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DETERMINATION OF ENTROPY HEATING VALUE OF DEEP CYCLED LEAD ACID BATTERIES IN TERMS OF ADIABATIC TEMPERATURE RISE DURING DISCHARGE

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Abstract

Determination of entropy heating value of deep cycled lead acid batteries in terms of adiabatic temperature rise during discharge has been done. The materials used for this work are; a 250 watts monocrystalline solar module, a digital multimeter, an inverter, a timing device, 200 watts bulb, six 12 volts deep cycled lead acid batteries and a digital thermometer. The study shows that the battery adiabatic temperature rises as the battery discharges continuously and the discharges result into power loss from the battery. The average entropy values for the six different battery models under consideration are 1.97J/K, 2.18J/K, 2.40J/K, 2.93J/K, 3.11J/K and 3.13J/K. The average entropy heating value for all the considered models of deep cycled Lead acid batteries is thus **2.62J/K.**

Keywords: Lead Acid Battery, Entropy, Adiabatic temperature, Discharge, Digital thermometer.

1.0 Introduction

Lead acid batteries are built with a number of individual cells containing layers of lead alloy plates immersed in an electrolyte solution, typically made of 35% sulphuric acid (H_2SO_4) and 65% water. The most common large-capacity rechargeable batteries are lead acid batteries. Their popularity is based on the fact that they are dependable and inexpensive on a cost-per-watt base. The charge retention and moderate life span of lead acid batteries are the best amongst rechargeable batteries. It is observed that lead acid batteries works more efficiently at cold temperature and is superior to lithium-ion batteries when operating in sub-zero conditions. Lead acid batteries are mainly divided into two classes, namely: vented lead acid batteries (which is spillable) and valve regulated lead acid batteries (VRLA) which is sealed or non-spillable.

A **deep-cycle battery** is a battery designed to be regularly deeply discharged using most of its capacity. The structural difference between deep-cycle and cranking lead-acid batteries is in the lead battery plates. Deep cycle battery plates have thicker active plates, with higher-density active paste material and thicker separators. Alloys used for the plates in a deep cycle battery may contain more metallic elements than that of starting batteries. The thicker battery plates resist corrosion through extended charge and discharge cycles. Figure 1 shows a typical deep cycled lead acid battery.

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Figure 1: Typical deep cycled lead acid battery.

The delivery and storage of electrical energy in lead acid batteries via the conversion of lead dioxide and lead to and from lead sulphate is simple. The performance of the battery depends on cell design, the materials of construction, a complex interplay between the copious parameters involved, plate preparation, the chemical composition and structure of the active materials, and the duty or conditions of battery operation. It is therefore not surprising that the causes for the degradation of battery performance and failure, are multitudinous.

Deep-cycle lead-acid batteries generally fall into two distinct categories; flooded (FLA) and valve-regulated lead-acid (VRLA). The VRLA type further subdivided into two types, Absorbed Glass Mat (AGM) and Gel. The reinforcement of absorbed glass mat separators helps to reduce damage caused by spilling and jolting vibrations. Further, flooded deep-cycle batteries can be divided into subcategories of Tubular-plated or flat plated. The difference generally affects the cycle life and performance of the cell. Deep cycle batteries have excellent high current performance and are therefore recommended for high current applications. Due to their construction, Gel batteries have a lower effective capacity at high discharge currents. On the other hand, Gel batteries have a longer service life, both under float and cycling conditions.

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Increasing attention to the global climate change and the sustainable development open new applications for energy storage using lead acid batteries such as electric transport, renewable energies, photovoltaic, wind, grid storage, quality and emergency supplies.

Entropy in statistical mechanics is a measure of the randomness of the microscopic constituents of a thermodynamic system. Adiabatic temperature changes are the temperature changes that occur without heat being added or taken away from the system.

The improvement on battery’s life time has been reported by some researchers which include fast charge of valve regulated lead acid batteries for electric car [1], battery management for photovoltaic applications [2] , and methods of maintaining the charge for stationary lead acid batteries [3]. Since lead-acid batteries are electrochemical systems, temperature affects a variety of their characteristics, such as electrical performance and life. Proper storage of deep-cycle batteries helps achieve better performance and longer life, while increasing reliability and value. All batteries, regardless of their chemical makeup, undergo a process called local action or self-discharge. The rate or speed at which this process occurs is dependent upon the chemical reactants in the battery's composition. The chemical reactants in a lead-acid battery consist of lead dioxide or lead peroxide in the positive electrode, sponge lead in the negative electrode and sulphuric acid in a dilute solution, called electrolyte. One basic principle in chemistry states that as the quantity of reactants increases, the rate of reaction increases. The number of plates in each cell, the density of the active material, and the concentration of pure sulphuric acid in the electrolyte solution all play a part in the rate at which the battery self-discharges during storage.

Researches on the effect of temperature on battery degradation of various cell components in Lithium battery have also been reported. The degradation of carbon negative electrode at elevated temperature, up to 80 degrees was studied [4]. The degradation of thermally aged $LiCoO_2$ and $LiMn_2O_4$ cathode was reported [5]. The thermal aging of electrolyte and the influence of housing material was studied [6]. The temperature effect on the degradation at electrode/electrolyte interface was investigated [7] and the capacity fade of Sony 18650 cells with $LiCoO_2$/graphite electrode materials at room temperature, 45˚C, 50˚C and 55˚C respectively was studied [8].

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Also, the performance characteristics of Lead acid deep cycle batteries through charge/discharge voltages, charge/discharge ratio and round-trip energy efficiency were studied using two solar panels (model:80W, SF 125×35V/4 Amps), one solar panel (model:45W, STP 045- 12/Rb), 2000VA inverter, 2 Gaston sealed rechargeable deep cycle batteries (12V/200 Amp-hr), 2 GA lead valve regulated batteries (12V/100 Amp-hr), a digital multimeter, two light bulbs (100W) and a thermometer. The study shows that the I–V characteristics of the two different batteries were non-ohmic [9].

The aim of this work is to determine the entropy heating values of some deep cycled lead acid batteries in terms of adiabatic temperature rise during discharge.

2.0 Materials and Methods

The materials employed in this study include :

(i) 12V/100AH Deep Cycled Lead battery **Crystal Plus** model
(ii) 12V/100AH Deep Cycled Lead battery **Sunfit** model
(iii) 12V/100AH Deep Cycled Lead battery **Rock** model
(iv) 12V/100AH Deep Cycled Lead battery **GBM** model
(v) 12V/100AH Deep Cycled Lead battery **Exclusive** model
(vi) 12V/100AH Deep Cycled Lead battery **Power Waves** model
(vii) Inverter
(viii) Bulb
(ix) Digital Thermometer
(x) 250W Solar Module
(xi) Digital Multimeter (Figure 4)

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The employed batteries have the following features:

1. Constant Voltage charge, Standby use: 13.5V ~ 13.8V.
2. Cycle use: 14.4V ~ 15.0V.
3. Initial current: less than 30A
4. Size (L x W x H cm): 35 × 19 × 27
5. Weight (kg): 30.5

Figure1 is a typical lead acid battery (GBM Model) used for this study.

Figure 1: Typical lead acid battery (GBM Model).

The specifications of employed inverter are [10]:

Max power	1000W
Continuous rating	600W
No load current drop	<0.3A
Input DC voltage range	DC10V-15V
Output voltage range	AC220+/-5%
Output frequency range	50+/-3HZ
Max outer temperature	<65°c
Max power efficiency	>90%
High voltage cutoff level	>DC15V
Low voltage alarm level	DC10.0 - 11.0V
Low voltage cutoff level	DC10V
Over load and short circuit protection	yes
Input voltage	DC12V
Output waveform	Modified sine wave
Built in cooling fan	yes
Product size	280 x150 x 71(mm)

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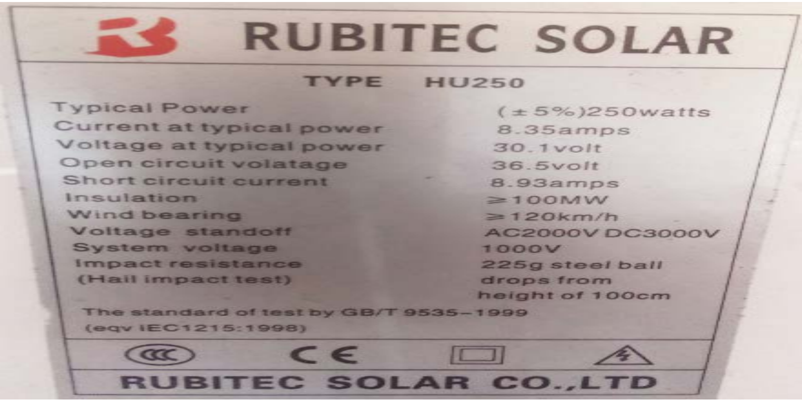
N.W	750g/PCS

The 200W bulb was used as a load to discharge the battery. Figure 2 is the typical bulb employed in the study.

Figure 2: Typical 200W bulb.

The employed solar panel has the following features (Figure 3):



RUBITEC SOLAR

TYPE HU250

Typical Power	(±5%)250watts
Current at typical power	8.35amps
Voltage at typical power	30.1volt
Open circuit volatage	36.5volt
Short circuit current	8.93amps
Insulation	≥100MW
Wind bearing	≥120km/h
Voltage standoff	AC2000V DC3000V
System voltage	1000V
Impact resistance (Hail impact test)	225g steel ball drops from height of 100cm

The standard of test by GB/T 9535–1999
(eqv IEC1215:1998)

CE

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Figure 3: Features of employed solar panel.

Figure 4: A typical digital multi-meter.

With the available materials, the following procedural steps were taken to determine the entropy heating values of all sampled deep cycled Lead Acid batteries in terms of Adiabatic Temperature rise during discharge:

i. The initial voltage V_0dc of the battery before connection was determined with a multimetere at full state.
ii. The temperature at the battery terminals was also determined.
iii. The battery was connected in parallel to the inverter.
iv. Both Vac and Vdc values were recorded from the inverter display.
v. Corresponding currents Iac and Idc were also calculated.
vi. A load (200W bulb) was connected to the inverter to discharge the battery. The Vac , V dc and temperature in (^{o}c) were measured at intervals of 15 minutes (1/4hr).
vii. Corresponding currents Iac and Idc were also calculated.
viii. The battery terminal temperature at each interval of 15 minutes during discharge was recorded.
ix. The graph of ΔT against Wh ($V_{dc.}I_{dc}H_d$) was plotted
x. ΔT was evaluated using the relation [11]:

$$\Delta T = \frac{WH_d}{MC_p}[1 - n_0 + \frac{E_d}{E_0}] \quad (1)$$

Where:

ΔT = adiabatic temperature rise of the battery

WH_d = watt – hour energy discharge

C_p = Battery specific heat (for lead acid = 0.35Wh/KgK)

M = Mass of battery = 30.5kg

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η_o = Voltage of efficiency factor on discharge

E_d = Average cell entropy energy per coulomb during discharge i.e. average loss per ampere of discharge, W/A.

E_o = Average cell open circuit voltage, volts.

xi. Evaluate average value of Entropy, S.

The same procedural steps were repeated thrice with the battery fully charged at each instance so as to minimize random error in the calculation.

3.0 RESULTS AND DISCUSSIONS

The effect of temperature on the overall performance of battery cannot be overlooked. The general optimal operating temperature of lead acid batteries is about 25˚C. The hotter a battery, the faster chemical reactions will occur. High temperatures sometime can cause increased performance of the batteries. It will result in faster and corresponding loss of battery life. At temperatures below optimal temperature, batteries will have a decreased capacity and longer life. Battery life is reduced at higher temperatures whether sealed, Gel, AGM, industrial or whatever.

The tables 1, 2 and 3 present the measured and calculated values for GBM battery model. The average entropy value is thus determined.

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Table 1 : First Measured and Calculated Values for GBM model battery.

H_d(T)	V_{ac} (V)	V_{dc} (V)	I_{ac} (A)	I_{dc} (A)	T (˚C)	PL= $I_{0dc}\times V_{0dc}-I_{0dc}\times V_{dc(W)}$	η_o = Vdc/Vo $\frac{V_{dc}}{V_0}$	E_o = $V_{o\,(V)}$	Ed = (IoVo - IdcVdc)/Idc	S = Q/T	ΔT	WHr
0.00	226	12.7	0.88	2.36	26.20	30.00	0.98	13.00	538.15	0.00	0.00	0
0.25	238	11.4	0.84	14.04	30.80	160.00	0.88	13.00	81.19	1.71	23.45	40.014
0.50	238	11.3	0.84	15.04	31.60	170.00	0.87	13.00	75.14	1.84	46.09	84.976
0.75	239	11.2	0.84	16.07	32.30	180.00	0.86	13.00	69.70	1.99	67.93	134.988
1.00	239	11.2	0.84	16.07	32.40	180.00	0.86	13.00	69.70	1.99	90.57	179.984
1.25	240	11.1	0.83	17.12	33.10	190.00	0.85	13.00	64.83	2.14	111.23	237.54
1.50	241	10.9	0.83	19.27	33.20	210.00	0.84	13.00	56.56	2.45	128.78	315.0645
1.75	241	10.7	0.83	21.50	32.40	230.00	0.82	13.00	49.77	2.78	144.88	402.5875
2.00	237	10.3	0.84	26.21	32.50	270.00	0.79	13.00	39.30	3.51	153.71	539.926

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The average entropy value, S, for GBM Lead Acid battery model for the first cycle is thus, **2.05J/K**. Figure 5 shows the behaviour of GBM Lead acid battery during discharge. The figure illustrates ΔT against WHr for the first cycle.

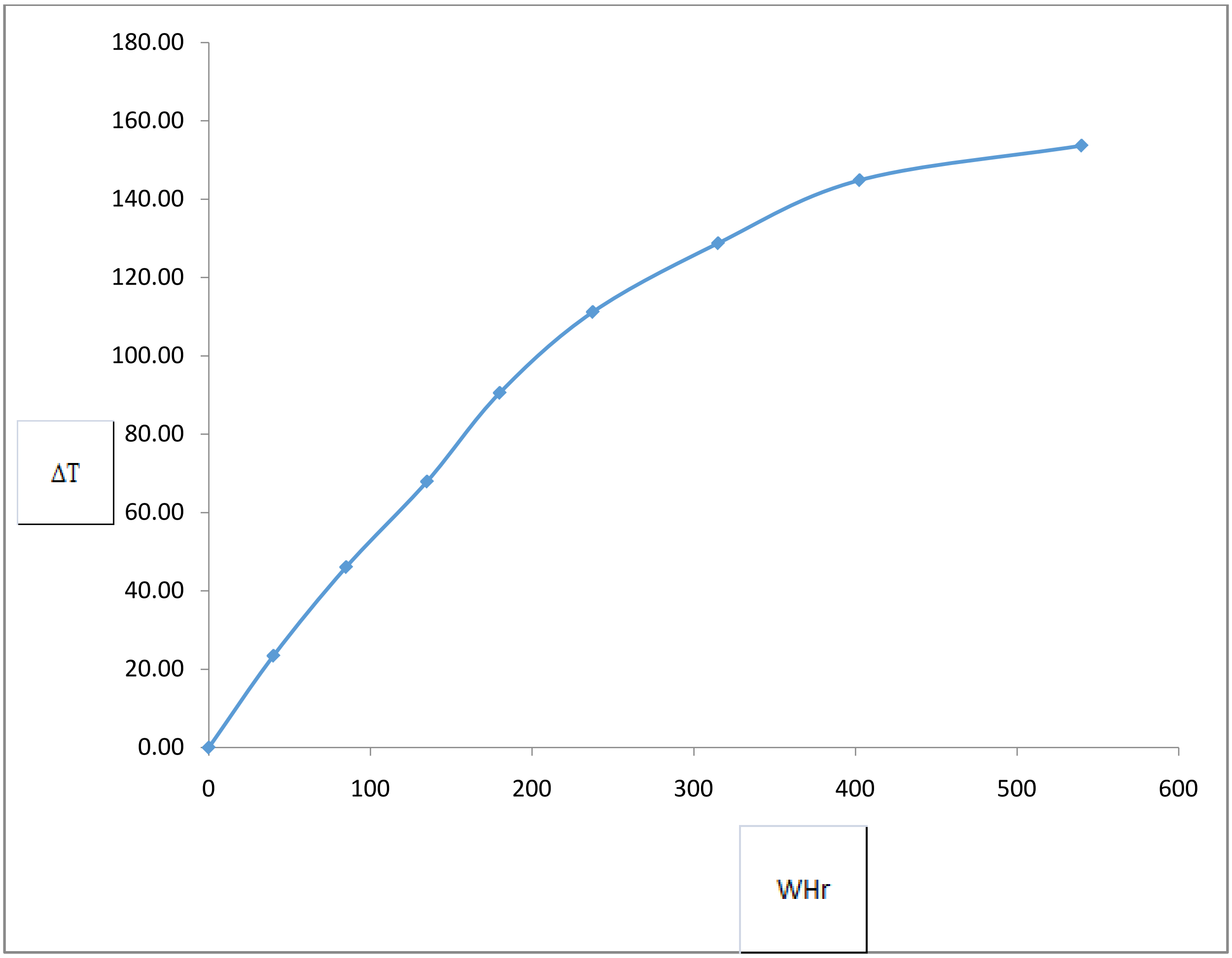

Figure 5**:** ΔT - Whr curve for first cycle.

Thus, from the graph, it can be clearly seen that as watt-hour increases, the change in temperature rises.

Table 2 : Second Measured and Calculated Values for GBM model battery.

H_d(T)	V_{ac} (V)	V_{dc} (V)	I_{ac} (A)	I_{dc} (A)	T (°C)	PL = $I_{0dc} \times V_{0dc} - I_{0dc} \times V_{dc}$(W)	$\eta_o = \frac{Vdc}{Vo}$ $\frac{V_{dc}}{V_0}$	$E_o = V_o$ (V)	$E_d = \frac{IoVo - IdcVdc}{Idc}$	S = Q/T	ΔT	WHr
0.00	237	11.5	0.84	23.48	35.30	270.00	0.81	14.20	48.98	0.00	0.00	0
0.25	238	11.3	0.84	25.66	73.30	290.00	0.80	14.20	44.04	3.43	21.16	72.4895
0.50	238	11.3	0.84	25.66	55.30	290.00	0.80	14.20	44.04	3.43	42.32	144.979
0.75	239	11.1	0.84	27.92	57.00	310.00	0.78	14.20	39.76	3.79	61.30	232.434
1.00	240	10.9	0.83	30.28	33.10	330.00	0.77	14.20	36.00	4.18	78.88	330.052
1.25	241	10.8	0.83	31.48	101.60	340.00	0.76	14.20	34.31	4.39	96.86	424.98
1.50	241	10.7	0.83	32.71	89.30	350.00	0.75	14.20	32.71	4.60	114.15	524.9955
1.75	236	10.3	0.85	37.86	85.00	390.00	0.73	14.20	27.21	5.52	123.72	682.4265

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The average entropy value, S, for GBM model battery for the second cycle is thus, **3.67J/K.**

Figure 6 shows the behaviour of GBM Lead acid battery during discharge. The figure illustrates ΔT against WHr for the second cycle.

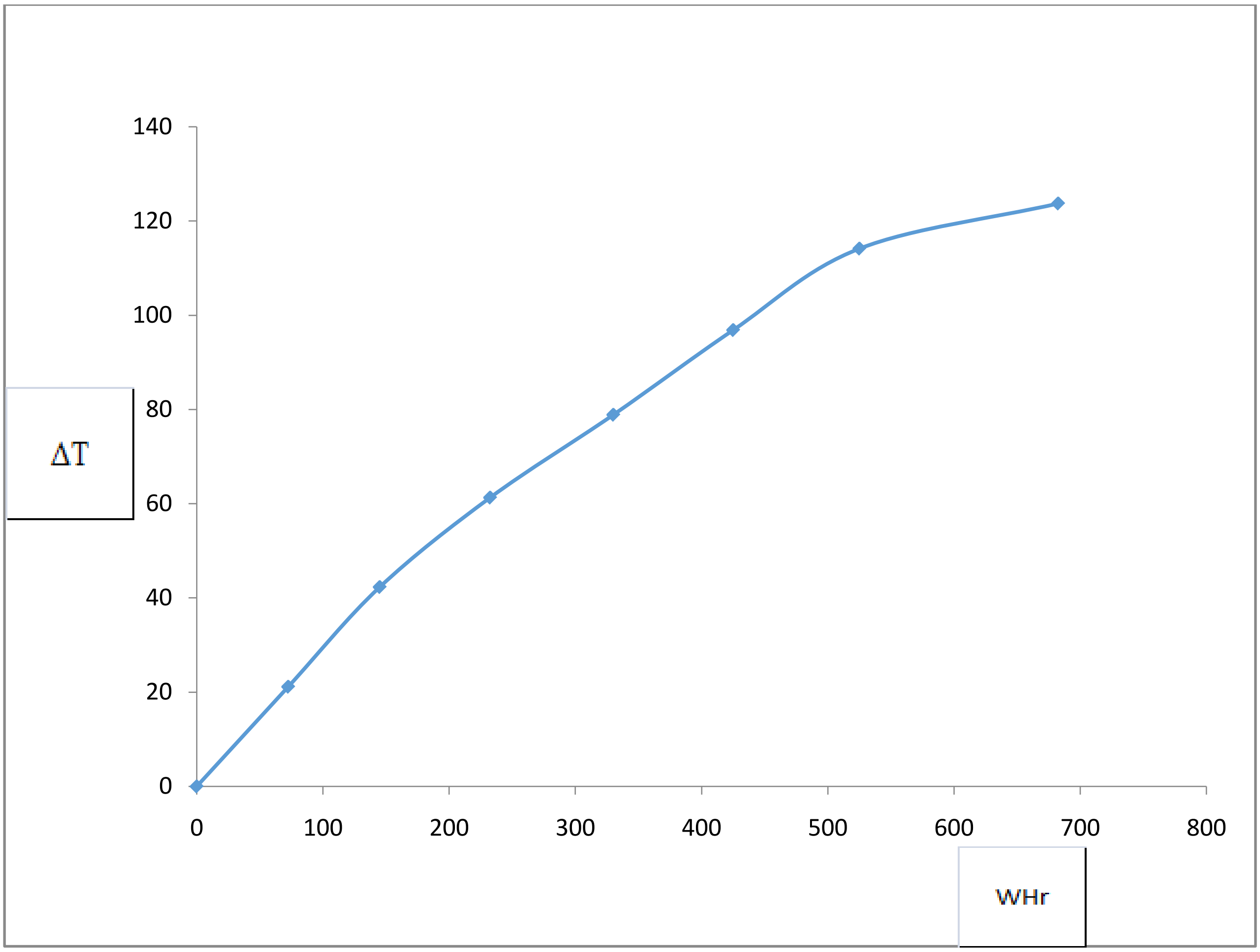

Figure 6**:** ΔT - Whr curve for second cycle.

In Figure 6, the change in temperature increases as watt – hour increases.

Table 3 : Third Measured and Calculated Values for GBM model battery.

H_d(T)	V_{ac} (V)	V_{dc} (V)	I_{ac} (A)	I_{dc} (A)	T (°C)	PL= $I_{0dc}\times V_{0dc}-I_{0dc}\times V_{dc}$(W)	η_o = $\frac{Vdc}{Vo}$ $\frac{V_{dc}}{V_0}$	E_o = $V_{o\,(V)}$	$E_d = \frac{IoVo - IdcVdc}{Idc}$	S = Q/T	ΔT	WHr
0.00	238	11.3	0.84	20.80	35.30	235.00	0.83	13.65	54.33	0.00	0.00	0
0.25	240	10.9	0.83	25.23	73.30	275.00	0.80	13.65	43.20	3.36	20.48	68.75175
0.50	241	10.7	0.83	27.57	55.30	295.00	0.78	13.65	38.81	3.73	39.50	147.4995
0.75	242	10.6	0.83	27.77	57.00	305.00	0.78	13.65	38.55	3.76	58.75	220.7715
1.00	236	10.3	0.85	32.52	33.10	335.00	0.75	13.65	31.67	4.57	73.37	334.956

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The average entropy value, S, for GBM Lead Acid battery for the third cycle is thus, **3.08J/K.**

Figure 7 shows the behaviour of GBM Lead acid battery during discharge. The figure illustrates ΔT against WHr for the third cycle.

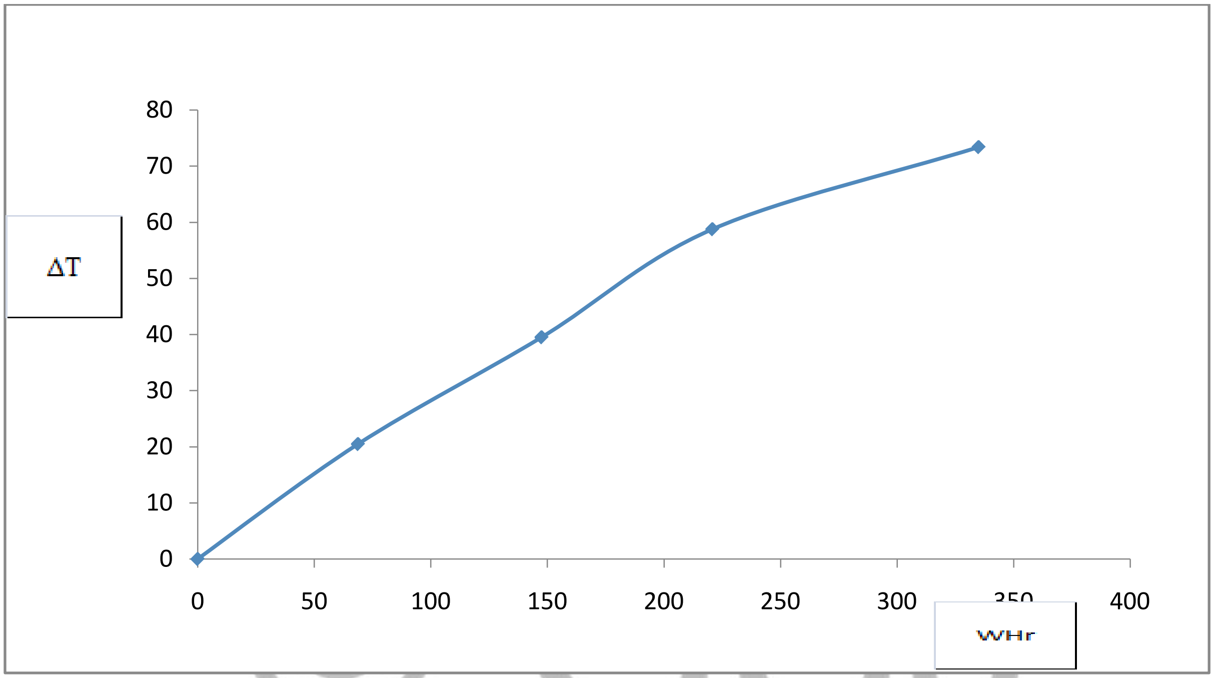

Figure 7**:** ΔT - Whr curve for third cycle.

The temperature of the battery rises as the watt – hour of discharging increases in Figure 7. Hence, the total average value of the entropy, S, for GBM model battery is **2.93J/K.**

The same procedures of determining entropy heating values were applied to other models of the batteries, viz; **CRYSTAL PLUS, SUNFIT , ROCK , GBM , EXCLUSIVES and POWER WAVES.**

The average entropy values, S, for the six different battery models available in the market, under consideration; **CRYSTAL PLUS, SUNFIT, ROCK , GBM , EXCLUSIVES**

and POWER WAVES are **1.97J/K, 2.18J/K, 2.40J/K, 2.93J/K, 3.11J/K and 3.13J/K** respectively.

The average entropy heating value, S, for all the considered models of deep cycled Lead acid batteries is thus **2.62J/K.**

4.0 Conclusion

Determination of entropy heating value of deep cycled Lead acid batteries in terms of adiabatic temperature rise during discharge has been done. The materials used for this study were a 250 watts Monocrystalline solar module for charging the battery, a digital multimeter for measuring DC and AC voltage, an inverter for the conversion of DC voltage to AC voltage, a timing device, 200 watts bulb for discharging the battery, six 12Volts deep cycled Lead acid batteries (**Crystal Plus, Sunfit, Rock , GBM , Exclusives and Power Waves**), and a digital thermometer for temperature readings.

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The study shows that the adiabatic temperature rises inside the battery as the battery discharges continuously. And the discharges result into power loss from the battery. Also, the frequent charging of the battery reduces the life cycle of the battery.

The average entropy values, S, for the six different battery models available in the market, under consideration; **CRYSTAL PLUS, SUNFIT, ROCK , GBM , EXCLUSIVES and POWER WAVES** are **1.97J/K, 2.18J/K, 2.40J/K, 2.93J/K, 3.11J/K and 3.13J/K** respectively.

The average entropy heating value, S, for all the considered models of deep cycled Lead acid batteries is thus **2.62J/K.**

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References

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[1] H. Smimite. Fast charge of valve regulated Lead acid batteries for electric cars, *Science and Techniques of Languedoc,* Page 125, 1997.

[2] P. Izzo. Battery Management for Photovoltaic Applications, *Science and Techniques of Languedoc,* Page 177, 2002.

[3] G. Dillenseger . Methods of maintaining the charge for stationary Lead acid batteries, *Science and Techniques of Languedoc*, Page 196, 2004.

[4] E. Markevich., E. Pollak., G. Salitra. and D. Aurbach. On the performance of graphitized meso-carbon microbeads (MCMB) and synthetic graphite electrodes at elevated temperatures, *Journal of Power Sources,* Vol. 174, Pages 1263-1269, 2007.

[5] H. Gabrisch, Y. Ozawa and R. Yazami. Crystal structure studies of thermally aged $LiCo0_2$ and $LiMn_2O_4$ cathodes, *Electrochim Acta*, Vol. 52, Pages 1499 – 1506, 2006.

[6] P. Handel, G. Fauler., K. Kapper, M. Schmuck, C. Stang and R. Fischer. Thermal aging of electrolytes used in lithium-ion batteries –An investigation of the impact of periotic impurities and different housing materials, *Journal of Power Sources,* Vol. 267, Pages 255-259, 2014.

[7] Van W, Schalkwijk and B. Scrosati. Advances in Lithium-Ion batteries, *Springer*, New York, Pages 47 - 68, 2002 .

[8] P. Ramadass, B. Haran, R. White. and B. N. Popov. Capacity fade of Sony 18650 cells cycled at elevated temperatures: Part I.cycling performance. *Journal of Power Sources* , Vol. 112, Pages 606-613, 2002.

[9] J. A. Amusan and O. Igbudu. The performance characteristics of Lead acid deep cycled batteries through charge/discharge voltages, charge/discharge ratio and round trip energy efficiency. A case study; *Scientia Africana*, Vol. 14 No.2, Pages 143-156, 2015.

[10] https://gzdoxin.en.made-in-china.com/product/poDQiJuHqPhW/China-Doxin-1000W-Car-Power-Inverter-DXP1000H-.html

[11] M. R. Patel. Wind and Solar Power System ; *CRC Press LLC, Boca Raton, Florida*, ISBN : 0 – 8493 – 1605 – 7, Pages 174, 1999.

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