BATTERY HEAT DISSIPATION DURING FLOAT OPERATION, RECHARGE AND DISCHARGE

Float operation

The heat dissipation power during the float operation mode can be calculated by the following equation for one cell:

$$P_{float} = \left(U_{float} - U_{gas}\right) \times I_{float} + R_i \times I_{ac}{}^2$$

U_{float} - is defined as float voltage (normally for flooded BAE batteries at 2,23V and for BAE valve regulated batteries at 2,25V)

U_{gas} - is a constant value (water decomposing voltage) given for all flooded batteries 1,48V, assuming, that all the current is used for water decomposition. For valve regulated batteries is this value equivalent to zero, assuming that all the current is used for internal recombination.

I_{float} - is defined as float current. At normal conditions (20°C and float voltage 2,23V for flooded batteries and 2,25V for valve regulated batteries) the float current is nearly 15mA / 100 Ah of nominal capacity for valve regulated batteries and 25 mA / 100 Ah for flooded batteries. (For higher temperatures and float voltages please see the dependence at figure 1.)

Float charge current per 100 Ah	
BAE OPzV / OGiV	10 - 20 mA
BAE OPzS / OGi	25 mA

During life time the float current of the vented (flooded) batteries increases by a factor of 1,5 to 2, caused by antimony poisoning of the batteries.

R_i - is the internal resistance of the cell. The internal resistance depends on the plate design of the cells and the capacity.

I_{ac} - is defined as effective ripple current of the charging unit. According to EN 50272-2 the maximum allowed permanent ripple current is 5A per 100 Ah.

Example 6 OPzS 300 cell (flooded cell with tubular plate technology):

$$P_{float} = (2{,}23\ \text{V} - 1{,}48\ \text{V}) \times 3 \times 25\ \text{mA} + 0{,}63\ \text{m}\Omega \times (3 \times 5\ \text{A})^2 = 0{,}133\ \text{W}$$

Example 7 OPzV 490 cell (valve regulated cell with tubular plate technology):

$$P_{float} = (2{,}25\ \text{V}) \times 4{,}9 \times 15\ \text{mA} + 0{,}51\ \text{m}\Omega \times (4{,}9 \times 5\ \text{A})^2 = 0{,}472\ \text{W}$$

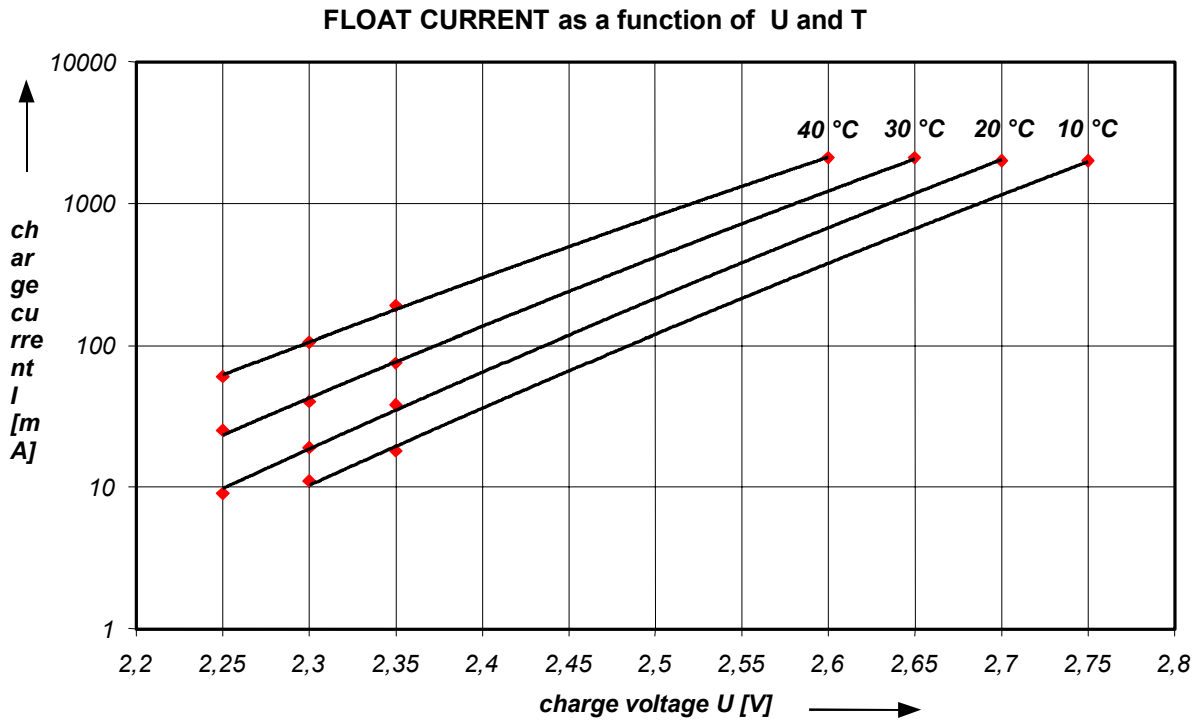

figure 1 – *float current as a function of voltage and temperature*

In accordance with the example 1 calculation, we get following results for the whole product range of flooded / vented OPzS cells:

Type	C10	I_{float}	R_i	P_{float}
	Ah	mA	mΩ	W / cell
4 OPzS 200	200	50,0	0,95	0,133
5 OPzS 250	250	62,5	0,76	0,166
6 OPzS 300	300	75,0	0,63	0,198
5 OPzS 350	350	87,5	0,70	0,280
6 OPzS 420	420	105,0	0,58	0,335
7 OPzS 490	490	122,5	0,50	0,392
6 OPzS 600	600	150,0	0,47	0,536
8 OPzS 800	800	200,0	0,35	0,710
10 OPzS 1000	1000	250,0	0,28	0,888
12 OPzS 1200	1200	300,0	0,23	1,053
12 OPzS 1500	1500	375,0	0,23	1,575
16 OPzS 2000	2000	500,0	0,17	2,075
20 OPzS 2500	2500	625,0	0,14	2,656
24 OPzS 3000	3000	750,0	0,11	3,038

In accordance with the example 2 calculation, we get following results for the whole product range of valve regulated SPzV60 / SPzV 110 and OPzV cells:

SPzV 60

Type	C10	I_{float}	R_i	P_{float}
	Ah	mA	mΩ	W / cell
2 SPzV 120	120	18,0	1,70	0,102
3 SPzV 180	180	27,0	1,13	0,152
4 SPzV 240	240	36,0	0,85	0,203
5 SPzV 300	300	45,0	0,68	0,254
6 SPzV 360	360	54,0	0,57	0,306
7 SPzV 420	420	63,0	0,49	0,358
8 SPzV 480	480	72,0	0,43	0,410
9 SPzV 540	540	81,0	0,38	0,459
10 SPzV 600	600	90,0	0,34	0,509

SPzV 110

Type	C10	I_{float}	R_i	P_{float}
	Ah	mA	mΩ	W / cell
3 SPzV 330	330	49,5	0,93	0,365
4 SPzV 440	440	66,0	0,70	0,487
5 SPzV 550	550	82,5	0,56	0,609
6 SPzV 660	660	99,0	0,47	0,735
7 SPzV 770	770	115,5	0,40	0,853
8 SPzV 880	880	132,0	0,35	0,975
9 SPzV 990	990	148,5	0,31	1,094
10 SPzV 1100	1100	165,0	0,28	1,218

OPzV

Type	C10	I_{float}	R_i	P_{float}
	Ah	mA	mΩ	W / cell
4 OPzV 200	200	30,0	1,20	0,188
5 OPzV 250	250	37,5	0,96	0,234
6 OPzV 300	300	45,0	0,80	0,281
5 OPzV 350	350	52,5	0,71	0,336
6 OPzV 420	420	63,0	0,60	0,406
7 OPzV 490	490	73,5	0,51	0,472
6 OPzV 600	600	90,0	0,45	0,608
8 OPzV 800	800	120,0	0,34	0,814
10 OPzV 1000	1000	150,0	0,27	1,013
12 OPzV 1200	1200	180,0	0,23	1,233
12 OPzV 1500	1500	225,0	0,24	1,856
16 OPzV 2000	2000	300,0	0,18	2,475
20 OPzV 2500	2500	375,0	0,14	3,031
24 OPzV 3000	3000	450,0	0,12	3,713

Discharge operation

The heating dissipation during discharge operation depends on the discharge current and the difference between the open-circuit voltage (U_0 = 0,84 + electrolyte gravity) and the actual discharge voltage of the battery. The gravity of the flooded cells were measured during the discharge. For the valve regulated batteries is it possible to assume the same GEL gravity at the end of discharge. The SPzV cell types are filled with GEL with a gravity of 1,26 kg/l. The higher GEL gravity shifts a bit the voltage difference $\left(U_0 - U_{discharge}\right)$. As equation for the heating calculation this formula is used

$$P_{discharge} = \left(U_0 - U_{discharge}\right) \times I_{discharge}$$

For all calculations a discharge during 1 h is assumed with a final voltage of 1,67 V per cell. As discharge current the current of the project planning data is selected, which includes the differences of the different plate lengths and plate numbers at a plate set.

OPzS cells:

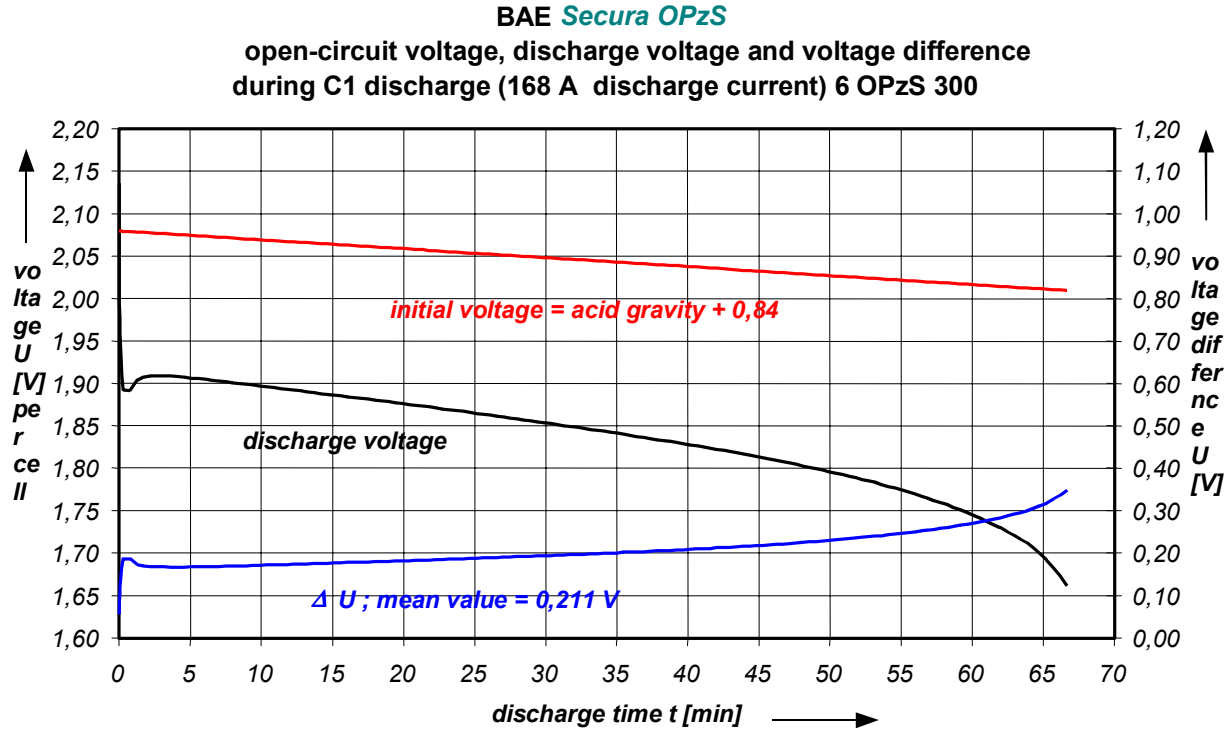

figure 2 – *discharge voltage, open-circuit voltage and voltage difference during 1 h discharge of BAE 6 OPzS 300*

So we can calculate for the heat dissipation power of a 6 OPzS 300 cell during 1 h discharge:

$$P_{discharge} = 0{,}211\,\text{V} \times 168\,\text{A} = 35{,}45\,\text{W}$$

Type	C10	I_{C1}	$P_{discharge}$
	Ah	A	W / cell
4 OPzS 200	200	112	23,63
5 OPzS 250	250	140	29,54
6 OPzS 300	300	168	35,45
5 OPzS 350	350	200	42,20
6 OPzS 420	420	240	50,64
7 OPzS 490	490	280	59,08
6 OPzS 600	600	320	67,52
8 OPzS 800	800	426	89,89
10 OPzS 1000	1000	533	112,46
12 OPzS 1200	1200	639	134,83
12 OPzS 1500	1500	780	164,58
16 OPzS 2000	2000	1040	219,44
20 OPzS 2500	2500	1300	274,30
24 OPzS 3000	3000	1560	329,16

OPzV cells:

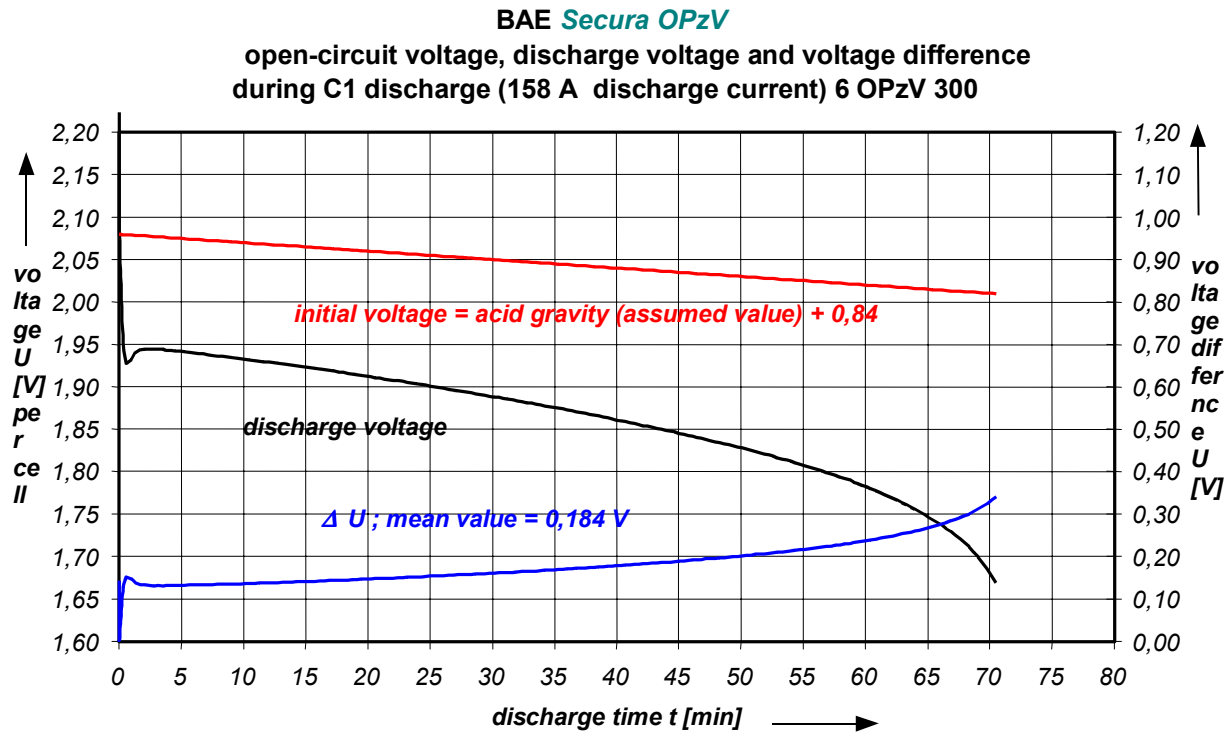

figure 3 – *discharge voltage, open-circuit voltage and voltage difference during 1 h discharge of BAE 6 OPzV 300*

Type	C10	I_{C1}	$P_{discharge}$
	Ah	A	W / cell
4 OPzV 200	200	133	24,47
5 OPzV 250	250	166	30,54
6 OPzV 300	300	199	36,62
5 OPzV 350	350	223	41,03
6 OPzV 420	420	268	49,31
7 OPzV 490	490	313	57,59
6 OPzV 600	600	383	70,47
8 OPzV 800	800	511	94,02
10 OPzV 1000	1000	638	117,39
12 OPzV 1200	1200	766	140,94
12 OPzV 1500	1500	850	156,40
16 OPzV 2000	2000	1134	208,66
20 OPzV 2500	2500	1417	260,73
24 OPzV 3000	3000	1701	312,98

SPZV 60

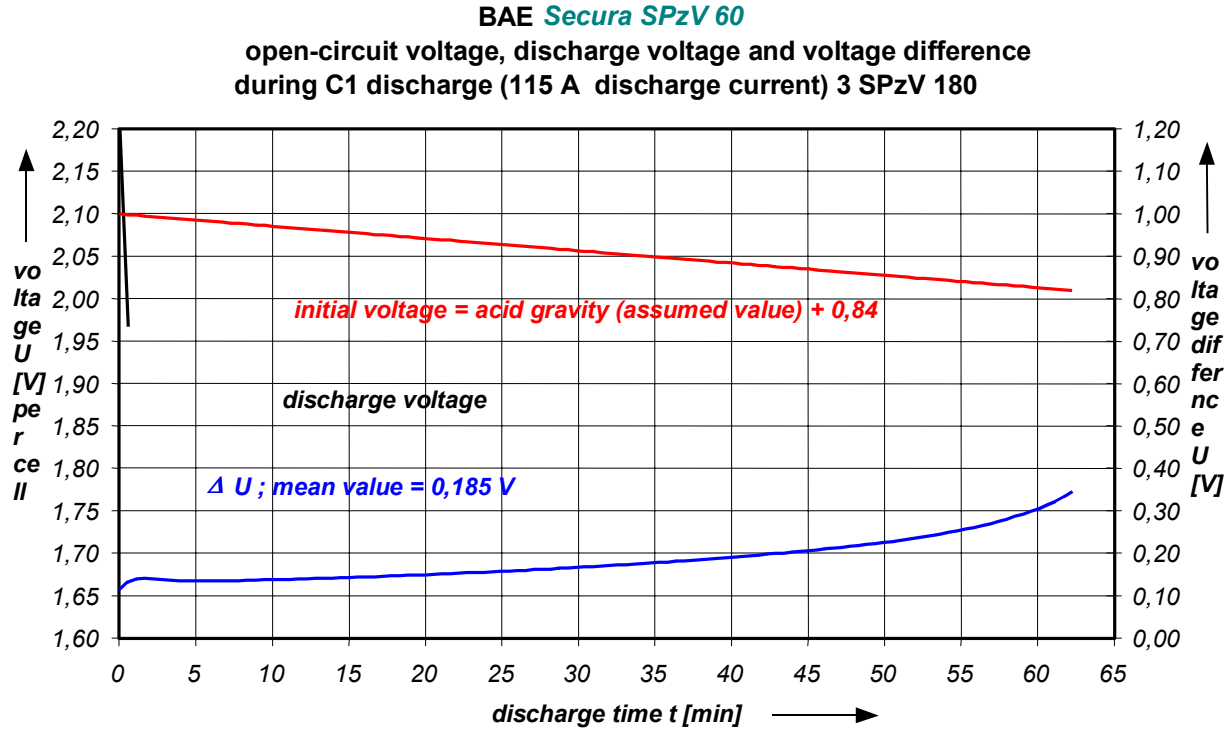

figure 4 – *discharge voltage, open.circuit voltage and voltage difference during 1 h discharge of BAE 3 SPzV 180*

Type	C10	I_{C1}	$P_{discharge}$
	Ah	A	W / cell
2 SPzV 120	120	77,2	14,28
3 SPzV 180	180	116	21,46
4 SPzV 240	240	154	28,49
5 SPzV 300	300	193	35,71
6 SPzV 360	360	232	42,92
7 SPzV 420	420	270	49,95
8 SPzV 480	480	309	57,17
9 SPzV 540	540	347	64,20
10 SPzV 600	600	386	71,41

SPzV 110

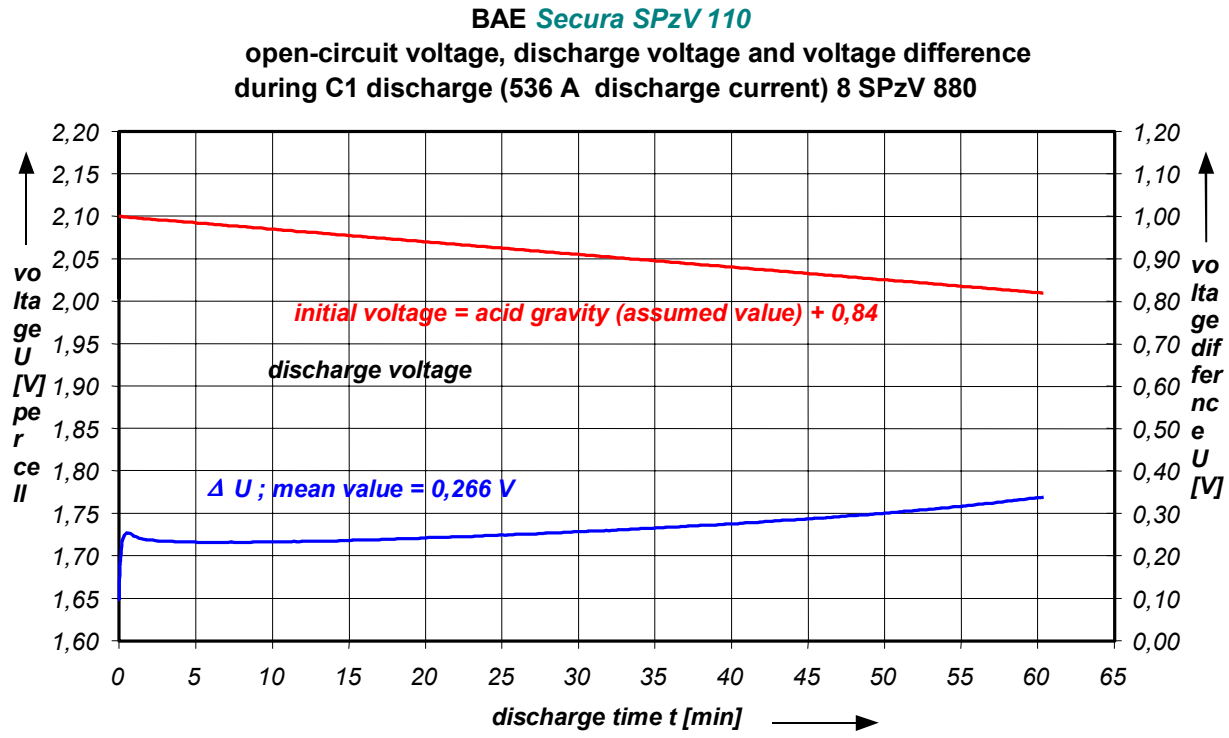

figure 5 – *discharge voltage, open-circuit voltage and voltage difference during 1 h discharge of BAE 8 SPzV 880*

Type	C10	I_{C1}	$P_{discharge}$
	Ah	A	W / cell
3 SPzV 330	330	181	48,15
4 SPzV 440	440	242	64,37
5 SPzV 550	550	302	80,33
6 SPzV 660	660	362	96,29
7 SPzV 770	770	423	112,52
8 SPzV 880	880	483	128,59
9 SPzV 990	990	544	144,67
10 SPzV 1100	1100	604	160,74

Recharge operation

The calculation is nearly the same like at discharge operation. The heat dissipation is now a product of the mean value of recharge current and the difference between the open-circuit and the recharge voltage. The heat dissipation due to the ripple current is neglected, because it is less than 5% of the recharge current effect. All calculation examples are carried out for a initial recharge current of 1,5 x I10 (nominal current) and a boost charge voltage of 2,4 V. The recharge time for the calculation is limited to a charging factor of 1,0. The average current during the boost charge operation can be assumed as 90 % of the initial current for all calculations. During the recharge there is nearly no difference between the recharge behaviour of OPzS, OPzV and SPzV 60 and SPzV110 cells.

$$P_{recharge} = \left(U_{recharge} - U_0\right) \times I_{recharge}$$

Example: Recharge during 315 min (5,25 h) of BAE 6 OPzS 300 cell, initial charging current 45 A (average charging current 40,3 A = 89,5 %):

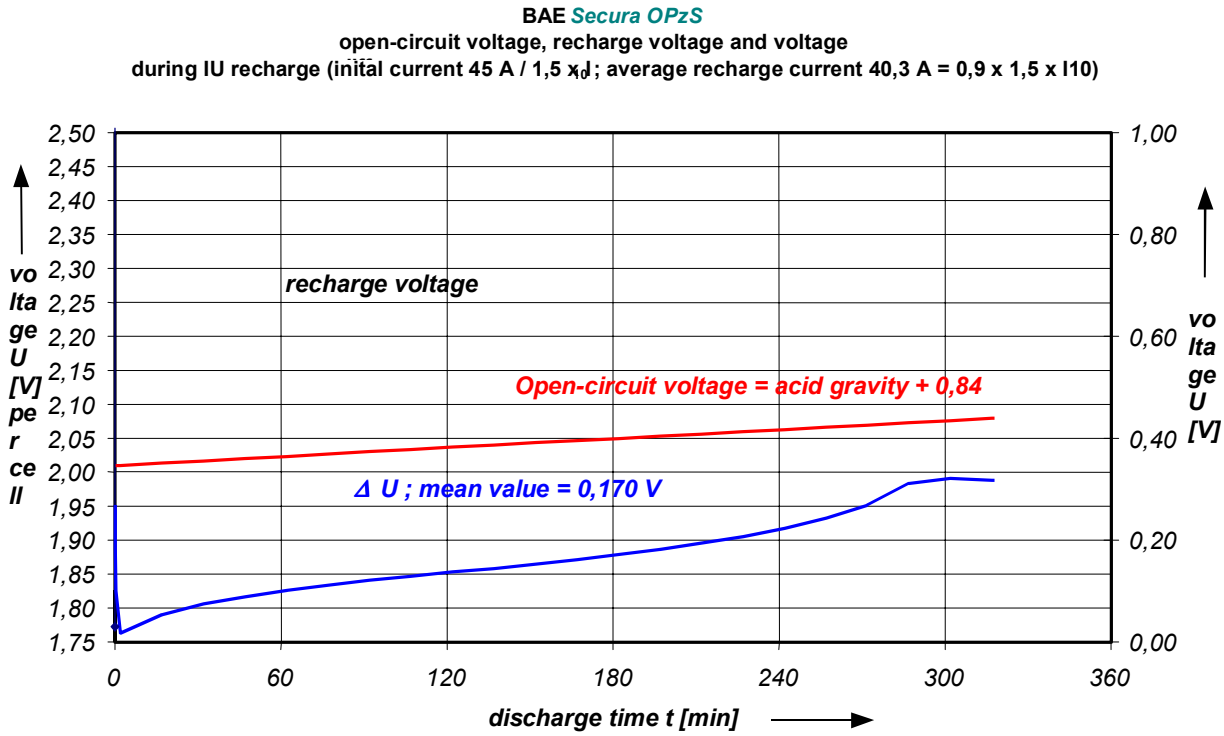

figure 6 - *recharge voltage, natural voltage and voltage difference of BAE 6 OPzS 300*

Heat dissipation power during recharge of the cell:

$$P_{rescharge} = 0{,}170\ \text{V} \times 40{,}3\ \text{A} = 6{,}851\ \text{W}$$

OPzS cells:

Type	C10	I_{C10}	$I_{1,5 \times C10}$ (90 %)	$P_{recharge}$
	Ah	A	A	W / cell
4 OPzS 200	200	20	27,00	4,62
5 OPzS 250	250	25	33,75	5,77
6 OPzS 300	300	30	40,50	6,93
5 OPzS 350	350	35	47,25	8,08
6 OPzS 420	420	42	56,70	9,70
7 OPzS 490	490	49	66,15	11,31
6 OPzS 600	600	60	81,00	13,85
8 OPzS 800	800	80	108,00	18,47
10 OPzS 1000	1000	100	135,00	23,09
12 OPzS 1200	1200	120	162,00	27,70
12 OPzS 1500	1500	150	202,50	34,63
16 OPzS 2000	2000	200	270,00	46,17
20 OPzS 2500	2500	250	337,50	57,71
24 OPzS 3000	3000	300	405,00	69,26

Example: recharge during 345 min (5,75 h) of BAE 6 OPzV 300 cell, initial charging current 45 A (average charging current 42 A = 93 %):

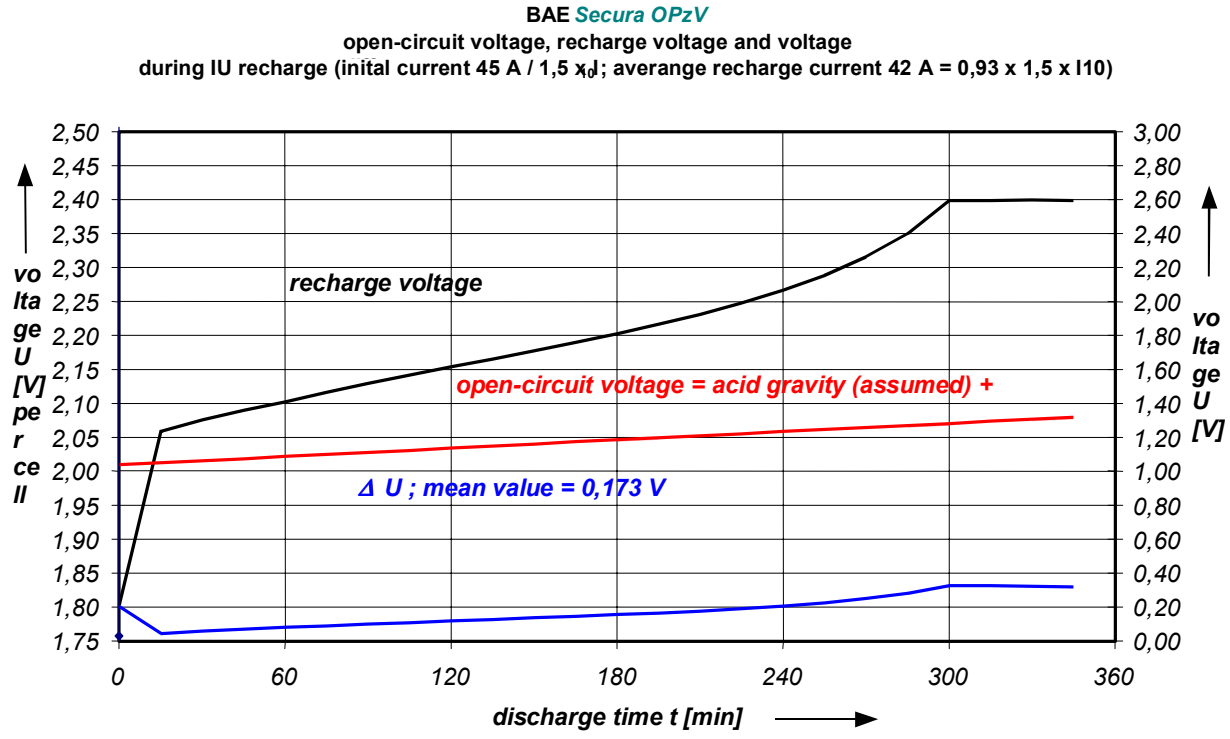

figure 7 - *recharge voltage, open-circuit voltage and voltage difference of BAE 6 OPzV 300*

Rejected continues power during recharge of the cell:

$$P_{recharge} = 0{,}173\ \mathrm{V} \times 42\ \mathrm{A} = 7{,}266\ \mathrm{W}$$

SPzV 60

Type	C10	I_{C10}	$I_{1,5 \times C10}$ (90 %)	$P_{recharge}$
	Ah	A	A	W / cell
2 SPzV 120	120	12	16,20	2,80
3 SPzV 180	180	18	24,30	4,20
4 SPzV 240	240	24	32,40	5,61
5 SPzV 300	300	30	40,50	7,01
6 SPzV 360	360	36	48,60	8,41
7 SPzV 420	420	42	56,70	9,81
8 SPzV 480	480	48	64,80	11,21
9 SPzV 540	540	54	72,90	12,61
10 SPzV 600	600	60	81,00	14,01

SPzV 110

Type	C10	I_{C10}	$I_{1,5 \times C10}$ (90 %)	$P_{recharge}$
	Ah	A	A	W / cell
3 SPzV 330	330	33	44,55	7,71
4 SPzV 440	440	44	59,40	10,28
5 SPzV 550	550	55	74,25	12,85
6 SPzV 660	660	66	89,10	15,41
7 SPzV 770	770	77	103,95	17,98
8 SPzV 880	880	88	118,80	20,55
9 SPzV 990	990	99	133,65	23,12
10 SPzV 1100	1100	110	148,50	25,69

OPzV

Type	C10	I_{C10}	$I_{1,5 \times C10}$ (90 %)	$P_{recharge}$
	Ah	A	A	W / cell
4 OPzV 200	200	200	270,00	46,71
5 OPzV 250	250	250	337,50	58,39
6 OPzV 300	300	300	405,00	70,07
5 OPzV 350	350	350	472,50	81,74
6 OPzV 420	420	420	567,00	98,09
7 OPzV 490	490	490	661,50	114,44
6 OPzV 600	600	600	810,00	140,13
8 OPzV 800	800	800	1080,00	186,84
10 OPzV 1000	1000	1000	1350,00	233,55
12 OPzV 1200	1200	1200	1620,00	280,26
12 OPzV 1500	1500	1500	2025,00	350,33
16 OPzV 2000	2000	2000	2700,00	467,10
20 OPzV 2500	2500	2500	3375,00	583,88
24 OPzV 3000	3000	3000	4050,00	700,65

All the calculation are carried out only for one cell. For the whole battery the continues power should be multiply by the number of cell of the battery.

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