PI 30.26-1

Electrical Equipment - Course PI 30.2

BATTERIES

OBJECTIVES

On completion of this module the student will be able to:

1. Recall, and list in writing, two types of batteries used in NGD.

2. Recall, and note in writing, the type of electrolyte which is used in a lead acid battery. For a lead antimony and lead calcium battery state the voltages and specific gravities when they are fully charged and fully discharged. (Exclude specific gravity for discharged Lead Calcium Battery).

3. Briefly explain, in writing, why antimony or calcium is used in lead acid batteries.

4. Recall, and note in writing, that the specific gravity of battery electrolyte decreases with an increase in temperature.

5. Given a set of readings identify in writing, whether the correction factor for the specific gravity is positive or negative, at various temperatures.

6. Briefly explain, in writing, why a correction to the voltage reading is not normally applied, for a minor change of temperature.

7. In writing, briefly state what constitutes a battery bank.

8. Recall, and list in writing the input voltage of the charger and the output voltage of the battery bank.

   a) Amp hour rating of a battery;
   b) Float charge;
   c) Equalizer charge;
   d) Float voltage;
   e) Pilot cell;
   f) Discharge capacity.

9. Recall, and list in writing, three conditions which dictate when the equalizer charge is to be stopped.

10. Briefly explain, in writing, how battery capacity is affected by:
    a) Discharge rate;
    b) Temperature.

11. Briefly explain, in writing, what is meant by a "capacity test".

12. Recall, and list in writing, the factors which affect battery life.

13. Recall, and list in writing, three hazards associated with batteries and give two precautions for each hazard.

14. In writing do a five point comparison of lead calcium versus lead antimony batteries.

1. Introduction

This lesson will introduce the reader to:

(a) The purpose of batteries in CANDU power plants.
(b) Types of batteries used in NGD.
(c) Battery characteristics.
(d) Charging of a battery.
(e) Float charge and equalizer charge.
(f) A comparison of the two types of batteries used in NGD.

2. Lead Acid Batteries

2.1 What Is a Battery

A lead acid battery is an electrochemical device that produces direct current (dc).

2.2 Purpose of the Batteries in the CANDU System

In the CANDU system, safety of the plant and the personnel is the utmost priority. **In the event of a power failure, a battery bank ensures an uninterrupted supply of power** to equipment which is essential for safe operation or shutdown. A typical load on the battery bank, in a CANDU system, is as follows:

(a) Emergency lighting
(b) Reactor shutdown system
(c) Safety mechanism
(d) Circuit breaker control

2.3 Type of Batteries

In the Nuclear Generation Division, two types of batteries are used.

(a) Lead Acid Antimony is used in nuclear generating stations.

(b) Lead Acid Calcium is used in the heavy water plants and is frequently the replacement battery specified in nuclear generating stations.

2.4 Lead Acid Battery Construction

Each cell of a lead acid battery consists of many positive and negative plates, which are insulated from each other, with porous plastic spacers. This whole assembly is inserted in a transparent plastic case. The case is filled with a dilute solution of sulphuric acid.

Figure 1 shows a section of a lead acid cell. For simplicity, only one positive and one negative plate is shown.

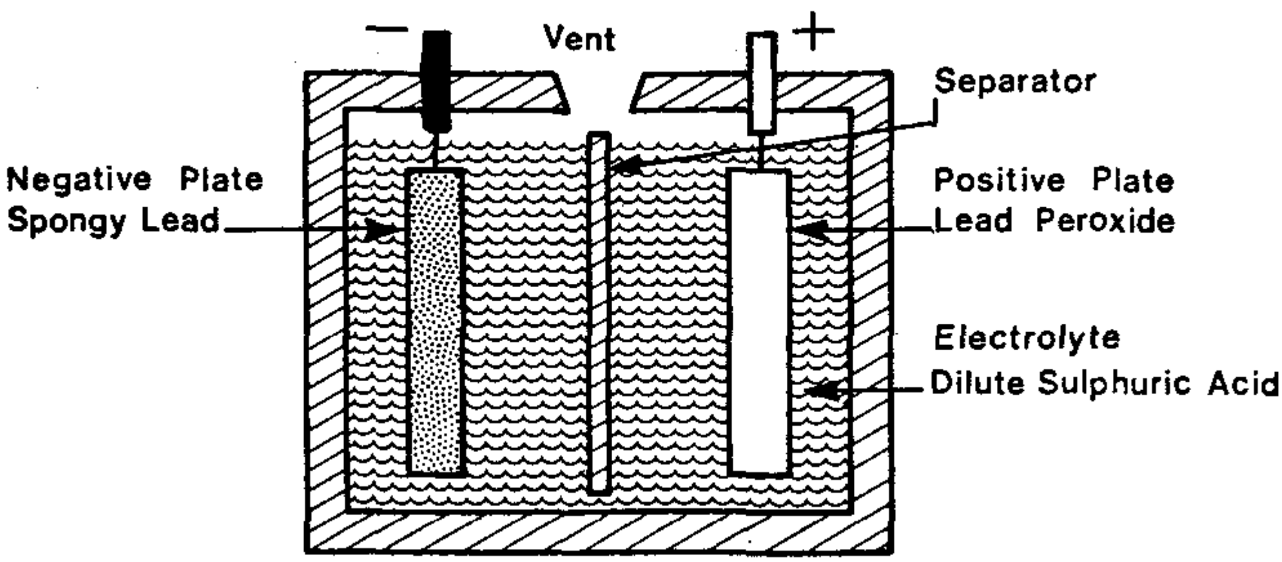

Figure 1: Sectional Diagram of a Lead Acid Battery With Two Plates

The plates are made from a cast lead grid which is covered with a paste. The positive plate is covered with a brown, lead peroxide (PbO_2) paste. The negative plate is covered with a spongy lead (Pb) paste. The plates are immersed in a dilute (50% concentration) sulphuric acid solution, which is called the **electrolyte.** The ratio of acid to water is measured as specific gravity. The following reversible chemical reaction takes place.

$$\underbrace{PbO_2 + Pb + 2H_2SO_4}_{\text{Battery charged}} \rightleftharpoons \underbrace{2PbSO_4 + 2H_2O}_{\text{Battery discharged}}$$

From the above, it can be seen that a charged battery has an electrolyte consisting of H_2SO_4, while a discharged battery has an electrolyte consisting of water. In practice, when discharged, the plates do not convert all the sulphuric acid to water and the electrolyte still contains a significant quantity of sulphuric acid.

Since lead is a soft, dense material, it can not maintain its dimensional integrity against forces produced by corrosion products or in some cases, even by its own weight. Antimony or calcium is provided in the alloy with lead to harden the grid. This makes the lead more workable, provides mechanical strength, and reduces buckling.

2.5 Cell Characteristics

For a lead acid antimony cell, Figure 2 shows the relationship between voltage/specific gravity and percent charge on the cell.

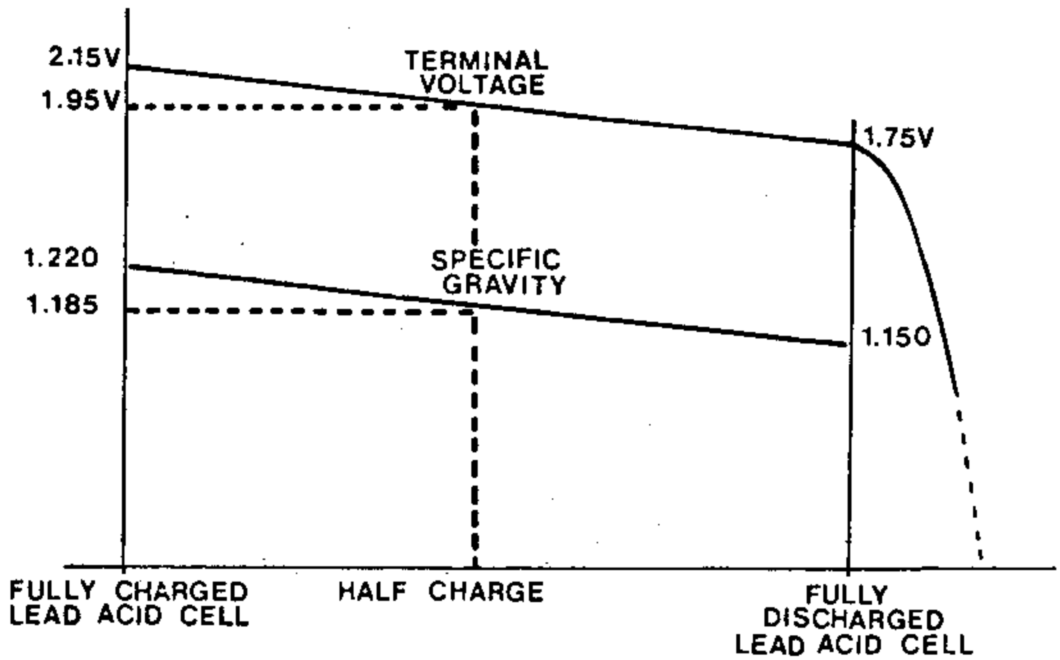

Figure 2: Curves of Terminal Voltage and Specific Gravity Versus Charge For a Lead Acid Cell (Antimony)

From Figure 2, note the following:

- Cell voltage at (100%) full charge state is 2.15 volts.
- Electrolyte specific gravity at full charge state is 1.220.
- Cell voltage in fully discharged state is 1.75 volts.
- Electrolyte specific gravity in fully discharged state is 1.150.

Because it uses chemical interactions, a lead acid cell is affected by changes in temperature. Performance ratings of lead-acid stationary batteries are based on a standard temperature of 25°C (77°F). Any deviation from that temperature affects battery performance and life expectancy.

Table 1, below, lists the specific gravity of the two types of batteries, at four different temperatures.

Table 1

Variation of Specific Gravity With Temperature in Fully Charged Lead Acid Cells

Temperature	Specific Gravity Per Cell	
	Antimony Type	Calcium Type
15°C	1.226	1.256
20°C	1.223	1.253
25°C	1.220	1.250
30°C	1.217	1.247

When taking readings of specific gravity at temperatures, which are significantly different from 25°C, a specific gravity correction must be applied. Such temperature corrections are usually not applied to voltage measurements, because voltage variations are very small, for each degree change in temperature. Also, the battery room is maintained at 25°C ±5°. Very low temperatures, will seriously affect the amount of electrical energy that can be taken out of the battery. Appendix A provides various correction factors. The ramp (slanted) characteristics of the battery's specific gravity and the cell voltage curves are used to predict the state of charge, of the battery.

3. Battery Bank.

The battery bank is a group of identically-sized cells, of the same construction, connected in series. The number of cells connected in series determines the voltage rating of the battery bank.

Each lead acid antimony cell, at full charge, has a voltage of 2.15 V. A battery bank in the CANDU system must provide 250 V. This is achieved by connecting 116 (lead calcium) or 120 cells (lead antimony) in series. See Figure 3.

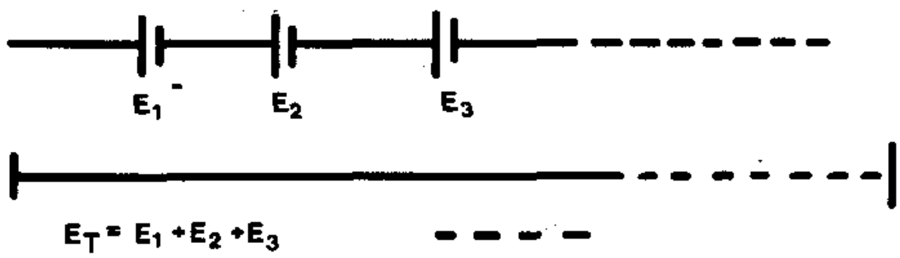

Figure 3: A Battery Bank

Ampere-hour rating of a battery = (current in amperes) x (time in hours).

If a battery is rated for 200 A-H then it can produce 200 A for one hour, 100 A for two hours, 50 A for four hours, etc. However, in practice, a battery can not deliver its full rated capacity, if it is discharged too rapidly.

4. Charging of a Battery Bank

4.1 Battery Charger

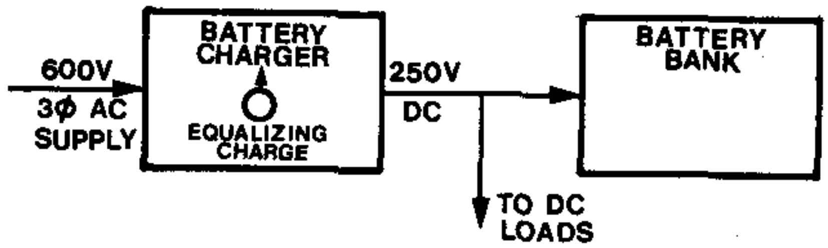

Figure 4: A Block Diagram of Battery *Bank and* Associated Charger

A battery bank is charged by a battery charger. Input to the charger is a 600 V, 3 AC supply and the output is 250 V DC. The charger also has a control to adjust its output voltage, to provide equalizing charge to the battery.

4.2 Pilot Cell

At the time of installation of a new battery, and **before the charger** is turned on, the specific gravity and voltage readings of each cell are recorded in the permanent logbook. The battery is then given an "initial charge", which is in essence, an extended *equalize charge, the duration of which is indicated in* the Installation and Operating Manual.

After the initial charge has been completed, the battery is placed on float, and at the end of one week, specific gravity, voltage per cell and battery float current readings are recorded in the permanent log. All future specific gravity readings and voltage per cell readings will be compared to these initial values.

The cell, with the lowest specific gravity at this time, is labelled the pilot cell and its readings are used as an indicator of the battery's state of charge. Regular comparison is made of the specific gravity and float current, where possible, with previous readings.

4.3 Float Charge

Normally, station lead-acid batteries are "floated" across the dc busbars, and the load is supplied by the charger. If the charger fails, the battery carries the load until the charger is restored to service.

While the battery bank is being recharged, the charger has to supply the load current, as well as the battery charging current. Battery charging current is called float charge. It has two purposes.

(a) Charge the battery, while in use.

(b) Supply the makeup charge to maintain the battery at its charged state. Makeup charge is required because internal leakage, in the battery, occurs at all times.

4.4 Equalizer Charge

The voltage across the battery bank is the algebraic sum of all the individual cells connected in series (120 cells for a 250 V lead antimony system, 116 cells for a 250 V lead calcium system).

However, no two cells are exactly alike due to the manufacturing, material, temperature and specific gravity variations. Therefore, one cell voltage may be higher than another cell. This means that the normal terminal voltage of a battery bank does not guarantee that each individual cell voltage is also normal. Some cells with higher than normal voltage will mask those cells with a lower than normal voltage. If a cell does not have a full charge voltage, it is not fully charged and the battery bank cannot deliver its rated output. Refer to the battery cell terminal voltage and charge curve, Figure 5.

To overcome this inconsistency of state of charge, in the individual cells, **the whole battery bank is intentionally overcharged periodically, under controlled conditions. This brings the weak cells to the required charge level and over charges the normal cells to some degree. This charge is called an equalizer charge.**

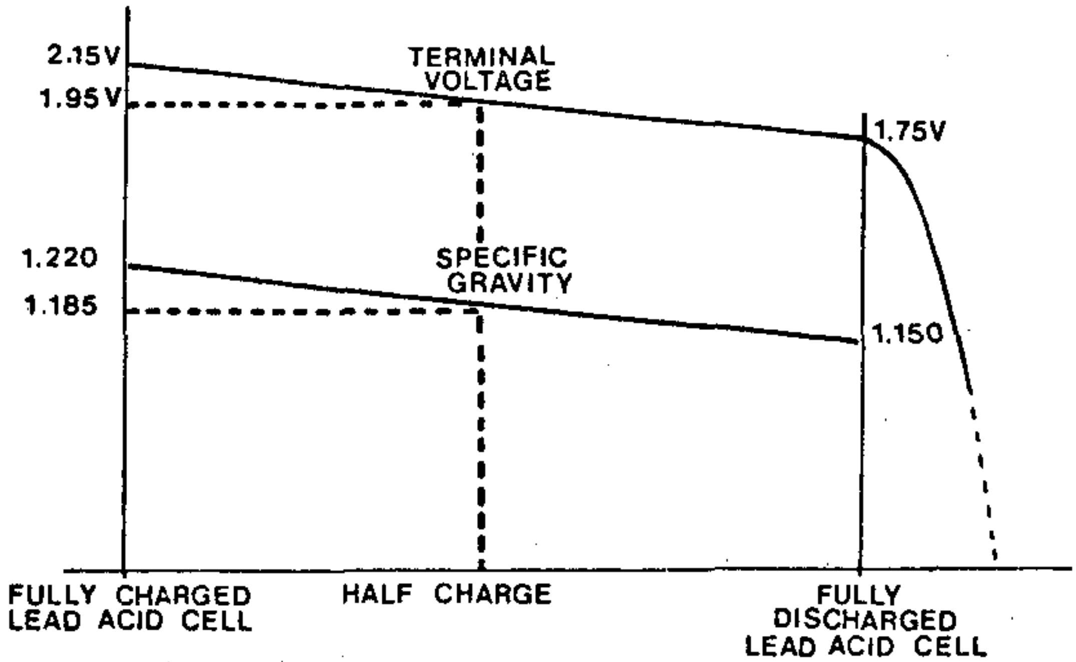

Figure 5: Curves of a Terminal Voltage and Specific Gravity For a Lead Acid Cell (Antimony)

During the equalizing charge, the battery and bus voltage is above the rated value. Care must be taken to ensure that other equipment connected to the battery bank is not damaged, due to this excess voltage.

An equalizing charge should be stopped if **any** of the following are exceeded:

Condition	Lead Antimony Type	Lead Calcium Type
(a) the voltage per cell exceeds	2.33 V	2.41 V
(b) the specific gravity of any cell exceeds	1.240	1.275
(c) the temperature of any cell exceeds	43°C	43°C

CAUTION: Batteries must not be left on equalizing charge for an extended period of time. Failure to observe this precaution will seriously reduce the life of the battery.

4.5 Float Voltage

The float voltage is the normal operating voltage of the battery, necessary to maintain the battery in a fully charged condition. The maximum recommended float voltage is 2.17 volts per cell for lead-antimony cells and 2.25 volts per cell for lead-calcium.

A minimum float voltage of 2.15 volts per cell for lead antimony and 2.17 volts per cell for lead-calcium will maintain the cells fully charged and provide optimum life. Any lower float voltage will result in less than fully charged cells.

5. Battery Capacity

5.1 Discharge Capacity

Discharge capacity of the battery is basically its ability to supply a given current for a given period of time, at a given initial cell temperature, while maintaining voltage above a given minimum value. This capacity is stated in amperes, at a given discharge rate. Most battery cells are rated for 8 h or 5 h.

For example, the ampere-hour capacity is the product of 8 times (or 5 times) the discharge rate in amperes, at a temperature of 25°C (77°F), when discharged to an average voltage of 1.75 volts per cell.

When discharged at higher than 8h (or 5h) rate, the expected output, in ampere-hours, is less than the rated capacity. At lower rates or intermittent loads, it is more.

The initial capacity may be slightly less than the rated capacity and will normally reach 100% within two years of service. The capacities of older batteries, particularly on charge-discharge routines, may be reduced due to loss of active material.

The ability of a fully-charged cell to deliver a certain number of ampere-hours, at a given discharge rate is determined, primarily by the size and/or number of positive and negative plates in the cell.

5.2 Capacity Variation With Temperature

Battery capacity increases with an increase in electrolyte operating temperature, but the life of the battery is reduced. Table 2 gives some idea as to the extent of this change, in terms of the capacity.

Table 2

Electrolyte Temperature (Degrees F)	Electrolyte Temperature (Degrees C)	Capacity (At 8 h Rate In Percent)
110	43	114
90	32	106
77	25	100
70	21	97
60	15.5	92
40	4	80
20	-6.7	65
0	-18	45

5.3 Capacity Test

To guarantee the Ampere-Hour rating of a battery, it is discharged, at its current rating, over an eight hour period. This discharge test is called a **capacity test.** The battery is then re-charged. The battery is not available for use while being capacity tested or re-charged.

A capacity test is performed routinely every two to three years, or whenever there is a doubt about a battery's performance.

Table 3 shows the size and type of batteries used in various generation stations and Heavy Water Plants, in NGD.

Table 3

Location	Battery Size/Bank	Battery Type
Bruce NGS B	975 AH	Lead Calcium
Bruce NGS A Unit Batteries	1350 AH	Lead Antimony
Pickering NGS B	825 AH	Lead Calcium
Pickering NGS A	912 AH	Changed to Lead Calcium Originally Lead-Antimony
NPD NGS	320 AH	Lead Antimony
Douglas Point NGS	600 AH	Lead Antimony
Heavy Water Plants	360 AH	Lead Calcium

Notes

6. Aging of Lead Acid Batteries

Lead acid batteries, as any other piece of electrical apparatus, have an economic life. In Hydro's experience, this is about 15 years, for lead antimony and 20 years, for lead calcium batteries. This useful service life will be shortened by poor maintenance and/or poor operation. The main factors which shorten the life of a battery are:

(a) Overcharging

This can occur if the charge rate is too high; that is, too high a charging current or too high a charge voltage. In both cases, the manufacturer's or the station's recommendations must be adhered to.

(b) Discharging at Too High a Rate

Too high a discharge rate will shorten the life of a battery. Again, the recommended values should not be exceeded.

(c) Excess Temperature

During charging and discharging, a battery's temperature will increase. It must not be allowed to exceed 43°C.

All of the above will shorten the life of a battery, causing the paste to become detached from the plates, and fall to the bottom of the cells. Figure 6 shows a cell where the paste has fallen to the bottom of the case. This paste forms a sediment which builds up until it touches both plates. When this occurs, the sediment forms a short-circuiting path and the battery no longer holds a charge.

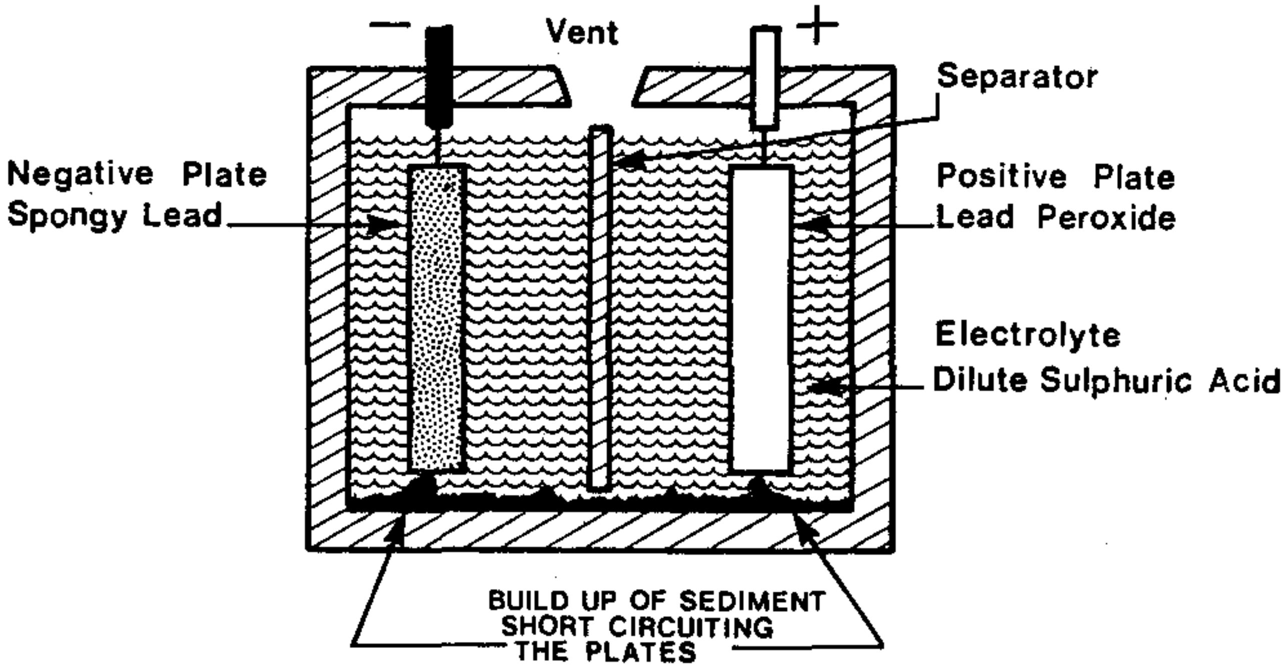

Figure 6: Plates Being Short-Circuited by Sediment

The lead plates may break if a battery is charged at too high a rate, or if the internal, cell temperature exceeds 43°C.

Battery cases are made of transparent material. This allows a visual inspection of the plate condition, electrolyte level, gassing state, and sediment level. Frequent inspections will prevent cell or battery failure.

7. Hazards and Precautions With Lead Acid Batteries

There are three safety hazards associated with lead acid batteries. The hazards are:

(a) Gases

Oxygen and hydrogen are given off from the electrolyte during charging and discharging. If these gases are allowed to accumulate, an explosion can result. **No smoking** or **naked lights** or **flames are permitted in a battery room.** It is essential that the ventilation systems in these areas are continuously operating. This should be checked by personnel prior to entry into a battery room.

(b) Acid

To avoid **acid burns,** before any work is done with acid, including taking specific gravity readings, **proper protective clothing** must be worn. A facemask to protect the eyes, and an **apron** and **gloves** to protect the body, are required. In addition,there must be a **supply of water available** to wash off any acid that may come into contact with eyes or skin.

(c) Electricity

It is often forgotten that a **battery contains a large amount of stored electrical energy.** It should be noted, that **station batteries have bare exposed terminals** and intercell connectors. **Short circuiting** battery terminals will produce large currents, which can **damage the battery, cut off the class 1 supply,** and **burn or electrocute** the person involved. Therefore, insulated tools must be used in a battery room. Aluminum ladders cannot be taken into a battery room.

8. Comparison of Lead Antimony and Lead Calcium Batteries

The lead calcium battery is a new development and it is just gaining acceptance in the Nuclear Generation Division, (as noted in Table 3).

A brief comparison of the two battery types is given below.

(a) The lead calcium battery has a longer life (20 years), as compared to lead antimony (15 years). Actual life may be affected by the application and maintenance.

(b) Lead calcium batteries require less makeup distilled water.

(c) Lead calcium batteries have a higher cell potential, 2.17 volts, as compared to 2.15 V, for lead antimony cells. Hence, fewer lead calcium cells need to be connected in series to give the desired output voltage.

(d) Lead calcium batteries produce less gas.

(e) Lead calcium batteries require less frequent equalizer charge. This also results in an increased life, since over-charging reduces battery life.

Notes

APPENDIX A

Specific Gravity Temperature Correction Chart

°C	SG Correction	°C	SG Correction	°C	SG Correction
6.7	-0.011	18.9	-0.003	31.7	+0.004
		19.4	-0.003	32.2	+0.004
7.2	-0.010	20	-0.003	32.8	+0.004
7.8	-0.010				
8.3	-0.010	20.6	-0.002	33.3	+0.005
		21.1	-0.002	33.9	+0.005
8.9	-0.009	21.7	-0.002	34.4	+0.005
9.4	-0.009				
10	-0.009	22.2	-0.001	35	+0.006
		22.8	-0.001	35.6	+0.006
10.6	-0.008	23.3	-0.001	36.1	+0.006
11.1	-0.008				
11.7	-0.008	23.9	0.000	36.7	+0.007
		24.4	0.000	37.2	+0.007
12.2	-0.007	25	0.000	37.8	+0.007
12.8	-0.007	25.6	0.000		
13.3	-0.007	26.1	0.000	38.3	+0.008
				38.9	+0.008
13.9	-0.006	26.7	+0.001	39.4	+0.008
14.4	-0.006	27.2	+0.001		
15	-0.006	27.8	+0.001	40	+0.009
				40.6	+0.009
15.6	-0.005	28.3	+0.002	41.1	+0.009
16.1	-0.005	28.9	+0.002		
16.7	-0.005	29.4	+0.002	41.7	+0.010
				42.2	+0.010
17.2	-0.004	30	+0.003	42.8	+0.010
17.8	-0.004	30.6	+0.003		
18.3	-0.004	31.1	+0.003	43.3	+0.011

These numbers are compiled from the following rule used by Exide and Gould. For every 1.67°C above 25°C add 0.001. For every 1.67°C below 25°C subtract 0.001 in SG readings.

Electrolyte Level Correction

1. Gould Cells - Add 0.006 to the Specific Gravity reading for each 0.64 cm below the high level mark.

2. Exide and C and D Cells - Add 0.015 to the Specific Gravity reading for each 1.27 cm below the high level mark.

Notes

ASSIGNMENT

1. Describe the principle used in a battery. (Section 2.1)

2. What is the purpose of a battery bank in the CANDU system. List three typical loads on the battery bank. (Section 2.2)

3. Which two types of batteries are used in NGD? (Section 2.3)

4. Why is antimony or calcium added to the lead? (Section 2.4)

5. What is the voltage and specific gravity of the lead antimony battery used in NGD at: (Section 2.5)

   (a) Full Charge

   (b) Full Discharge

6. How is specific gravity affected by temperature? When is the specific gravity correction factor positive/negative? (Section 2.5)

7. Why is a correction factor not applied to the voltage, for minor changes in temperature? (Section 2.5)

8. What is a battery bank? Give the expression for total terminal voltage of the battery bank. (Section 3)

9. What is the input voltage, output voltage, and voltage type (AC or DC) for a battery charger? (Section 4.1)

10. Define what is meant by:

(a) Ampere-Hour rating of a battery. (Section 3)

(b) Pilot cell. (Section 4.2)

(c) Float charge. (Section 4.3)

(d) Equalizer charge. (Section 4.4)

(e) Float voltage. (Section 4.5)

(f) Discharge capacity. (Section 5.1)

11. List the three conditions which dictate when an equalizer charge must be stopped. (Section 4.4)

12. How is battery capacity affected by:

(a) Discharge rate. (Section 5.1)

(b) Temperature. (Section 5.2)

13. What is a capacity test and how often is it performed? (Section 5.3)

14. List three hazards associated with batteries and two precautions for each hazard. (Section 7).

15. Compare lead antimony and lead calcium batteries. (Section 8).

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