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Assessment of the energy properties of alkaline batteries

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***Abstract*—The paper presents the results of research based on an original method for assessing the energetic properties of alkaline batteries commonly available on the market. The study was carried out on a sample of AA size and AAA size batteries from several randomly selected manufacturers, under conditions of continuous discharge with a constant resistive load. A comparative analysis was performed on the basis of the total energy obtainable from a battery for a given load, as well as the energy efficiency factors of the useful energy and the potentially useful energy.**

***Keywords*—alkaline batteries; constant value resistance discharge; usable energy; energy efficiency**

I. INTRODUCTION

PRIMARY sources, commonly referred to as batteries, are widely used in many consumer devices and various industrial sectors, including marine vessels. These are single-use sources, meaning they must be disposed of after use. Unlike single-use sources, secondary sources, commonly referred to as accumulators, are reusable [1]. This article compares selected performance characteristics mainly of alkaline batteries generally available on the market. Some carbon-zinc batteries were also tested for comparison. Achievable analyses in this area typically refer to general, qualitative comparisons. There is a lack of precise quantitative information that would allow for comparison of the energy properties of batteries from different manufacturers [2, 3, 4]. Alkaline batteries are characterized by high variability in performance parameters depending on load type and temperature. Therefore, discharge characteristics in several modes are presented to determine their performance: constant discharge or variable current, power, and resistance [5, 6]. Additionally, impulse tests are conducted to verify compliance with standard requirements in various modes [5, 6]. Alkaline batteries from renowned brands such as Duracell, Energizer, GP, Varta, and Panasonic are available on the market, as are lesser-known batteries manufactured specifically for specific retailers such as Lidl, Auchan, Kaufland, and Jysk.

The basic parameter used to describe alkaline batteries is voltage, whose nominal value is 1.5 V. Another important performance parameter is capacity, which is not always specified because its value depends largely on the battery's use. Hence, marketing terms used by manufacturers appear, such as: DURACELL: "30x Extra live*," Energizer: "up to 100% longer lasting," or GP: "+200% more Power." These terms convey little to the user, even though manufacturers provide the truth, but they relate this information to very specific conditions of various comparative tests, often to the parameters of carbon-zinc batteries. Therefore, this paper attempts to compare batteries from recognized manufacturers according to a single criterion: constant load discharge, i.e., constant resistance value. This test is the only one that allows for the determination of the full battery discharge characteristics, also beyond the EV (end-point voltage) value. The EV voltage in the standard [6] is 0.8 V, 0.9 V, or 1 V, respectively, depending on the test performed.

It worth noted that electrochemical process inside batteries are extremely sophisticated and mostly are modeling to the similar value of EV [7, 8, 9,].

The authors' approach to the comparison of the considered batteries is developed in the following way. The measurement method is presented in Chapter II. The subject of research is described in Chapter III. Next, the new ideas concerning batteries discharge and complete batteries discharge processes are shown and discussed in the Chapters IV and V, respectively. Finally, the conclusions, including the proposed synthetic parameters discussion, are formulated.

II. MEASUREMENT METHOD

The measurement system was built using an Arduino Uno R3 module with an ATmega328P microcontroller (8-bit, 16 MHz) [10]. connected to a PC running Arduino IDE 2.3.7(8) software A diagram of the measurement system is shown in Fig. 1.

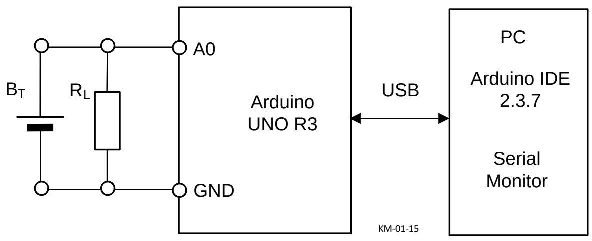

Fig. 1. Measuring system for testing a battery discharged with a constant resistance value, BT - tested battery, RL - discharge resistor

In a constant-load measurement system, discharge characteristics can be measured well below the end point voltage (EV), allowing for a more comprehensive determination of the energy properties of a given battery.

The discharge voltage sampling period can be programmed from ms to hours. After numerous experiments, 1 or 5 minutes was adopted as the optimal basic recording period.

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The conducted tests yielded results with discharge voltage fluctuations of several mV, and sometimes as much as 20 mV. These fluctuations will be omitted for the purposes of this analysis, as they are not significant. However, they will be the subject of further detailed research aimed at distinguishing fluctuations resulting from the measurement depending on the inherent behavior of the battery itself [1]. It is worth noting that the measurement set used allows for measurements with a resolution of +/- 4.9 mV, which corresponds to a 10-bit converter, with a reference voltage of 5V.

The measurement results obtained in the "Serial Monitor" module were transferred to other programs in order to perform relevant analyses, graphical visualization of characteristics and interpretation of measurement results.

III. SUBJECT OF RESEARCH

The study involved AA and AAA mainly alkaline batteries from various manufacturers, marked with the relevant symbols as shown in Table I and II. Measurements were conducted at an ambient temperature of 22°C. All batteries were discharged using the same resistance values. For comparison purposes, after numerous tests, four resistance values were selected: 2 Ω, 5 Ω, 10 Ω, and 20 Ω, respectively, to which the individual batteries were discharged. The choice of resistance was based on the relationship between performance testing and battery discharge duration. It should be emphasized that the intention was to test the battery discharge characteristics to a voltage below 0.2 V and in some cases for full discharge to 0 V.

Table I lists the battery AA size and manufacturers whose batteries were tested. For three reputable manufacturers, two battery types were selected, one with higher performance (marked "A") and the other with lower performance (marked "B"), based on their marketing performance specifications. The discharge parameters of a battery manufactured under the SWITCHON brand for the Kaufland retail chain are also presented.

TABLE I
TESTED AA SIZE BATTERIES

Trademark	Marketing Description / Name	Battery marking
DURACELL	Optimum, 30x extra life	DXXA
DURACELL	15x extra life	DXXB
Energizer	MAX, up to 100% longer lasting	EXXA
Energizer	POWER, up to 50% longer lasting	EXXB
GP	Ultra+, G-TECH, +200% more power	GXXA
GP	Super G-TECH +50% More Power	GXXB
Kaufland	SWITCHON	KXX
OKTAN	OKTAN MAX (zinc-carbon)	OXX

where XX is the number of the tested battery

Table II presents the tested AAA batteries from selected manufacturers for comparison.

TABLE II
TESTED AAA SIZE BATTERIES

Trademark	Marketing Description / Name	Battery marking
DURACELL	Optimum	DXXA
DURACELL	Extra life	DXXB
GP	Super G-TECH +50% More Power	GXX
OKTAN	OKTAN MAX (zinc-carbon)	OXX

where XX is the number of the tested battery,

Additionally, zinc-carbon batteries from one manufacturer were tested, both AA and AAA sizes.

IV. BATTERY DISCHARGE

After analyzing the exemplary battery discharge characteristics and manufacturers' information materials [2, 3, 4], in order to compare the properties, reference points were selected in relation to time t, voltage U, as well as energy E and charge Q obtained from the battery.

These points are presented in the example discharge characteristics of the G11A size AA battery with a constant resistance value R_L = 10 Ω and a sampling period of 5 min, shown in Fig. 2, where t_A – time after which the battery is discharged to the voltage U_A = 1 V, during which the charge obtained from the battery reaches the value Q_A and the energy – the value E_A.

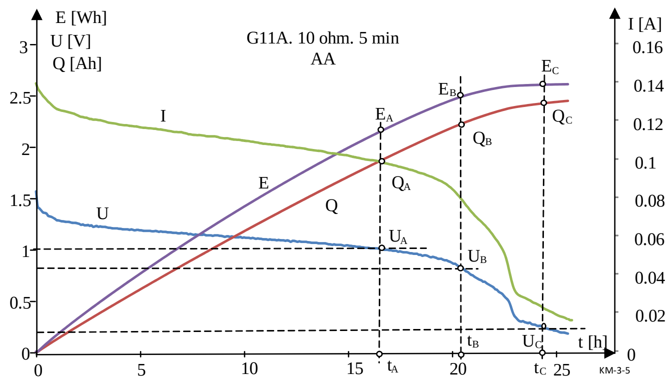

Fig. 2. Discharging the G11A battery size AA with a constant resistance of 10 Ω, where: U – discharge voltage, I – discharge current, Q – charge obtained from the battery, E – energy obtained from the battery

Accordingly, the parameters with the index "B" refer to the conditions when the battery voltage reaches U_B = 0.8 V, and the parameters with the index "C" refer to the situation when the battery is discharged to a voltage U_C = 0.2 V. The graph also shows the discharge current I. The charge Q acquired from the battery represents the area under the current waveform determined from the beginning of discharge to a given moment in time. For comparison purposes, the charges Q_A, Q_B, and the energies E_A, E_B, as well as the reference values Q_C and E_C, were determined. The Q_C and E_C values were adopted as reference values for battery capacity and energy at a discharge voltage of U_C = 0.2 V.

Table III presents, as an example, the values of the charge Q that can be obtained from the tested batteries and the energy E at the characteristic points marked in Fig. 2 relating to the G11A battery AA size.

TABLE III
CHARACTERISTIC PARAMETERS OF PARTIAL DISCHARGE OF THE G11A BATTERY SIZE AA WITH A RESISTANCE OF 10 Ω

Battery G11A	Voltage of partial discharge		
	U_A=1 V	U_B=0,8 V	U_C=0,2 V
Q [Ah]	1,87	2,24	2,45
E [Wh]	2,16	2,50	2,61
t [h]	16:35	20:35	24:00

Similar to discharging characteristics for example of AA size battery, in the Fig. 3 set of discharging characteristics for AAA size battery was presented and adequate parameters were marked.

TABLE IV
CHARACTERISTIC PARAMETERS OF PARTIAL DISCHARGE OF THE D42A BATTERY AAA SIZE WITH A RESISTANCE OF 20 Ω

Battery D42A	Voltage of partial discharge		
	U_A=1 V	U_B=0,8 V	U_C=0,2 V
Q [Ah]	0.85	0.92	0.96
E [Wh]	1.03	1.10	1.12
t [h]	14:24	15:57	17:45

The corresponding value of the obtained charge Q, energy E and discharge time of the D42A AAA size battery is shown in Table IV, which corresponds to the parameters defined in Fig. 3.

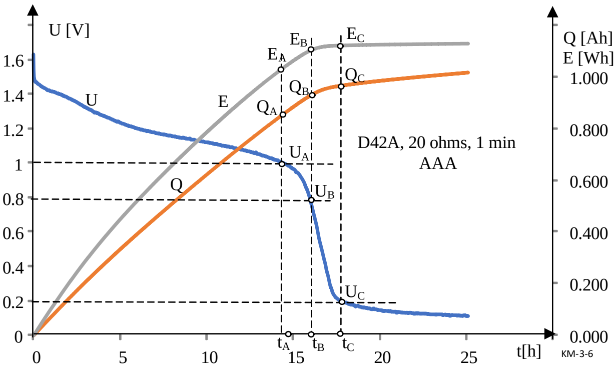

Fig. 3. Discharging the D42A battery size AAA with a constant resistance of 20 Ω, where: U – discharge voltage, Q – charge obtained from the battery, E – energy obtained from the battery

For further analysis, the terms potentially useful charge Q_{BA} and potentially useful energy E_{BA} will be introduced. These parameters determine the difference between the charge Q_B and the charge Q_A, and the difference in the energy values E_B and E_A, respectively. These terms were introduced to emphasize that many battery-powered devices stop working efficiently at voltages below 1 V, but some can operate with a single battery voltage lower than 0.8 V, provided the battery has sufficient energy. This situation can occur when powering devices from a stack of three or more batteries connected in series. This situation most often occurs in toy power supplies.

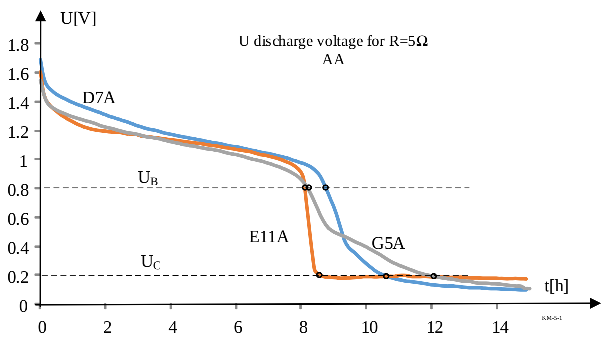

Fig. 4. Example of typical battery discharge characteristics with a 5Ω resistance

Battery discharge characteristics may vary depending on type and manufacturer. Battery discharge patterns in the usable (U_A = 1 V) and potentially usable (U_{AB} = 1.0÷0.8 V) ranges are very similar, but differences in the characteristics were observed between the discharge voltages from U_B = 0.8 V to U_C = 0.2 V. The typical observed discharge characteristics are shown in Fig. 4.

A parameter that accurately describes the characteristic curve in this region is the time difference Δt_{CB} between the discharge time from voltage U_B to voltage U_C. For further discussion, this time is defined as the characteristic fall time. Selected time values for batteries with the discharge characteristics shown in Fig. 4 are presented in Table V. Fig 4 only marks the points whose coordinates are given in Table V.

The fall time Δt_{CB} of the characteristics is closely related to the amount of charge that has no usable value. The shorter this time, the more charge from a given battery is used within the usable voltage range. Considering the tested batteries, the E11A battery has the most favorable discharge characteristics (Fig. 4).

TABLE V
AA SIZE BATTERY DISCHARGE CHARACTERISTICS FALL TIMES

Battery	t_C [h]	t_B [h]	$\Delta t_{CB=}$ t_C-t_B [h]	ΔQ_{CB} [Ah]
D7A	10:30	7:45	2:45	0.1
G5A	11:45	8:10	3:30	0.29
E11A	8:35	8:15	0:30	0.02

The course of discharge characteristics of a given size of battery depends on the method of discharging. Fig. 5 shows example discharge characteristics of Energizer AA batteries from the "POWER, up to 50% longer lasting" series with load resistance values of 2 Ω, 5 Ω, 10 Ω and 20 Ω, respectively.

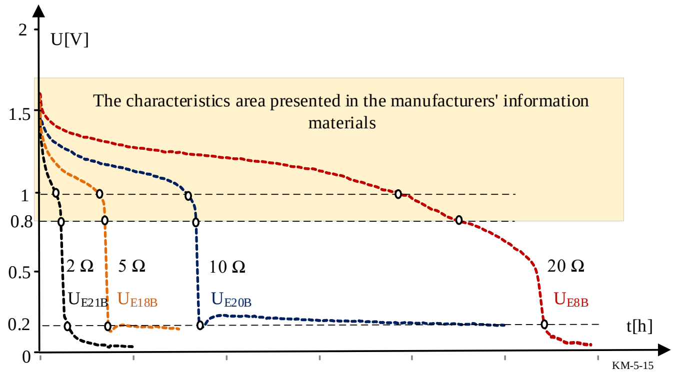

Fig. 5. Battery size AA discharge characteristics with resistance values E21B - 2 Ω, E18B - 5 Ω, E20B - 10 Ω and E8B – 20 Ω, respectively

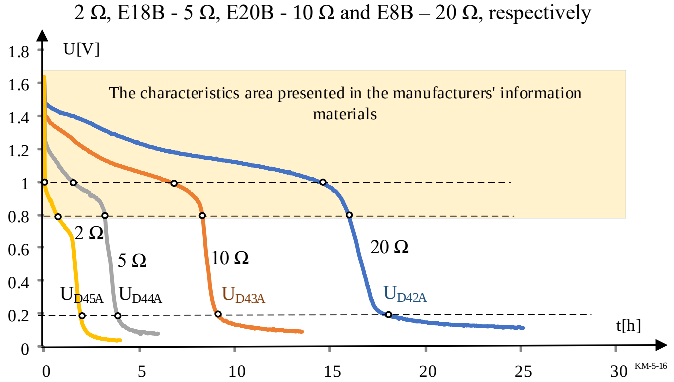

Fig. 6. Battery size AAA discharge characteristics with resistance values D45A - 2 Ω, D44A - 5 Ω, D43A - 10 Ω and D42A – 20 Ω, respectively

Fig. 6 shows the characteristics for Duracell Optimum AAA batteries with the same set of discharge resistances. The characteristics were limited to the time in which the battery voltage dropped to a value slightly below U_C = 0.2 V. It is worth emphasizing that manufacturers present battery discharge characteristics in various configurations (discharge with a constant current value, discharge with a constant power value, pulse discharge referring to specific methods of battery use, constant resistance value) limited to a discharge voltage not lower than 0.8 V, which is highlighted in Fig. 5 and Fig. 6 [2, 3, 4].

Analyzing the characteristics in Fig. 5 and Fig. 6, we can only refer to the battery discharge time, which significantly depends on the load, which translates into the discharge current. At a higher discharge current (lower resistance), the discharge time will be correspondingly shorter.

V. COMPLETE BATTERY DISCHARGE

Discharging a battery to a voltage of U_C = 0.2 V does not allow for the assessment of the actual total Q_D charge available in a battery discharged under specific conditions. This knowledge is useful for assessing what portion of the total charge is usable, potentially usable, or reference. Determining the total battery charge for a given load resistance is only possible by completely discharging the battery to a voltage of U_D = 0 V. It is worth noting that the time to discharge the battery to a voltage of U_D = 0 V takes a relatively long time compared to the time to discharge to a voltage of U_C = 0.2 V, as illustrated by the example discharge characteristic of battery K1 with a 10 Ω resistor shown in Fig. 7.

In this case, in the Fig. 7 introduces additional symbols describing the state of complete discharge, such as voltage U_D = 0 V, complete discharge time t_D = 142 h, and total charge obtained from the battery Q_D = 2.98 Ah. Compared to the reference charge for this battery Q_C = 2.31 Ah, it is 22.5% higher. However, comparing the Q_D value to the potentially useful charge Q_B = 2.1 Ah, it is 29.5% higher.

Determining the total charge would allow for comparison of batteries of the same size and estimation of their energy value. However, a disadvantage of this approach is the discharge time, which varies significantly depending on the discharge resistance value. A pattern can be observed in which the full discharge time increases with increasing discharge resistance, as does the total Q_D capacity.

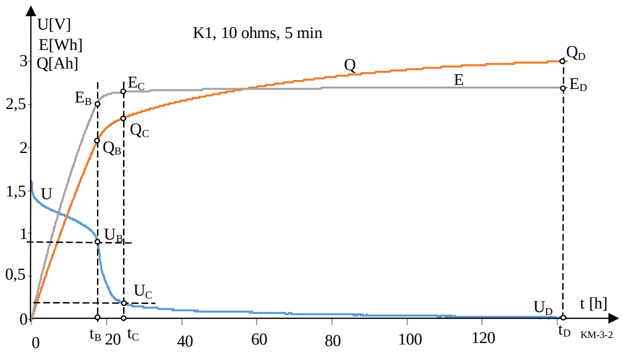

Fig. 7. Full discharge of the K1 battery size AA with a resistance of 10 Ω to a voltage of U_D=0V

However, due to the very long discharge time, this criterion is impractical and difficult to accept. To compare batteries, a simplified criterion can be used and the battery discharged to a voltage of 1 V, 0.8 V, or 0.2 V.

Each solution creates uncertainty regarding the total battery capacity, which, when determined in a simplified manner, can deviate from the actual capacity by up to several dozen percent, depending on the battery size. A better criterion for assessing the energy value of a battery is the extractable energy E. Fig. 7 shows the extractable energy E curve against the background of the charge Q. The voltage value is taken into account in the energy calculation itself.

The result is a parameter that provides information about the energy value of the battery relatively quickly. Over 95% of the total energy can be recovered by the discharge time t_C. As previously defined, t_C is the time required to discharge the battery to the reference voltage of U_C = 0.2 V.

For the K1 battery, whose characteristics are shown in Fig. 7, the relevant characteristic parameters are presented in Table VI.

TABLE VI
EXPERIMENTAL RESULTS OF DISCHARGING THE K1 BATTERY AA SIZE WITH A RESISTANCE OF 10 Ω (ALKALINE)

Battery G11A	Discharge parameters K1 battery			
	U_A=1 V	U_B=0,8 V	U_C=0,2 V	U_D=0 V
Q [Ah]	1,97	2,1	2,31	2,98
E [Wh]	2,41	2,54	2,63	2,69
t [h]	16:30	18:00	23:30	142:45

Additionally, in Figs. 8, 9, and 10 for illustrative purposes, the others total discharging characteristics were presented for different types of batteries.

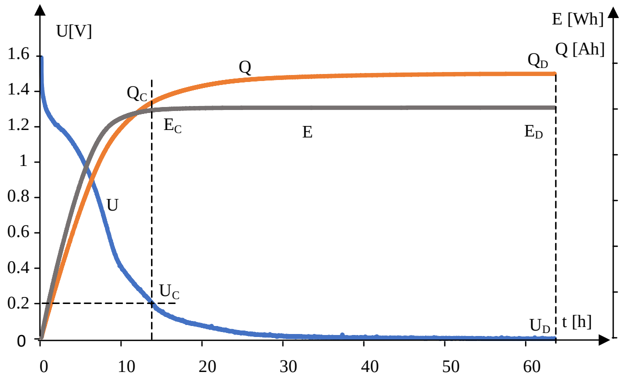

Fig. 8. Full discharge of the O03 battery size AA with a resistance of 10 Ω to the voltage of U_D=0V (carbon zinc)

TABLE VII
EXPERIMENTAL RESULTS OF DISCHARGING THE O03 BATTERY AA SIZE WITH A RESISTANCE OF 10 Ω (CARBON ZINC)

Battery O03	Discharge parameters O03 battery			
	U_A=1 V	U_B=0,8 V	**U_C=0,2 V**	**U_D=0 V**
Q [Ah]	0,62	0,77	**1,05**	**1,18**
E [Wh]	0,73	0,88	**1,01**	**1,02**
t [h]	5:16	7:01	**13:43**	**54**

On the characteristic only crucial parameters were marked for reference voltage U_C=0.2 V and complete discharging voltage U_D=0V but detailed parameters are presented in the related tables.

TABLE VIII
EXPERIMENTAL RESULTS OF DISCHARGING THE D33B BATTERY AAA TYPE WITH A RESISTANCE OF 5 Ω (ALKALINE)

Battery D33B	Discharge parameters D33B battery			
	U_A=1 V	U_B=0,8 V	**U_C=0,2 V**	**U_D=0 V**
Q [Ah]	0,58	0,69	**0,73**	**1,21**
E [Wh]	0,66	0,0,78	**0,79**	**0.81**
t [h]	2:41	3:17	3:19	102

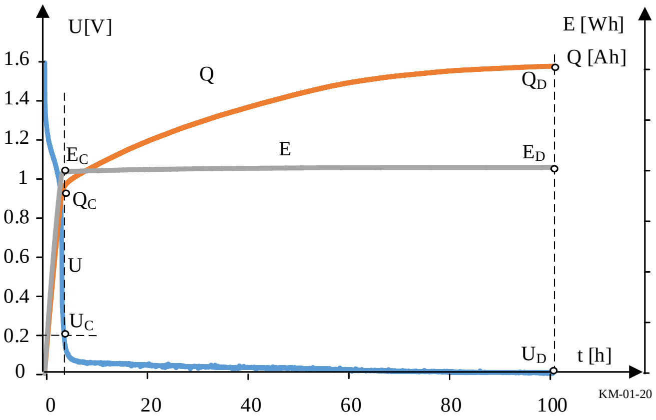

Fig. 9 Full discharge of the D33B battery size AAA with a resistance of 5 Ω to the voltage of U_D=0V (alkaline)

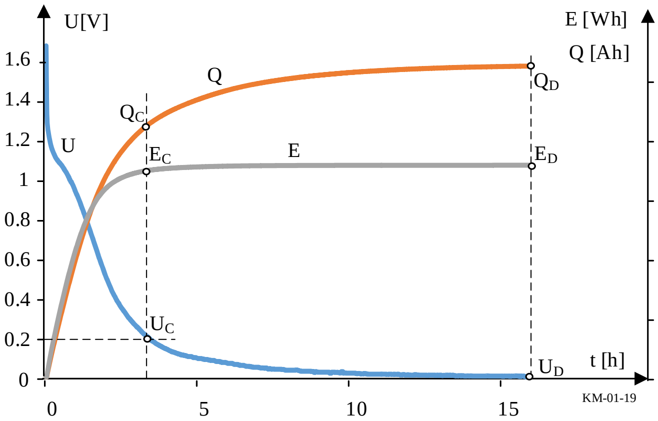

Fig. 10 Full discharge of the O11 battery size AAA with a resistance of 5 Ω to the voltage of U_D=0V (carbon zinc)

TABLE IX
EXPERIMENTAL RESULTS OF DISCHARGING THE O11 BATTERY AAA SIZE WITH A RESISTANCE OF 5Ω (CARBON ZINC)

Battery O11	Discharge parameters O01 battery			
	U_A=1 V	U_B=0,8 V	**U_C=0,2 V**	**U_D=0 V**
Q [Ah]	0,15	0,25	**0,42**	**0.52**
E [Wh]	0,17	0,26	**0.34**	**0.35**
t [h]	0:45	1:18	**3:23**	**16**

Resalts presented in Fig 7, 8, 9 and 10 together with related Tables VI, VII, VIII and IX show that available energy measured at discharging voltage U_C=0.2 V better describes energy property of batteries then available charge, regardless of whether they are alkaline or carbon-zinc batteries.

A similar effect can be observed by presenting the battery discharge parameters in the form of graphs in Fig. 11 and 12. Fig. 11 shows the charge obtained from the battery set at the discharge voltage U_C = 0.2 V and U_D = 0 V. It shown the difference between available charge Q_C at U_C=0.2 V to the total charge Q_D at voltage U_D=0 V. For the same parameters the energy available are presented in Fig 12. In the Fig. 12 it can be observed that total available energy E_D are little difference to the reference energy E_C.

The battery set consisted of 4 identical batteries (of the same size, manufacturer and from the same packaging). Subsequent batteries from the set were completely discharged adequately by resistance 2Ω-D45A, 5Ω-D44A, 10Ω-D43A and 20Ω-D42A.

Additionally, both Figure 11 and Figure 12 illustrate the unique properties of a battery, which vary the available energy or charge depending on the load resistance. Lower resistances, corresponding to higher discharge currents, generate less energy or charge. Discharging a battery with higher resistance generates more energy or charge.

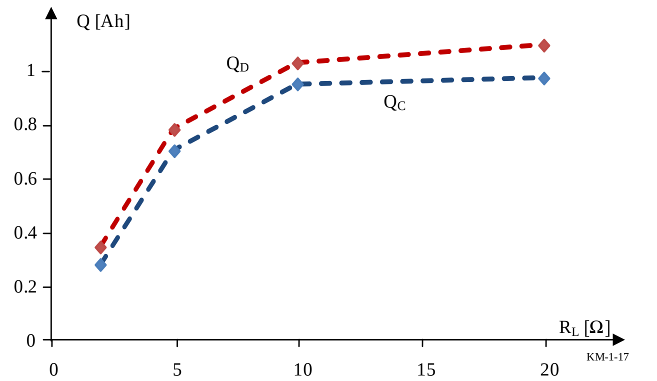

Fig. 11 Available charge of batteries depending on value of load resistance for: 2Ω-D45A, 5Ω-D44A, 10Ω-D43A and 20Ω-D42A, where R- value of load resistance, DXXA- individual number of battery

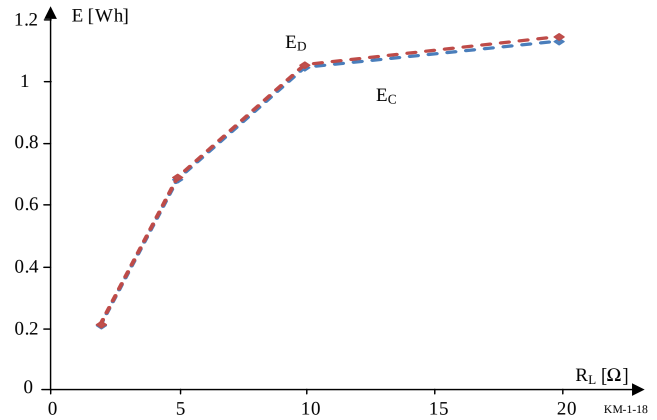

Fig. 12. Available charge of batteries depending on value of load resistance for: 2Ω-D45A, 5Ω-D44A, 10Ω-D43A and 20Ω-D42A, where R- value of load resistance, DXXA- individual number of battery

Analyzing the experimental results, it can be concluded that operating parameters in the form of charge. or energy that can be effectively used from a given battery strongly depend on the discharge method. The obtained research results justify the statement that the most reliable operating parameter is voltage, but the recoverable energy is also important. Determining the charge for the discharge voltage U_A is not reliable, because the difference between the total charge and the value measured at this voltage is several dozen percent, and information about total charge can be obtained after a very long discharge time t_D, often longer than 100 hours. However, using the energy quantity indicator, the total energy value can be determined with an accuracy of several percent when the battery is discharged to the reference voltage U_C = 0.2 V. The discharge time t_C is dramatically shorter than the full discharge time t_D. Based on the above analysis, the following synthetic parameters for comparing the energy properties of alkaline batteries discharged with a constant resistance are proposed.

TABLE X
EXPERIMENTAL RESULTS OF DISCHARGING THE SET OF BATTERY AA SIZE WITH A RESISTANCE OF 2 Ω AND 5Ω

Battery	Load resistance with value R_L=2 Ω		
	E_C [Wh]	η_{EA} [%]	η_{EBA} [%]
D6A	1,52	23	51
D8B	1,4	33	56
E10A	1,27	25	68
E21B	1,25	75	22
G6A	1,47	27	49
G8B	1,36	66	30
K3	0,69	55	36
O1*	0,52	28	39
Battery	**Load resistance with value R_L=5 Ω**		
	E_C [Wh]	η_{EA} [%]	η_{EBA} [%]
D7A	2,48	90	7
D4B	1,99	83	13
E1A	2,25	93	5
E18B	1,69	91	7
G5A	2,18	81	5
G1B	1,94	75	23
K2	2,02	83	12
O2*	0,8	56	22

*) carbon-zinc battery

1. Total energy E_C that can be obtained from the tested battery when continuously discharged at a given resistance value, determined for a reference discharge voltage of U_C = 0.2 V.

2. Relative energy efficiency coefficient of useful energy μ_{EA}, which determines the fraction of energy that can be obtained for a battery discharge voltage of U_A = 1 V relative to the total energy E_C.

3. Relative energy efficiency coefficient of potentially useful energy μ_{EBA}, which determines the fraction of total energy that can be obtained between a discharge voltage of U_A = 1 V and a discharge voltage of U_B = 0.8 V relative to the total energy E_C.

Tests on 32 size AA batteries, the types of which are listed in Table I, were conducted. The results are presented in Tables X and XI, respectively. The results of the tests on the 16 AAA batteries size from Table II are presented in Tables XII and XII, respectively. The tables provide three synthetic indicators for each case: E_C – total energy, η_{EA} – relative coefficient of efficiency of useful energy expressed in %, and η_{EBA} – relative coefficient of efficiency of potentially useful energy expressed in %. Analyzing the experimental results, it can be seen that the amount of total energy E_C that can be extracted strongly depends on the load.

TABLE XI
EXPERIMENTAL RESULTS OF DISCHARGING THE SET OF BATTERY AA SIZE WITH A RESISTANCE OF 10 Ω AND 20 Ω

Battery	Load resistance with value R_L=10 Ω		
	E_C [Wh]	η_{EA} [%]	η_{EBA} [%]
D8A	2,84	87	9
D14B	2,66	94	4
E2A	3,1	88	10
E20B	2,25	88	11,6
G7A	2,76	89	3
G2B	2,67	79	15
K1	2,63	92	5
O3*	1,01	73	14
Battery	**Load resistance with value R_L=20 Ω**		
	E_C [Wh]	η_{EA} [%]	η_{EBA} [%]
D11A	3,65	89	8
D10B	3,23	93	3
E15A	3,13	88	10
E8B	3,31	85	10
G9A	3,28	91	6
G4B	3,22	82	12
K4	3,05	92	5
O4*	1,17	82	8

*) carbon-zinc battery

This applies to virtually every type of battery. For higher loads, which involve higher rate current consumption, the usable energy available decreases, and for this situation, the share of usable energy is also much smaller relative to the potentially usable energy.

TABLE XII
EXPERIMENTAL RESULTS OF DISCHARGING THE SET OF BATTERY AAA SIZE WITH A RESISTANCE OF 2 Ω AND 5Ω

Battery	Load resistance with value R_L=2 Ω		
	E_C [Wh]	η_{EA} [%]	η_{EBA} [%]
D45A	0,21	3	46
D35B	0,43	2	34
GP25	0,23	3	36
O14*	0,23	1	50
Battery	**Load resistance with value R_L=5 Ω**		
	E_C [Wh]	η_{EA} [%]	η_{EBA} [%]
D44A	0,37	54	41
D32B	0,75	86	12
GP23	0,94	76	20
O11*	0,34	50	25

*) carbon-zinc battery

TABLE XIII
EXPERIMENTAL RESULTS OF DISCHARGING THE SET OF BATTERY AAA SIZE WITH A RESISTANCE OF 10 Ω AND 20 Ω

Battery	Load resistance with value R_L=10 Ω		
	E_C [Wh]	η_{EA} [%]	η_{EBA} [%]
D43A	0,86	83	15
D36B	0,91	88	11
GP22	1,23	81	14
O12*	0,44	62	44
Battery	**Load resistance with value R_L=20 Ω**		
	E_C [Wh]	η_{EA} [%]	η_{EBA} [%]
D42A	1,03	92	6
D38B	1,11	94	4
GP21	1,51	78	12
O13*	0,56	80	9

*) carbon-zinc battery

This situation is illustrated by the results presented in Table V for discharging the battery with a resistance of R_L = 2 Ω. This implies that batteries with higher energy efficiency should be used for loads with a current of several hundred mA.

Of all the batteries tested, Duracell type A batteries stood out for their higher energy efficiency compared to batteries from other manufacturers.

It is worth noting that batteries from the same manufacturers, type A and B, do show differences, but these differences do not reflect marketing terms that suggest significant differences in energy efficiency. However, it is clearly observed that as the load resistance value increases, the variance between batteries decreases, and the usable energy always exceeds 90%.

CONCLUSION

Primary sources of electricity, commonly known as batteries, are commonly available, disposable sources of electricity used to power portable devices.

Generally available knowledge about energy properties is based on imprecise marketing information. Detailed technical information provided by manufacturers prevents objective comparisons of the properties of individual battery types.

This is partially justified by the fact that battery properties strongly depend on the method of discharge, which in turn depends on the properties of the receivers.

This article presents the results of tests on batteries from various manufacturers, presents a methodology, and proposes an approach not previously used.

The comparative study was based on the study of energy properties, which involved examining the amount of electric charge and energy that can be obtained during discharge under specific conditions from the initial voltage to full discharge, i.e., a battery voltage of 0 V.

The article presents the results of the tests, limited to discharging batteries with constant resistance values. This approach allowed for complete discharge of the batteries.

The article presents the results of tests on 48 AA and AAA batteries size from several manufacturers. Common alkaline batteries were tested, and the results of tests on carbon-zinc battery packs were presented for comparison. The full set of tested batteries is presented in Table I for size AAA and in Table II for size AAA.

To assess the energy properties of the tested batteries, testing was proposed for four load resistance values R_L: 2 Ω, 5 Ω, 10 Ω, and 20 Ω, respectively. Next, the charge and energy extracted from the tested battery were determined for battery voltages U_A = 1 V, U_B = 0.8 V, U_C = 0.2 V, and U_D = 0 V, respectively.

The concept of the relative useful energy efficiency coefficient η_{EA} and the potentially useful energy efficiency coefficient η_{EBA} was introduced in relation to the total recoverable energy E_C, with the reasonable assumption that $E_C \approx E_D$.

The discharge characteristics of representative batteries are presented in graphs, and detailed parameters are provided in the corresponding tables. The final test results are presented in tabular form in Tables X and XI for AA size batteries and in Tables XII and XIII for AAA size batteries, respectively.

Analyzing the obtained test results, the following conclusions can be drawn:

1. Both the total Q_D charge and the E_D energy of the battery strongly depend on the discharge conditions. Discharging with a high rate current significantly reduces the available charge and energy, and vice versa (Figs. 11, 12).
2. Under the test conditions, it was observed that it is more efficient to use the total energy $E_C \approx E_D$ than the total charge $Q_D \neq Q_C$. This is due to the fact that the reference time t_C is often significantly shorter than the full discharge time t_D.
3. The energy efficiency of all battery types and sizes increases with lower rate current discharge. For the test conditions, the highest efficiency is for a load resistance of R_L = 20 Ω. However, as R_L increases, the portion of energy in the effective energy region increases.
4. Alkaline batteries are more energy efficient than carbon-zinc batteries and have significantly higher total energy.
5. The battery size should be matched to the load to achieve a total energy efficiency ratio (η_{EA} + η_{EBA}) greater than 90%.
6. The latest generation of batteries marked with the letter A do not have significantly more favorable energy properties than batteries marked with the letter B, as suggested by their marketing claims.

The conducted research should be considered preliminary, based on which further research directions can be indicated, extending it to include studies for higher load resistances (R_L) and time-varying loads.

REFERENCES

[1] Kirby W. Beard, Linden's Handbook of Batteries, Fifth Edition, McGraw-Hill Education, 2019

[2] Datasheet_GP_AAA_PC2400_EA_REGION.pdf, (15-02-2026)

[3] https://batteryspecialties.com/assets/pdf/energizer-alkaline-handbook-application-manual.pdf, (10-02-2026)

[4] Duracell. 2023. Alkaline-Manganese Dioxide Battery Technical Bulletin [www.duracell.com] (09.02.2026)

[5] IEC 60086-1:2026-01 Primary batteries - Part 1: General

[6] IEC-60086-2_2021 Primary batteries - Part 2: Physical and electrical specifications

[7] M. Stewart Leah, S. John Okasinski., T. Matthew Wendling. H. H Chadderdon, W. Joshua Gallaway Joshua, Modeling High Current Pulsed Discharge in AA Battery Cathodes: The Effect of Localized Charging during Rest, ACS Applied Energy Materials 2025, 8, 1636-1646

[8] A. Djordjevic, D. Karanovic, Battery testing by calculated discharge-curve method—Constant resistive load algorithm, Journal of Power Sources , 12. 2006, 162(2):920–926,

[9] M. T. Castro, J. A. D. Del Rosario, J. D. Ocon, Energy Density Optimization in a Primary Alkaline Battery Using Multiphysics Modeling, Chemical Engineering Transaction, vol.94, pp 301-306, Sep. 2022, doi: 10.3303/CET2294050

[10] D. Kwiatkowski, M. Mazuryk, Testing the operational properties of electrical energy sources used in portable devices, (in Polish) BEng Thesis, Gdynia Maritime University, Poland, 2026 (promoter Dudojć B.)