CHAPTER 4

CORRELATION OF CAPACITY AND RATE OF DISCHARGE.

Equations to relate current and time.

A number of attempts have been made to develop equations which would relate the current to the time of discharge, in order that the capacity of batteries might be computed for any rate or time of discharge. The most widely used of these equations is Peukert's equation *

$$I^n T = C. \qquad \text{(1)}$$

In this equation, n and C are constants which may be evaluated by tests made on any cell or battery at two different rates of discharge. It will be assumed that the different rates are I_1 and I_2, the times of these discharge corresponding to T_1 and T_2,. The values for n and C may therefore be calculated as follows:

$$I_1^n T_1 = C \qquad \text{(2)}$$
$$I_2^n T_2 = C$$

$$n \log I_1 = \log C - \log T_1 \qquad \text{(3)}$$
$$n \log I_2 = \log C - \log T_2$$

$$n = \frac{\log T_2 - \log T_1}{\log I_1 - \log I_2} \qquad \text{(4)}$$

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The numerical value for n being found for any particular type, the other constant C may be determined by solving either of the equations (2).

Peukert's equation, being logarithmic, can be plotted as a straight line on log - log paper. Similarly the observed relation of current and time of a battery's discharge should plot as a straight line if the relationship is strictly a logarithmic function. Many observers have reported, however, that the experimental results deviate slightly from calculated values based on Peukert's formula. These deviations are attributed to ohmic resistance of the cells and to a fixed or an incorrect choice of cut - off voltages.

Conditions.

Electrolyte.

Composition of the electrolyte

The electrolyte of starter batteries is accumulater sulphuric acid, free from harmful matter.

Specific gravity of the electrolyte

For the purposes of the test, the specific gravity of the electrolyte shall be measured at a temperature of 30°C. and, with the battery in the fully - charged state, shall be 1.280 ± 0.010

Accuracy of Measuring Instruments.

Electrical measuring instruments.

a) Current measurements

The measuring instruments used for measuring currents shall be permanent - magnet moving coil ammeter of an accuracy class equal to at least 1.0

The range of the instruments used shall be appropriate for the magnitude of the voltage or current to be measured. In general, this implies that readings shall be taken in the last third of the scale

b) Voltage measurements.

The measuring instruments used for measuring voltages shall be permanent - magnet moving coil voltmeters of an accuracy class equal to at least 0.5

The resistance of the voltmeters used shall be at least 300 ohms. per velt.

c) Resistors. Resistors shall be within ½ percent of the stated value and of material having a negligible change of resistance with temperature.

Hydrometers.

The specific gravity of the electrolyte shall be measured by hydrometers provided with a graduated scale, one division of which shall represent at the most 0.005 unit of specific gravity. The accuracy of the calibration shall not be less than 0.005 unit of specific gravity.

Thermometer.

Thermometers with an appropriate scale shall be used for measuring temperatures, and one division of the graduated scale shall represent at the most 1 centigrade degree. The accuracy of the calibration shall not be less than ½ centigrade degree.

Rated Capacity (Slow discharge rate capacity).

The rated capacity, C_{20}, of a starter battery should be that stated by the manufacturer. It is defined as the capacity determined by a discharge at the 20 Hr-rate at a constant current of $I = 0.05\ C_{20}$ A., the temperature of the electrolyte being 30°C. The discharge of the battery is continued until the terminal voltage has fallen to 5.25 V in the case of a 6-volt battery or 10.5 V in the case of a 12-volt battery. The discharge is made at a temperature between 20°C to 40°C.

If the temperature of the electrolyte differs from 30°C, the capacity measured shall be corrected to the reference temperature 30°C by the use of the following formula:

$$C_{30°C,} = \frac{C_t}{1 + 0.01(T-30)}$$

where C_t is the capacity in ampere-hours measured at a temperature T,

T being the average of the initial and final temperatures during discharge,

and 0.01 is the temperature coefficient of variation of capacity for temperature between 20°C and 40°C. (This represents a capacity variation of 1 percent per Centigrade degree of the temperature differ from 30°C.

Checking the rated capacity.

When fully charged, the level and specific gravity of the electrolyte of each cell are checked and, if necessary, adjusted.

The battery is then discharged at a continuous current of I = 0.05 C_{20} A until the battery terminal voltage has fallen to 5.25 V in the case of a 6-volt battery and 10.50 V in the case of a 12-volt battery.

The discharge shall commence within a period of 2 to 8 hours from the end of the charge.

During discharge, the following values be checked and noted at suitable intervals.

a) The battery terminal voltage and the voltage of the individual cells.

b) The discharge current.

c) The specific gravity and temperature of the electrolyte.

d) Room temperature.

When the voltage of any cell has fallen below 1.90 V, the voltage shall be checked at half-hourly intervals,

When the voltage of any cell has fallen below 1.80 V, the voltage shall be checked at 15 minute intervals.

The duration of discharge is the time (R) hours calculated from the commencement of discharge until the battery terminal voltage has fallen to 5.25 V. in the case of a 6-volt battery and 10.5 V. in the case of a 12-volt battery.

The capacity in ampere - hours at a temperature $T^{\circ}C$ is equal to

$$C_{T^{\circ}C} = R \times 0.05\ C_{20}\ Ah,$$

T being the average value of the initial and final electrolyte temperature measured in the central cell.

If the average value $T^{\circ}C$ differs from the reference temperature of $30^{\circ}C$ during discharge, the measured capacity shall be corrected to its theortic l value at $30^{\circ}C$, to which the rated capacity C_{20} is referred.

Tests.

Filling and Charging for Test Purposes.

Batteries shall give the specified performance when filled and charged under the following conditions:

The ambient air temperature during charging periods will be 20°-$40^{\circ}C$ (68° - $104^{\circ}F$)

(1) Fill with sulphuric acid of sp.gr. 1.280 at $30^{\circ}C$ to the - level 10 mm. above the plate.

(2) The battery will stand for 6 hours after filling. Should the temperature of the electrolyte at the end of this period be above $43^{\circ}C$ ($110^{\circ}F$) the charge will not be commenced until it has fallen below this value.

(3) The charging rate in amperes will be one-twentieth of the ampere-hour capacity of the battery at the 20 hour discharge rate. The charge will be complete when the voltage of the cells and the specific gravity of the electrolyte remain constant for three consecutive half-hourly readings. Should the temperature of the electrolyte reach $50^{\circ}C$ ($122^{\circ}F$) the charge will be interrupted until it falls below $43^{\circ}C$ ($110^{\circ}F$). The charge shall normally be complete in 70 to 80 hours but will be continued until the conditions at (4) below are satisfied.

(4) The specific gravity of the electrolyte at the completion of the charge shall be within the limits of 1.275 and 1.295. The specific gravity will then be adjusted to 1.280 0.010.

(5) During the standing and charging periods the electrolyte will be maintained at the level stated in (1) by the addition of acid of sp.gr. 1.270.

After filling and first charge in accordance with sequences - stated above, the sample battery will be subjected to the following Performance Test in the sequence shown:

For battery Type 2H *

First discharge: Rating Test 20 hour-rate.
Discharge current 6.0 amperes to 5.25 volts.

Second discharge: Rating Test 20 hour-rate.
Discharge current 6.0 amperes to 5.25 volts.

Third discharge: 10 hour-rate.
Discharge current 12.0 amperes to 5.25 volts.

Fourth discharge: 5 hour-rate.
Discharge current 20.0 amperes to 5.25 volts.

Fifth discharge: 1 hour-rate.
Discharge current 72.0 amperes to 5.00 volts.

For battery type 4H *

First discharge: Rating Test 20 hour-rate.
Discharge current 7.5 amperes to 5.25 volts.

Second discharge: Rating Test 20 hour-rate.
Discharge current 7.5 amperes to 5.25 volts.

Third discharge: 10 hour-rate.
Discharge current 15 amperes to 5.25 volts.

Fourth discharge: 5 hour-rate.
Discharge current 20 amperes to 5.25 volts.

Fifth discharge: 1 hour-rate.
Discharge current 90 amperes to 5.00 volts.

For battery type 4D *

First discharge: Rating Test 20 hour-rate.
Discharge current 7.5 amperes to 10.5 volts.

Second discharge: Rating Test 20 hour-rate.
Discharge current 7.5 amperes to 10.5 volts.

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Third discharge: 10 hour-rate.
Discharge current 15 amperes to 10.5 volts.

Fourth discharge: 5 hour-rate.
Discharge current 22 amperes to 10.5 volts.

Fifth discharge: 1 hour-rate
Discharge current 90 amperes to 10.0 volts.

For battery type 8D *

First discharge: Rating Test 20 hour-rate.
Discharge current 10 amperes to 10.5 volts.

Second discharge: Rating Test 20 hour-rate
Discharge current 10 amperes to 10.5 volts.

Third discharge: 10 hour-rate
Discharge current 19 amperes to 10.5 volts.

Fourth discharge: 5 hour-rate
Discharge current 31 amperes to 10.5 volts.

Fifth discharge: 1 hour-rate
Discharge current 120 amperes to 10.0 volts.

Before each discharge, batteries should be fully charged as - stated in (3) and left open circuit within 2 - 8 hours.

For more informations see page 73 - 76

Table 1 Relation of Discharge Current and Time at Various Rates of Discharge.

Plotted Values							
2 H		4 H		4 D		8 D	
A	T	A	T	A	T	A	T
6.0	20.25	7.5	21.00	7.5	21.00	10.0	20.25
12.0	9.25	15.0	9.45	15.0	10.00	19.0	9.50
20.0	5.05	20.0	6.82	22.0	6.67	31.0	5.25
72.0	1.13	90.0	1.15	90.0	1.50	120.0	1.07
Derived Values.							
2 H		4 H		4 D		8 D	
T	A	T	A	T	A	T	A
20	6.1	20	7.8	20	7.8	20	10.2
10	11.1	10	14.25	10	15	10	18
5	20.25	5	26.0	5	29.0	5	32
1	80	1	102	1	130	1	125

Table 2. Average Cell Temperature and Mean Voltage at Various Rates of Discharge.

Bty. type.	Average cell temp. (°F.) (°C.)				Mean voltage (volts).			
	20	10	5	1	20	10	5	1
2H	83.9 28.9	83.3 28.5	85.0 29.4	90.5 32.5	6.04	6.00	5.99	5.91
4 H	83.5 28.6	87.8 30.8	87.8 30.8	89.1 31.8	6.04	6.04	5.98	5.95
4 D	83.5 28.6	84.8 29.2	85.2 29.7	89.5 32.0	12.10	12.00	11.98	11.90
8 D	84.5 29.1	90.2 32.3	86.7 30.3	89.8 32.1	12.09	12.07	12.06	11.97

Table 3. Capacity at Cell Temp. and Capacity at 30°C.

Bty. type	Capacity at cell temp.(Ah)				Capacity at 30°C (Ah).			
	20	10	5	1	20	10	5	1
2 H	122	111	101.25	80	123.5	112.7	102.0	78.0
4 H	156	142.5	130	102	158.0	141.5	129.0	100.2
4 D	156	150	145	130	158.0	151.2	145.5	127.4
8 D	204	180	160	125	205.8	176.0	159.5	122.1

Table 4. Comparison of Percentage Capacity, Mean Voltage and Percent Watt - hour Capacity of Battery type 2 H and 4 H

Hour-rate.	Ah. Capacity.		Percentage Ah.Cap.		Mean Voltage.		Wh.Capacity. *		Percent Wh.Cap.	
	2 H	4 H	2 H	4 H	2 H	4 H	2 H	4 H	2 H	4 H
20	123.5	158.0	100	100	6.04	6.04	745	954	100	100
10	112.7	141.5	91.3	89.5	6.00	6.04	767.2	864	90.7	90.5
5	102.0	129.0	82.6	81.6	5.99	5.98	610	771	81.9	81.0
1	78.0	100.2	63.1	63.5	5.91	5.95	461	597	61.9	62.6

* Ampere - hour capacity multiplied by mean voltage.

Table 5. Comparison of Percentage Capacity, Mean Voltage and Percent Watt - hour Capacity of Battery type 4 D and 8 D.

Hour-rate.	Ah. Capacity.		Percentage Ah.Cap.		Mean Voltage		Wh.Capacity. *		Percent Wh.Cap.	
	4 D	8 D	4 D	8 D	4 D	8 D	4 D	8 D	4 D	8 D
20	158.0	205.8	100	100	12.10	12.09	1910	2480	100	100
10	151.2	176.0	95.6	85.6	12.00	12.07	1815	2120	95.0	85.5
5	145.5	159.5	92.0	77.6	11.98	12.06	1740	1920	91.1	77.4
1	127.4	122.1	80.6	59.6	11.90	11.97	1517	1461	794	59.0

* Ampere - hour capacity multiplied by mean voltage.

Table 6. Correlation of Capacities of Automotive Batteries at Various Rates of Discharge.

Discharge Rate.	2 H	4 H	4 D	8 D
20 hour Ah	100	100	100	100
A	5	5	5	5
10 hour Ah	91.3	89.5	95.6	85.6
A	9.13	8.95	9.56	8.56
5 hour Ah	82.6	81.6	92.0	77.6
A	16.52	16.32	18.40	15.52
1 hour Ah	63.1	63.5	80.6	59.6
A	63.1	63.5	80.6	59.6

Table 7. Comparison of Calculated Discharged Current, Using Peukert's Formula, with Observed Values.

Discharge Rate.	Observed Valued				Calculated Value.			
	2H	4H	4D	8D	2H	4H	4D	8D
20	6.18	7.90	7.90	10.29	6.3	7.86	7.98	9.80
10	11.27	14.15	15.12	17.60	11.3	14.20	15.10	17.55
5	20.40	25.80	29.10	31.90	20.2	25.50	28.70	31.80
1	78.00	100.20	127.40	122.10	78.0	100.20	127.40	122.50

The constants calculated for Peukert's formula are:

2 H : n = 1.190 : C = 179
4 H : n = 1.175 : C = 225
4 D : n = 1.080 : C = 188
8 D : n = 1.188 : C = 300

CONCLUSION

From the experiment it will be seen that, when a battery which is rated at some low rate, such as 20 hr-rate, subjected to test at other higher rates at specified condition; its capacity will decrease but not linearly depending upon rates of discharge and proper values of cut-off voltage.

The constants from these experiments can be used to evaluate the unknown currents or times at any required values, and is fixed only for each type of battery it cannot be interchangeable.

For further study, (about one year research program) the following items are worth noting:

- Corosion of grid alloys at various percentage of antimony.
- Effect of consistency of active material on capacity and life.
- Discharge characteristics of lead - acid battery.

(For other applications not in automotive field.)