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Effect of External Resistance on the Efficiency of the Thermal Cell

FALAH H. HUSSEIN*, WALEED M. SARHAN†, AHMED N. ALKHATEEB‡ and KAREEM D. OMRAN
Chemistry Department, College of Science for Women, Babylon University, Iraq
E-mail: abohasan_hilla@yahoo.com

The effect of resistance on voltage with time for the laboratory thermal cell has been carried out by loading resistances of the range 1–1800 ohm. The 1800 ohm resistance proved to be the best because of exhibiting a steady discharge beside the longest period for consumption of the cell which approached 65 sec. The passing current across the resistance was of 0.44 mA, whereas the voltage for the closed circuit was 0.62 V, which was the highest value with the lowest current, compared with the other resistances. Investigation of the same effect of the same range of resistances, *i.e.*, 1–1800 ohm was accomplished with the assembled cell. The results showed that the 1800-ohm resistance was again the best because it gave rise to a steady discharge accompanied with the longest period, which was close to 110 s. The passing current through the resistance was of 1.2 mA, while the voltage for the closed circuit was 1.94 V, which was the highest value with the lowest current, compared with other resistances.

Key Words: Thermal battery, Thermal cell, External resistance, Efficiency.

INTRODUCTION

During the last three decades, thermal batteries have proved to possess excellent performance characteristics in generating full power. They have long shelf life, which exceeds ten years without any defect in performance. In addition, they are rugged, reliable and safe and need no maintenance.

Moreover, they could be instantaneously activated to provide a high burst of power for a short period. These properties make them ideal for military uses. Numerous studies have been published concerning thermal batteries[1].

Our previous studies[2, 3] investigated the effects of composition of electrodes and temperature upon the efficiency of thermal cells. In the first study[2], which investigated the effect of composition of electrodes on the efficiency of the thermal cell, an efficient high temperature molten salt thermal cell was assembled. In another study[3], concerning the temperature effect, the operational temperature

†Chemistry Department, College of Science, Kufa University, Iraq.
‡Chemistry Department, College of Science, Ibb University, Yemen.

of the laboratory thermal cell was found to be within the range 455–460°C, at which the alloy, $CaLi_2$ was produced, which gave rise to the oxidation of the calcium anode and the release of electrons.

Concerning the effect of external resistance upon the efficiency of the thermal cell, according to our best knowledge, no report has been published. Compressibility behaviour of powders used in thermal batteries was also studied[4]. A linear relation was obtained for the relation between green strength and compacting pressure. Another model was found for the relation between green strength and powder density[5,6].

The present work aimed to study the relation between voltage produced from the laboratory and the assembled cells *vs.* time with loading a range of variant resistances The cell was composed of Ca or Mg as the anode whereas the cathode was fabricated by blending the three components: $CaCrO_4$, K_2CrO_4 or $K_2Cr_2O_7$ as the depolarizer (D), LiCl-KCl eutectic mixture as the electrolyte (E) and SiO_2 as the binder (B).

EXPERIMENTAL

All the utilized chemicals were purchased from BDH, E. Merck or Fluka, with purities > 95% and utilized as supplied. Preparation of the molten salts as well as storing the components of the thermal cell were performed inside a dry box flushed with argon.

Effect of resistance upon the voltage of the assembled thermal cell

The effect of resistance upon the thermal cell voltage was investigated by connecting several different resistances with the cell once a time. The cell containing the molten eutectic mixture, laid in the furnace, was connected to the voltmeter. After reaching the proper temperature for the operation of the cell, the first resistance of 1 ohm was serially connected and the change of voltage was monitored. The procedure was repeated with other resistances within the range 10–1800 ohm. The resistances were connected in parallel with the thermal cell to determine the optimum period for the operation of the cell connected with the resistances.

Effect of resistance upon the voltage of the assembled thermal cell

The effect of resistance on the voltage of the assembled thermal cell, in the activation process by the self-made pyrotechnique disc, was studied by applying several different resistances. Firstly, when the cell was ready for operation, a resistance of 1 ohm was connected in parallel with the cell to be operated. Then, resistances of the range 10–1800 ohm were sequentially parallel-connected with the thermal cells, whose components were present inside the self-produced container and joined to the voltmeter. The ignition head, which was fastened at the container cover, was linked to the power supplier. In each run of the cell operation, the voltage and the corresponding time were recorded.

RESULTS AND DISCUSSION

Effect of resistance on the voltage of the laboratory thermal cell

Table-1 displays the effect of resistances of the range 1–1800 ohm on the voltage of the laboratory cell. Obviously, the external load is an important effective factor in the production of electric energy[7]. The study was performed at the operation temperature. At each time, the molten salt was prepared, mixed with the depolarizer, $CaCrO_4$ and the binder. In each run, one resistance was parallel-connected with cell to give a voltage of 0.8 V.

Using a resistance of 1 ohm led to the consumption of the cell within some tenths of a second due to the converse relation between the current and the resistance, *i.e.*, the low resistance increased the passing current to exhaust the cell. With utilizing resistances of 10 and 30 ohms, the cell exhausting time became 1 sec. However, loading with 70 ohm rendered the exhausting time of 3 s. These resistances, *i.e.*, 10, 30 and 70 ohm, had a passive effect on the laboratory thermal cell, which could not generate energy due to the failure of the electrochemical system to produce energy after a very short period.

TABLE-1
EFFECT OF RESISTANCE UPON THE VOLTAGE OF THE LABORATORY CELL

Time (sec)	Voltage (volt)										
	Resistance (ohm)										
	1	10	30	70	100	500	1000	1500	1600	1700	1800
0	0.800	0.800	0.800	0.800	0.80	0.800	0.80	0.800	0.80	0.80	0.800
1	—	0.001	0.001	0.800	0.80	0.800	0.80	0.800	0.80	0.80	0.800
3	—	—	—	0.001	0.80	0.800	0.80	0.800	0.80	0.80	0.800
4	—	—	—	—	0.09	0.800	0.80	0.800	0.80	0.80	0.800
5	—	—	—	—	0.03	0.340	0.36	0.370	0.80	0.80	0.800
7	—	—	—	—	0	0.340	—	0.360	0.80	0.80	0.800
8	—	—	—	—	—	0.150	—	0.360	0.80	0.80	0.800
10	—	—	—	—	—	0.100	0.44	0.350	0.42	0.58	0.600
13	—	—	—	—	—	0.001	—	0.340	0.40	0.56	0.580
15	—	—	—	—	—	—	0.40	0.330	0.38	0.55	0.560
20	—	—	—	—	—	—	0.40	0.300	0.32	0.54	0.500
25	—	—	—	—	—	—	0.07	0.250	0.30	0.50	0.450
30	—	—	—	—	—	—	0	0.180	0.26	0.45	0.400
35	—	—	—	—	—	—	—	0.080	0.20	0.40	0.370
40	—	—	—	—	—	—	—	0.001	0.13	0.36	0.340
45	—	—	—	—	—	—	—	—	0.05	0.27	0.300
50	—	—	—	—	—	—	—		—	0.25	0.240
55	—	—	—	—	—	—	—	—	—	0.14	0.210
60	—	—	—	—	—	—	—	—	—	—	0.200
65	—	—	—	—	—	—	—	—	—	—	0.112

However, with the 100 ohm resistance, the current was 8 mA, the closed circuit voltage was 0.29 V and with a cell age of only 6 s. Loading with 500 ohm resistance gave a closed circuit voltage of 0.34 V and an exhausting time of 13 s, whereas with 1000 ohm resistance the cell age was 30 s and the voltage was depressed to 0.36 V to ascend to 0.44 V within 5 s and to depress again to 0 V through 30 s. This result occurred due to the fast consumption of the electrons, produced from the electrochemical reactions, whose rates increase quickly ascending the voltage value, after which a steady discharge process took place until the end of 30 s.

At 1500 ohm resistance, the cell had a longer age, which was 40 s and the voltage was 0.37 V after 5 s of the operation. The steady discharge process continued, due to the equilibrium of the electrochemical reactions, until the voltage depressed to 0.001 V through 40 s.

Loading with 1600 ohm resistance, the cell age became much longer, *i.e.*, 50 s. Moreover, the discharge curve became steadier than the previous mentioned cases, which is related to the equilibrium between the consumption of the electrons and the assimilation reaction due to the littleness of the crossing current, which was 0.5 mA. By utilizing 1700 ohm resistance, the voltage went down to 0.61 V through 5 s, and the cell was exhausted in 55 s, which is so far the longest period. The crossing current was 0.74 mA. These results can be explained as follows: increasing the resistance value decreased the current withdrawn from the cell and finally led to a lowered rate reaction.

Finally, with the 1800-ohm resistance, the results were a regular discharge, longest period of 65 s for voltage consumption, a current of 0.44 mA and 0.62 V voltage of the closed circuit. This voltage was of the highest value with the lowest current, compared with the above mentioned cases of lower resistances.

Table-2 represents a comparison for the consumption of the energy produced in the laboratory thermal cell of a load of 100–1800 ohm, and periods for working of 7–65 s when the voltage depressed to 0.001 V.

TABLE-2
COMPARISON OF CONSUMPTION FOR ENERGY PRODUCED FROM THE LABORATORY THERMAL CELL AT SPECIFIC RESISTANCES.

Resistance used (ohm)	Crossing current (mA)	Open circuit voltage (V)	Closed circuit voltage (V)	Voltage descending (V)	Time of cell voltage consumption(s)
100	8.00	0.8	0.29	0.51	7
500	1.60	0.8	0.34	0.46	13
1000	0.80	0.8	0.36	0.44	30
1500	0.53	0.8	0.37	0.43	40
1600	0.50	0.8	0.42	0.38	50
1700	0.47	0.8	0.61	0.19	55
1800	0.44	0.8	0.62	0.18	65

Effect of resistance upon the voltage of the assembled thermal cell, using the thermal disc in the activation process

Table-3 represents the effects of resistances of the range 1–1800 ohm upon the voltage of the assembled thermal cell. It is clearly noticed that the resistances of the range 1–100 ohm led to a maximum period for the exhaustion of the thermal cell of

TABLE-3
EFFECT OF THE RESISTANCE UPON THE VOLTAGE OF THE ASSEMBLED CELL

Time (sec)	Voltage (volt)										
	Resistance (ohm)										
	1	10	30	70	100	500	1000	1500	1600	1700	1800
0	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3	2.3
1	—	—	—	—	—	—	—	—	—	—	—
3	—	0.002	—	—	—	—	—	—	—	—	—
4	—	—	—	0.41	—	—	—	—	—	—	—
5	—	—	0.002	—	—	—	—	—	—	—	1.940
7	—	—	—	0.001	—	—	—	—	—	—	—
8	—	—	—	—	—	0.94	—	—	—	—	—
10	—	—	—	—	—	—	0.97	0.981	—	—	—
11	—	—	—	—	0.001	—	—	—	—	—	—
12	—	—	—	—	—	0.51	—	—	—	—	—
13	—	—	—	—	—	—	—	—	—	—	—
15	—	—	—	—	—	—	—	—	1.001	1.68	1.900
18	—	—	—	—	—	0.001	—	—	—	—	—
20	—	—	—	—	—	—	0.85	0.906	—	—	1.890
21	—	—	—	—	—	0.000	—	—	—	—	—
25	—	—	—	—	—	—	—	—	—	—	—
30	—	—	—	—	—	—	0.66	0.816	—	—	1.840
35	—	—	—	—	—	—	—	—	0.813	1.53	1.810
40	—	—	—	—	—	—	0.43	0.710	—	—	—
45	—	—	—	—	—	—	0.37	—	—	—	1.760
50	—	—	—	—	—	—	—	0.566	0.685	1.4	1.720
55	—	—	—	—	—	—	0.26	—	—	—	—
60	—	—	—	—	—	—	—	0.347	—	—	—
65	—	—	—	—	—	—	0.001	—	—	—	1.600
70	—	—	—	—	—	—	—	—	0.331	1.16	1.580
80	—	—	—	—	—	—	—	—	—	—	1.510
85	—	—	—	—	—	—	—	—	0.090	0.79	1.480
90	—	—	—	—	—	—	—	—	—	—	1.410
100	—	—	—	—	—	—	—	—	—	0.45	1.340
105	—	—	—	—	—	—	—	—	—	—	1.210
115	—	—	—	—	—	—	—	—	—	—	0.670
120	—	—	—	—	—	—	—	—	—	—	0.320
123	—	—	—	—	—	—	—	—	—	0.05	—
130	—	—	—	—	—	—	—	—	—	—	0.004

7 s. This could be attributed to the high consumption of the current which brought about a fast exhaustion of the cell. Resistance of 100 ohm was of higher time, compared with the other previous resistances, which equals 11 s. The voltage for the closed-circuit was 0.92 V with a great decline in the voltage which approached 1.36 V.

Loading with 500 ohm, the age of the cell reached 21 s whereas the voltage of the closed circuit equals 1.016 V with a voltage decline that approached 1.284 V.

Concerning the resistance 1000 ohm, the period of the active cell increases to get to 65 s. Connection of this resistance reduces the voltage to 1.0053 V to ascend to 1.12 V after 15 s to be ultimately stabilized. This is due to the fast consumption of electrons released from the thermochemical reactions, whose rates were speeded up with time to substitute the deficiency, which led to the steadiness of the cell discharge up to the complete consumption of the cell through 65 s.

The resistance, 1500 ohm, was found to have less effect compared with the previous analogues, where the voltage descended from 2.3 V to 1.082 V after 5 s and then to 0.932 V after 15 s Afterwards, the cell went on in a steady discharge and up to 70 s.

Utilization of 1600-ohm resistance gave rise to the elongation of the period to become 85 s with the voltage 0.09 V. The voltage of the closed-circuit was 1.286 V. The cell started a steady discharge after 15 s. Thereafter, the voltage was completely consumed after 85 s. As mentioned before, the reason of the increment in the cell age was the complete equilibrium between consumption of electrons and the assimilation reactions which released them due to the shortage of the current, passing this resistance, which equalled 1.4 mA

Loading with 1700 ohm resistance led to the reduction of the voltage from 2.3 V to 1.75 V. The consumption period of the cell was 123 s. The cell carried on a steady discharge until reaching 1.16 V, which was the proper one for the construction of the air equipment and through a time of 75 s. After that, it started to be diminished until the value 0.05 V.

Finally, the results shown in Table-3 demonstrate the relation between the alterations of voltage against time, with the connection of the resistance 1800 ohm, which is of the highest value in our work. The cell here had a steady excellent discharge of voltage with a time of 110 s. In addition, the cell was carrying on the generation of voltage up to 1.21 V. This was attributed to the complete equilibrium between the rates of consumption of the electrons and the rates of assimilation reactions leading to their production, which ultimately gave rise to a longer age for the laboratory cell, which equals 110 sec. The voltage for the closed-circuit was 1.94 V.

A comparison of the consumption of the produced energy from the assembled thermal cell, after the connection of the load, is shown in Table-4. It is clearly observed that the greater the connected resistance, the higher the voltage of the close-circuit voltage with a consequent longer time for the voltage consumption. Increasing the resistance value shortened the crossing current through the resistance, which resulted in lowering the rate of the thermochemical reaction that exhausted the reacting materials. As a result, a longer age for the thermal cell was attained.

Concerning the electrical functions resulting from the assembled thermal cells, where resistances of the range 100–1800 ohm were connected, Table-5 illustrates that the functions, namely, the withdrawn current, electrical capacitance, power, specific power and the energy power, increase with operation time of the cell, upon which the high resistance loaded and hence represent the optimum consumption of this cell.

TABLE-4
COMPARISON OF THE CONSUMPTION OF THE ENERGY PRODUCED FROM THE ASSEMBLED THERMAL CELL.

Resistance (ohm)	Current passed into the resistance (mA)	Voltage of the open circuit (V)	Voltage of the closed circuit (V)	Voltage decline (V)	Time of cell voltage consumption(s)
100	2.3	2.3	0.920	1.380	11
500	4.6	2.3	1.016	1.284	21
1000	2.3	2.3	1.053	1.274	65
1500	1.5	2.3	1.082	1.218	70
1600	1.4	2.3	1.268	1.032	85
1700	1.3	2.3	1.750	0.550	123
1800	1.2	2.3	1.940	0.360	130

TABLE-5
ELECTRICAL FUNCTIONS OBTAINED FROM THE ASSEMBLED THERMAL CELL

Resistance (ohm)	Current produced (A)	Electrical capacitance (A h)	Electrical capacitance* (A h g^{-1})	Electrical power (W)	Specific power (W kg^{-1})	Specific energy (W h kg^{-1})
100	0.2530	910.80	226.229	0.5891	144.535	520327.8689
500	0.0966	347.67	86.378	0.2221	55.166	198599.1058
1000	0.1495	538.20	133.681	0.3438	85.394	307421.7586
1500	0.1070	385.20	95.678	0.2461	61.127	22059.6120
1600	0.1360	489.60	121.600	0.3128	77.694	279701.9370
1700	0.1664	599.04	148.792	0.8270	95.057	342205.6632
1800	0.1661	597.96	148.524	0.3820	94.883	341579.7310

*The weight of the assembled cell = 4.026 g.

REFERENCES

1. D. Linden and T.B. Reddy, Handbook of Batteries, Part 3: Reserve Batteries, 3rd Edn., Culinary and Hospitality Industry Publications Services (2002) and references therein.
2. W.M. Sarhan, A.N. Alkhateeb and F.H. Hussein, *Asian J. Chem.*, **18**, 397 (2006).
3. W.M. Sarhan, A.N. Alkhateeb, K.D. Omran and F.H. Hussein. *Asian J. Chem.*, **18**, 982 (2006).
4. G. Portal, E. Euvrard, P. Tailhades and A. Rousset, *Powder Metall.*, **42**, 34 (1999).
5. W. Duckworth, *J. Am. Chem. Soc.*, **36**, 68 (1953).
6. G.W. Halldin, K.T. Yung and T.H. Tsal, *Prog. Powder Metall.*, **37**, 383 (1981).
7. A.I. Vogel, A Text Book of Macro and Semi-micro Qualitative Inorganic Analysis, 4th Edn., Longman (1954).

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