kg (Burzy et al., 2019).

Figure 6.

Depending on the design, operating mode (long or short discharges) and purity of the materials used, the service life is from 100 to 900 charge-discharge cycles. Modern (lamellar) industrial nickel-cadmium batteries can serve up to 20-25 years.

Nickel-cadmium batteries (NiCd), along with Nickel-Saline batteries, can be stored discharged, unlike nickel-metal hydride (NiMH) and lithium-ion batteries (Li-ion), which must be stored charged. A nickel-metal hydride battery (Ni-MH or NiMH) is a secondary chemical power source in which the anode is a hydrogen metal hydride electrode (usually nickel-lanthanum or nickel-lithium hydride), the electrolyte is potassium hydroxide, and the cathode is nickel oxide (Canals et al., 2018; Chin et al., 2018; Dambone et al., 2018; Chen et al., 2024).

Figure 7.

Research into NiMH battery technology began in the 1970s as an attempt to overcome the shortcomings of nickel-cadmium batteries. However, the metal hydride compounds used at that time were unstable and the required characteristics were not achieved. As a result, the development of NiMH batteries stalled. New metal hydride compounds stable enough for use in batteries were developed in 1980.

Since the late 1980s, NiMH batteries have been steadily improving, primarily in terms of energy density. Their developers have noted that NiMH technology has the potential to achieve even higher energy densities.

A lithium-polymer battery (lithium-ion polymer battery; abbreviations: Li-pol, Li-polymer, LIP, Li-poly, etc.) is an improved design of a lithium-ion battery. A polymer material is used as an electrolyte (Worwood et al., 2018), (Wu et al., 2019), (Xia et al., 2021), (Yehorov et al., 2024), (Zhang and Lyu, 2018). It is used in mobile phones, digital equipment, radio-controlled models, etc.

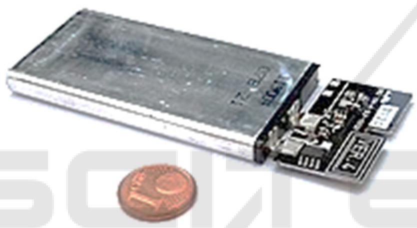

Figure 8.

Fully compatible with Li-ion. Unlike Li-ion, they can deliver strong currents - 10-40 C. They can be of any thickness and shape. They are suitable for powering very miniature devices, such as compact micro-equipment. They are usually sold in an already assembled battery, with protective boards and cables for balancing. They work even worse in the cold.

Lithium iron phosphate battery (LiFePO4, LFP) is a type of electric battery, which is a type of lithium-ion battery that uses LiFePO4 as a cathode.

Further evolution of lithium batteries. Batteries of the future. Unlike Li-ion, they: are not afraid of frost; are not fire hazardous; deliver currents up to 50 C; can be charged with a strong current in 15 minutes; have a huge number of charge-discharge cycles (2000-8000 up to a loss of 20% of capacity); are practically not subject to capacity loss during storage (Tom, 2012; Noh et al., 2019; Osara & Bryant, 2019).

Figure 9.

Disadvantages compared to Li-ion: more expensive and have lower capacity; have lower energy capacity; are not compatible with conventional Li-ion cells due to a different voltage range of 2-3.65 V. And, just like Li-ion, require compliance with their voltage range of 2-3.65 V.

Lanthanum fluoride battery (La-Ft) is a very powerful chemical current source with a solid electrolyte. The anode is metallic lanthanum or cerium, the electrolyte is lanthanum fluoride with the addition of barium fluoride (about 6%) or, in the case of a cerium anode, cerium (III) fluoride with the addition of strontium fluoride, the cathode is bismuth or lead fluoride with the addition of potassium fluoride (~ 6%).

Figure 10.

Additions of potassium and alkaline earth metal fluorides promote disordering in the anion sublattice of lanthanum/cerium fluorides, which ultimately leads to a 6-8-fold increase in the specific conductivity of the solid electrolyte.

Lithium titanate battery (Li4Ti5O12) is a variant of lithium-ion batteries that uses lithium titanate (Li4Ti5O12) as an anode. To increase the area, the anode has a nanocrystalline structure.

Figure 11.

This solution allows for an anode surface area of up to 100 m2/g, compared to 3 m2/g for carbon, which allows for a significant increase in the recharge rate and high current density (De et al., 2018; Jinlei et al., 2019; Wei et al., 2024).

A silver-cadmium battery (Ag-Cd) is a chemical current source in which the anode is cadmium, the electrolyte is potassium hydroxide, and the cathode is silver oxide.

Figure 12.

Compared to a silver-zinc battery, it has lower specific characteristics (EMF 1.6 V, 45-90 Wh/kg), but at the same time a significant service life (over 3000 charge-discharge cycles, which is explained by the fact that during charging, due to the lower solubility of cadmium in alkali, cadmium dendrites do not form).

NMC - one of the most successful options for the implementation of a lithium-ion electrochemical system is a combination of nickel, manganese and cobalt.

Figure 13.

NMC battery in the 18650 cell size for moderate load has a capacity of 2800 mAh and can provide a current of 4-5 A. The capacity can be increased to 4000 mAh. But the maximum current is 20 A. Over 2000 charge-discharge cycles (Hildebrand et al., 2018), (Kovtun et al., 2024), (Kuo et al., 2019), (Wang et al., 2004).

LiCoO2 is a lithium-cobalt battery in the 18650 cell size with a capacity of 2400 mAh can be charged and discharged with a current not exceeding 2400 mAh.

Figure 14.

Charge-discharge cycles 500-1000. Performance at low and high temperatures.

Below are the parameters of batteries that can be used in electric vehicles.

Table 1: Average values obtained in the experiment.

Designation	EMF (V)	Energy capacity (Wh/kg)	Energy density (Wh/dm3)	Operating temperature (°C)	Number of charge/ discharge cycles	Self-discharge per year (%)	Fast charge time (minutes)
NiCd	1,37	237	50-150	-50…+40	100-900	10	1,5
Ni-MH or NiMH	1,25	300	150	-60…+50	300-500	100	1,5
Li-pol	3,7	161	120	-20…+60	1000	60	1,5
LiFePO4	3,3	90-250	220-350	-30…+50	2000-8000	50	-
La-Ft	2.3-2.7	290-350	1330	+400…+500	-	-	-
Li4Ti5O12	3,7	30-110	177	-30...+60	15000	5	7
Ag-Cd	1,6	45-90	120	-30…+50	3000	-	-
Li-ion	3,7	110-250	-	-20…+60	1000	-	60
Lead-Acid	2,1	135	1250	-40…+40	200-300	36-120	480-720
Ni-Zn	1,65	60	255	-30…+40	250-370	-	120
NMC	3,6-3,7	150-220	-	+210	1000-2000	-	180
LiCoO2	3,0-4,2	150-240	-	+150	500-1000	-	180

3 RESULTS AND DISCUSSION

But whatever the layout, batteries are at the top of this list. Electric vehicles use batteries assembled into a single block with a series, parallel and mixed connection. Since when choosing the optimal connection scheme, you can achieve a positive effect by reducing the number of batteries and, accordingly, the weight of the battery block (Daminov et al., 2022a; Daminov et al., 2022b; Yehorov et al., 2024).

The battery of the TESLA electric car has been of interest to specialists in this field for some time, who have sought to learn the secret of the connection. In principle, this is not a secret, but a competent choice of batteries with high energy capacity (Wh/kg), energy density (Wh/dm3) and the number of charge/discharge cycles.

These justifications can be summarized in the following simple arithmetic solutions.

A lithium-ion battery has the following parameters. 3.7 V and 2.2 Ah.
Power of one battery;

$$3{,}7 \cdot 2{,}2 = 8{,}14 \text{ WA/h}$$

If you connect 100 cells in parallel or in series, or even combine them, the result is obtained according to the formula;

$$1003{,}72{,}2 = 814 \text{ WA/h}$$

Tesla model S has 7104 batteries with a capacity of 85,000 W (A/h). According to the data, these batteries are manufactured by Panasonic.

The parameters of the battery are NCR 18650B, voltage 3.6 V and current 3.4 Ah. It consists of 16 modules of 5300 W (A/h). One module has 444 elements. There are 6 groups of 74 batteries. These batteries are connected in parallel, and the power of the groups is calculated using the formula;

$$3{,}6\ 3{,}4\ 7104 = 86952 \text{ WA/h}$$

We have considered different ways of connecting batteries. In turn, we can draw the following conclusions. Regardless of how you connect the batteries, the maximum value of w·h (running time in hours) will remain unchanged. In particular, among different manufacturers of electric vehicles, the same w·h (power hour) remains unchanged when analyzing the Tesla Model C, which has a battery capacity of 85 kWh. When calculating losses of approximately ≈85 kW (A/h), these calculations show that the range of a Tesla electric car has nothing to do with the connection of the battery.

4 CONCLUSIONS

We conducted our research, considering from the small list which is provided above it is difficult to choose what met the requirements of the electric vehicle manufacturers. The parameters are not unambiguous and go to the optimal solution. Therefore, based on the climate of the Central Asian region for electric vehicles, it is necessary to select the appropriate battery suitable for operation in a hot and dry environment. The most suitable elements from the above list are lithium-titanate batteries ($Li_4Ti_5O_{12}$). The battery is more optimal in parameters and meets the minimum requirements presented for the battery for electric vehicles such as a long service life based on charge-discharge cycles and the shortest charging time (Tillaxodjayev et al., 2021; Daminov et al., 2022).

Currently, the most pressing problem for many electric vehicle manufacturers, including Tesla electric vehicles, is to increase the mileage. The power reserve depends on some characteristics of the electric vehicle, in particular, on the power of the main source of electricity in it - batteries, which can be provided by choosing more advanced batteries. And the aspect associated with the problem of environmental safety associated with the disposal of used batteries can be compensated for by batteries with a long service life and rational use of battery capacity.

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