Energy Density

By Bob Smith

This is a term which is used to express the efficiency of a re-chargeable battery in terms of its ability to store energy per unit weight. We usually simplify it slightly by using electrical units for the energy (watt hours) rather than absolute units (joules) but it is simply the battery discharge capacity (amps x volts x hours) divided by its weight. We also need to specify the rate of discharge in terms of current draw (usually constant) as the battery performance changes with increased current so the simple approach is to measure values at a 1C discharge (3.2 amps for a 3200 mAh battery). This 1C discharge rate is usually (but not invariably) the rate used by the manufacturer to determine the specified capacity of a battery, so this is consistent.

As the discharge of a battery proceeds the voltage changes and we get the typical voltage V time curve shown in graph 1. Since our calculations have to include the current and voltage it is better if we look at the watts V time curve as in graph 2, and then the energy density of the battery is the area under this curve (amps x volts x time) divided by the weight of the battery. For electric flight we have used NiCd and NiMH cells for several years with LiPo and LiIo cells now becoming very popular. The introduction of lithium batteries has been very swift because we quickly realised that these gave us the same level of energy/power at lower weights (or greater energy/power at the same weight). One of the strange features of this conversion has been that little attempt has been made to quantify the relative energy densities of the two systems. The calculations are simple to make but I have seen few numerical comparisons of different makes and types of flight batteries in these terms. The information is available within the specifications of the cells and so I have extracted this for a number of typical cells and calculated the values given in the following tables.

I have not had time to carry out discharge tests for each cell (as I would need to do to obtain accurate voltage drop curves at 1C discharge) so I have assumed average voltage figures of 1.2 volts for the nickel and lead systems and 3.6 volts for the lithium ones. At least any errors arising from these assumptions are constant throughout the table. The figures in the table are for single cells (1S), but for the Lithium table, some examples are based on a subdivision of data for larger packs e.g. the data from a 4S pack with the voltage, weight and thickness divided by 4. There will be some variations due to cable size and length and in cases where a circuit board is included, and the weights and thicknesses are therefore approximate. The make and size of cells has been chosen at random but you will see from the table that the variation in energy density between brands is lower than I expected. The clearest variation is in terms of size where, perhaps unsurprisingly, the energy density increases as the size of the cell increases, simply meaning that larger cells are more efficient

In the case of the second table covering various other battery types, the situation is simplified by the use of standard case sizes (e.g. D, C, sub-C, etc) but there are still slight variations in the cell size and weight. Although the energy densities are well down on the Lithium cells, the ratios are not as high as you might expect with 2/1 being an average comparison.

As I have mentioned above, there are a number of simplifications involved in the calculation of this data but it does give a broad-brush impression of where we are. There are many other factors involved in battery performance which I have deliberately ignored in this comparison. I have not considered the ability of the different cells to discharge at higher rates than 1C, especially since this involves a voltage drop throughout the discharge, nor have I included the effect of temperature as all of the data in the tables can be considered to be applicable to normal ambient conditions (20 degrees C). The importance of such additional factors is very much dependent on the application (sports flying, competitions, etc.) where they can sometimes outweigh the simple energy density comparison, but it is an interesting area of consideration.

Energy Density for Lithium Polymer Cells

Make of Cell	Capacity mAh	Weight gms	Approx.Dimensions L x W x T mm	Energy Density Whrs/Kg
Kokam	360	11	52 x 34 x 3	118
Kokam	910	23	59 x 34 x 6	142
Kokam	1500	35	70 x 38 x 7	154
Kokam	3200	83	128 x 44 x 8	139
Tornado	360	13	53 x 34 x 5	100
Tornado	1500	40	86 x 34 x 7	135
Tornado	3200	100	138 x 42 x 9	115
Polypro	800	21	65 x 36 x 4	137
Polypro	1500	38	100 x 32 x 5	140
Polypro	3300	85	142 x 45 x 6	142
Flightpower	400	14	76 x 37 x 3	102
Flightpower	1500	41	101 x 31 x 6	132
Flightpower	3300	85	146 x 48 x 6	140
EnErG Pro	1200	35	115 x 35 x 6	123
EnErG Pro	3200	85	135 x 45 x 8	135
AirPower	800	25	67 x 35 x 5	115
AirPower	2000	58	102 x 35 x 8	124
BRC Hobbies	1500	42	86 x 33 x 7	128
BRC Hobbies	3300	80	137 x 35 x 7	148

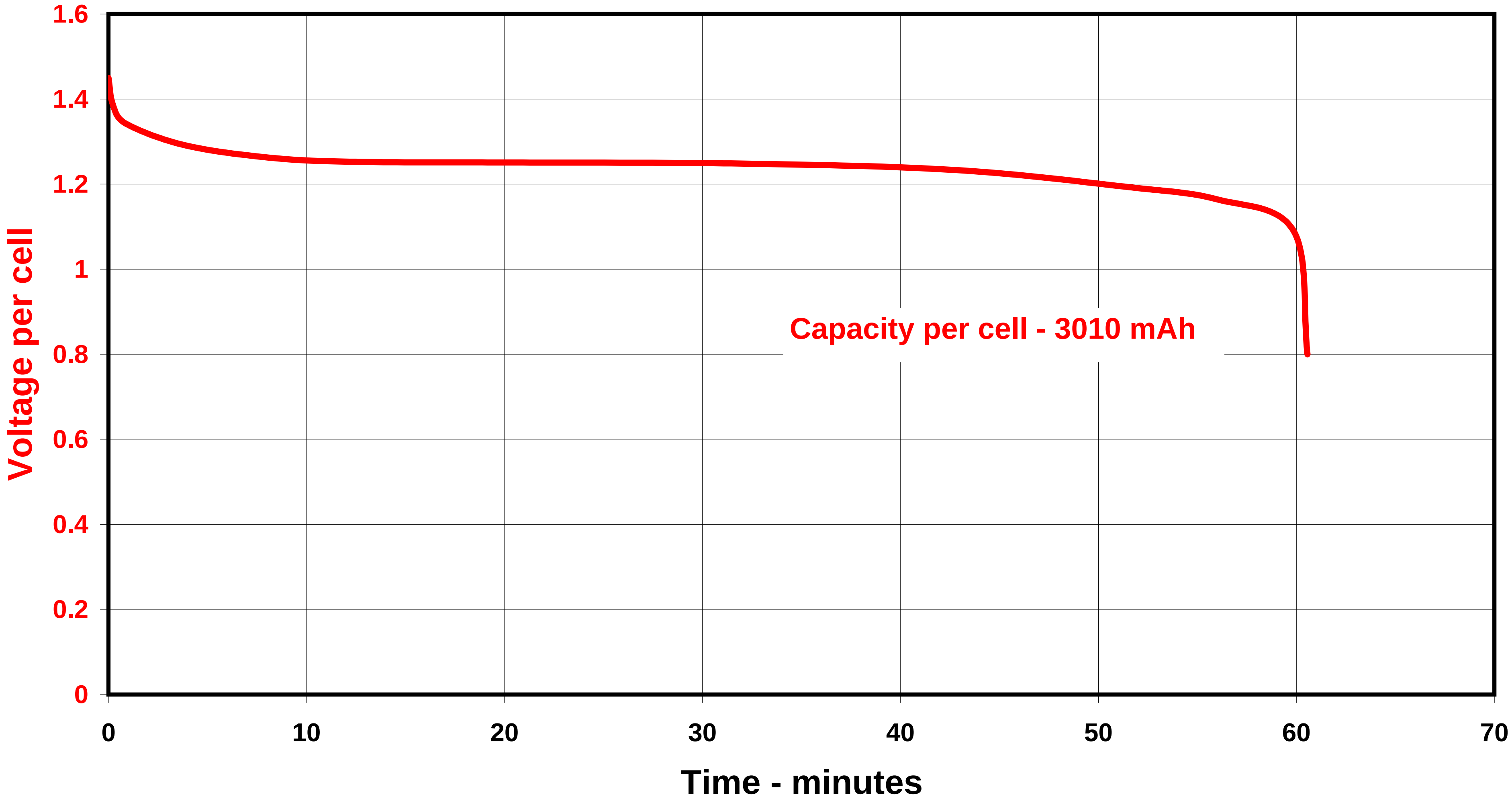
Energy Densities for Other Battery Types

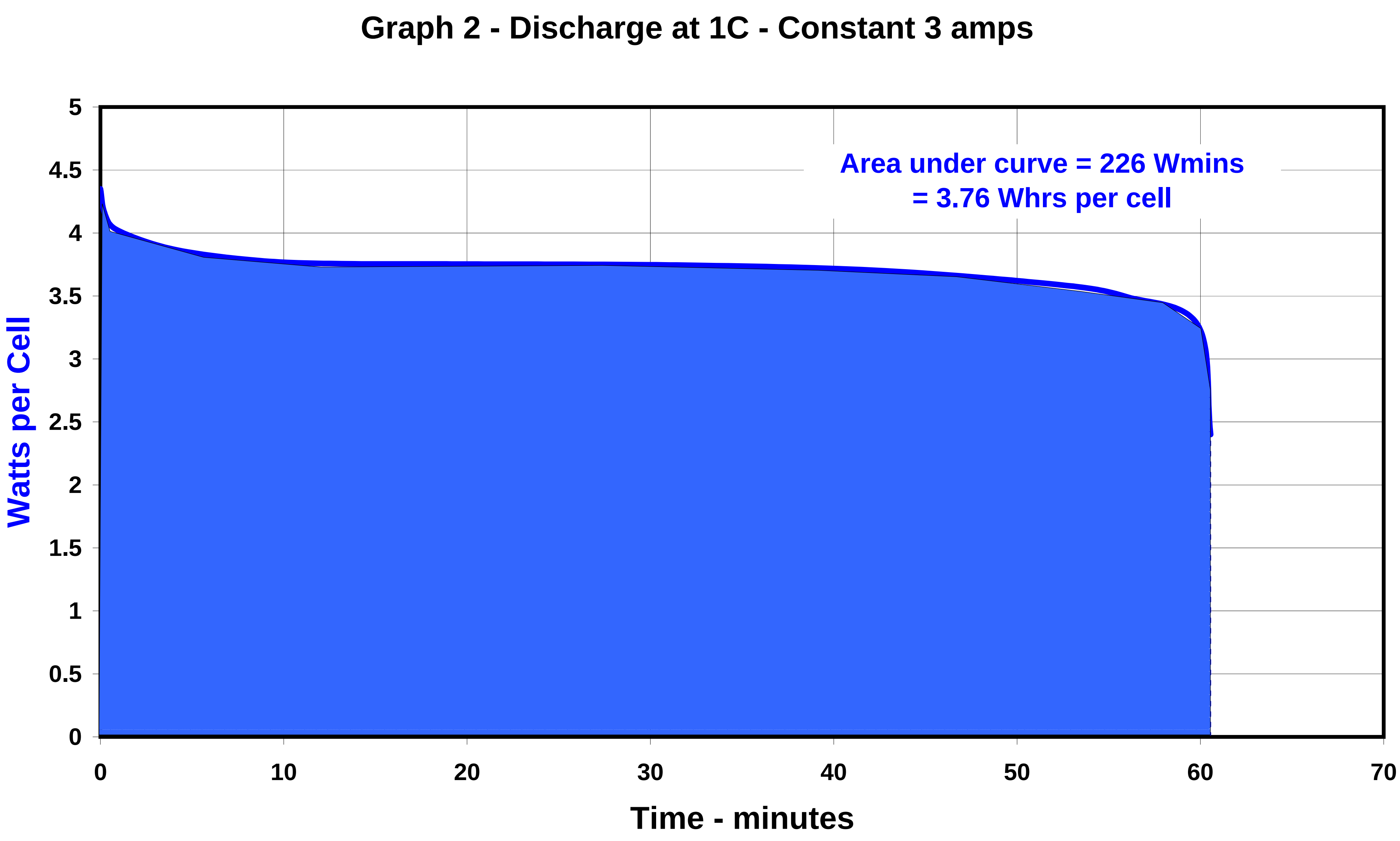
Make/Type	Size	Capacity mAh	Weight gms	Energy Density Whrs/Kg
Intellect NiMH	2/3 AF	1400	23	73
Intellect NiMH	Sub C	4200	67	75
Sanyo NiMH	D	10000	175	68
Sanyo NiCd	Sub C	2400	58	49
Sanyo NiCd	C	3000	85	42
Sony LiIo	4/3 AF	1100	48	80
Lead Gel	6 volt	12000	1850	39
Leisure Lead Acid	12 volt	80000	20000	48

Photograph title

An assortment of typical batteries as included in the tables.

Graph 1 - Discharge at 1C - Constant 3 amps




Graph 2 - Discharge at 1C - Constant 3 amps
Area under curve = 226 Wmins
= 3.76 Whrs per cell
Watts per Cell
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
10
20
30
40
50
60
70
Time - minutes

YUASA
maintenance-free
rechargeable
battery
NP 6-12 12V.6.0Ah
YUASA BATTERY(UK)LTD
CAUTION:
AVOID SHORT CIRCUIT.
DO NOT CHARGE
IN A SEALED CONTAINER
Poly-PRO
3300 XXHD GOLD
Lithium Polymer
11.1V 3S1P XXHD
20C Discharge 40C Bursts
Intellect
4200
GP NiMH
2000
Poly-PRO
1500 XXHD GOLD
Lithium Polymer
11.1V 3S1P XXHD
20C Discharge 40C Bursts
Kokam
Lithium Polymer
Rechargeable
Cells
SANYO
RC-2/3 SC
THUNDER POWER
1250 mAh
Li-Pol aku
HP 11,1 V
GP NiMH
1100
SANYO
2400