Agenda

Presented by John Kim, EnerSys
MCPQG/IEEE Meeting
02/21/13

- Battery fundamentals
- Applications
- Selection/Sizing criteria
- Specification writing
- Battery charging
- Operations guidelines
- Maintenance outline

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Lead Acid Battery Fundamentals

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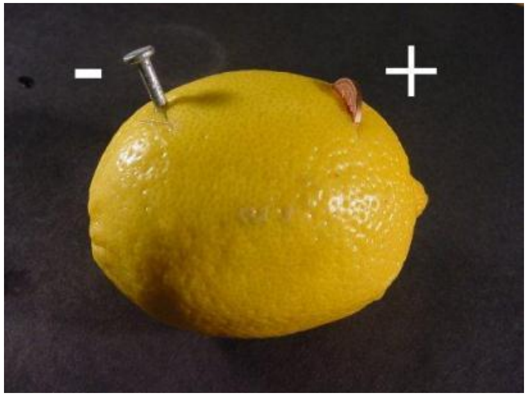
Basic battery theory



- Two dissimilar metals
  - Positive Plates (electrodes)
  - Negative Plates (electrodes)
- Electrolyte
  - Capable of conducting electric current
- Electro-chemical reaction
- Suitable container and cover
- Connecting Hardware
- Primary Battery = One-time use (one-way chemical reaction)
- Secondary Battery = Can be recharged & used multiple times (reversible chemical reaction)

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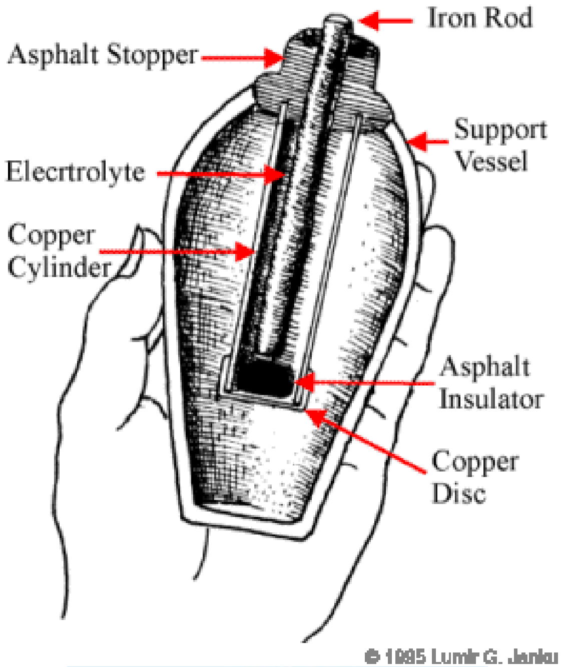
History - earliest discovery



- The Baghdad Battery?
  - Dated about 2000 years old
  - 5 inch tall earthenware pot
  - Iron rod and Copper cylinder
  - Filled with a juice or vinegar electrolyte, generates almost 2 volts of potential
  - No confirmed ideas on what it was used for...

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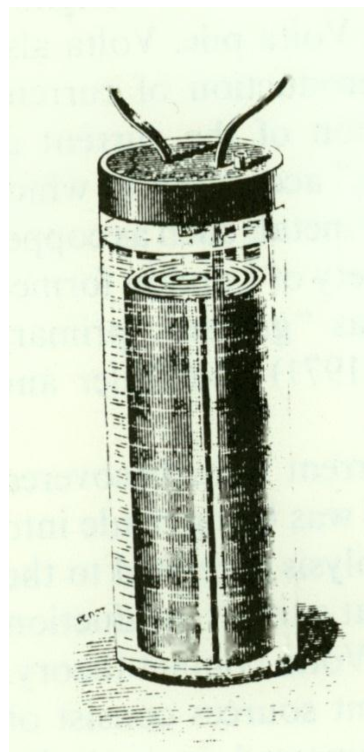
Origins of modern day lead acid battery

- In 1859, by immersing lead sheets separated by rubber strips into sulfuric acid and applying charge and discharge currents, Gaston Planté produced the first working model of a rechargeable lead-acid battery



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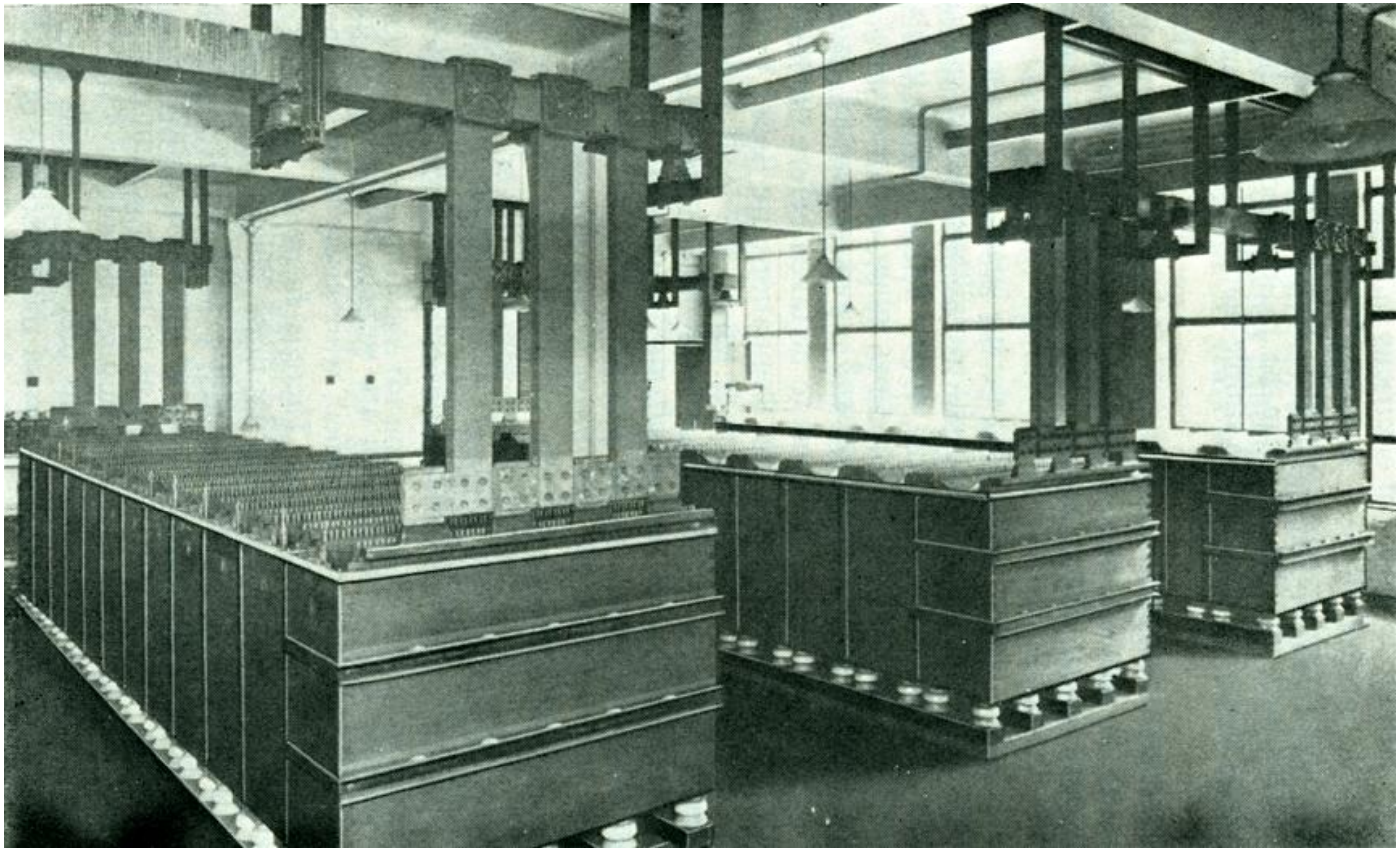
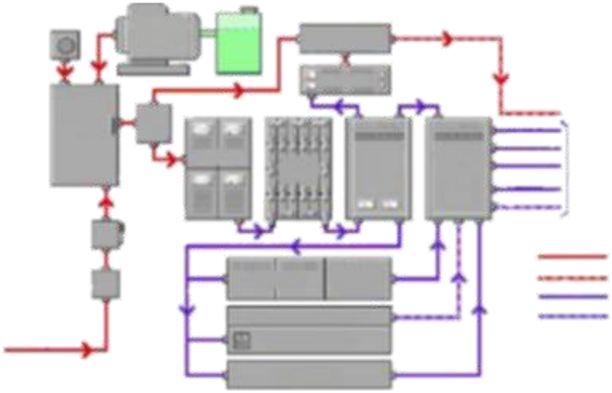
Origins of standby lead acid battery

- In the beginning standby batteries used large Planté plates that were contained in open lead-lined wood boxes and connected externally to the system buss



Purpose of Batteries

- Once AC power is lost, batteries pick up the load until the generator starts or until power is regained
- Batteries provide power for both AC and DC equipment during outages
- Benefits of using batteries
  - Immediate response (compared to generator)
  - Do not require fuel source to be replenished
  - Noiseless (no muffler)
  - Only emissions are Oxygen & Hydrogen – no Carbon or Nitrous emissions



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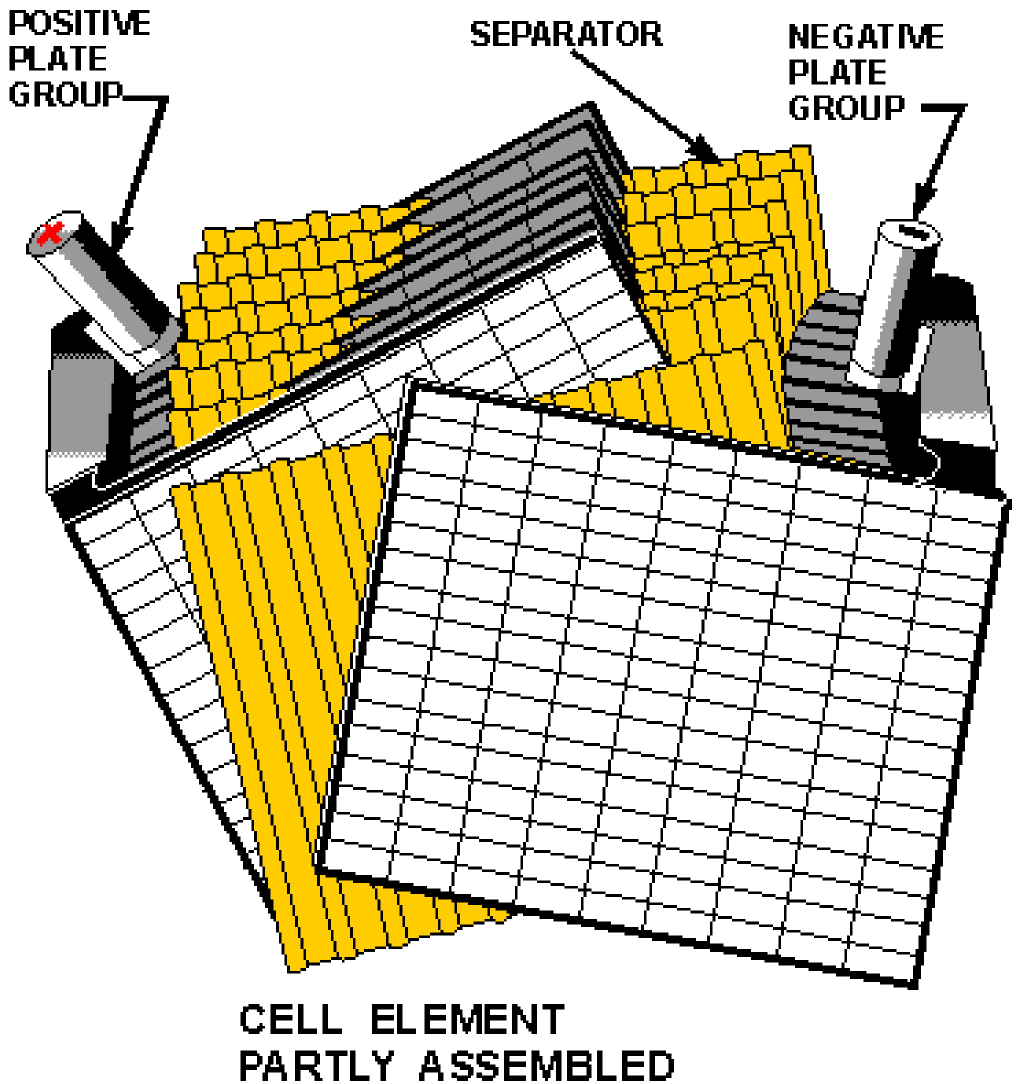
Lead acid battery components

- Lead-acid battery consists of two dissimilar metals in acid solution
  - Positive plate – PbO_2 (black or dark chocolate brown when healthy)
  - Negative plate – Pb (light gray or gray)
  - Acid – H_2SO_4 (clear – water and sulfuric acid mixture)
  - Separator (keeps positive and negative plates from touching)
  - Jar/Cover (you have choices)

Lead acid battery construction



Chemical reaction

Both plates form sulfate during discharge (same reaction in both VRLA & Flooded types)

- Positive Plate:

  $PbO_2 + 4H^+ + SO_4^{-2} + 2e^- \Leftrightarrow PbSO_4 + 2H_2O$

- Negative plate:

  $Pb + SO_4^{-2} \Leftrightarrow PbSO_4 + 2e^-$

- Overall:

Discharge

$$PbO_2 + Pb + 2H_2SO_4 \Leftrightarrow 2PbSO_4 + 2H_2O$$

Recharge

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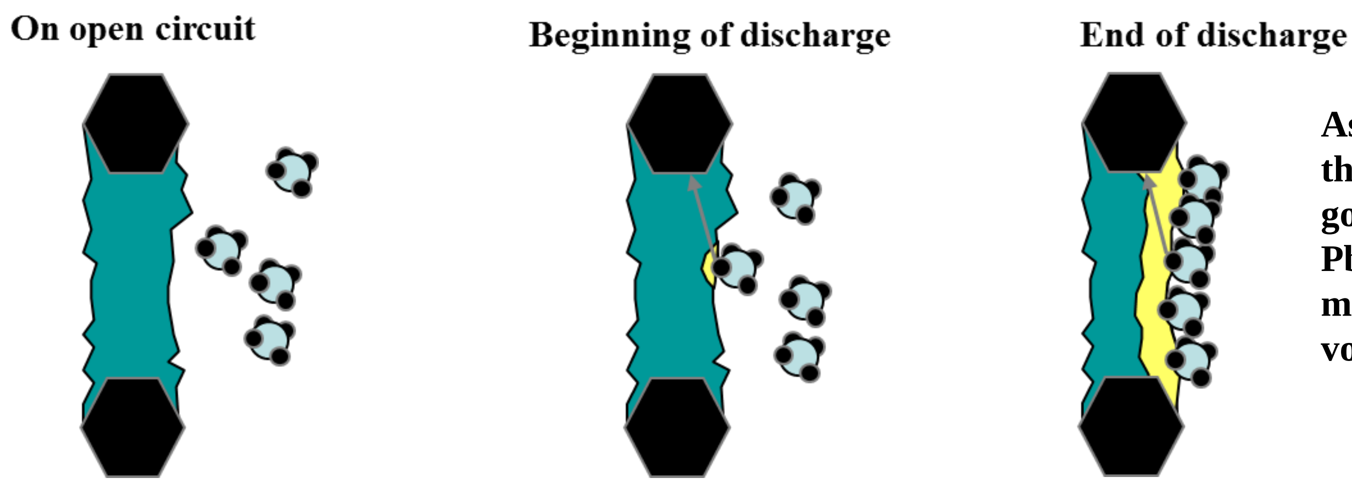
The lead-acid plate function

- The reaction begins at the surface of the plate, then proceeds to the interior of the plate from both sides
- This speed of the reaction is strongly affected by the surface area of the active material
- The reaction will end when the battery voltage drops as the lead sulfate layer grows



As reaction proceeds, the current path must go through more $PbSO_4$ discharge material, causing the voltage to drop

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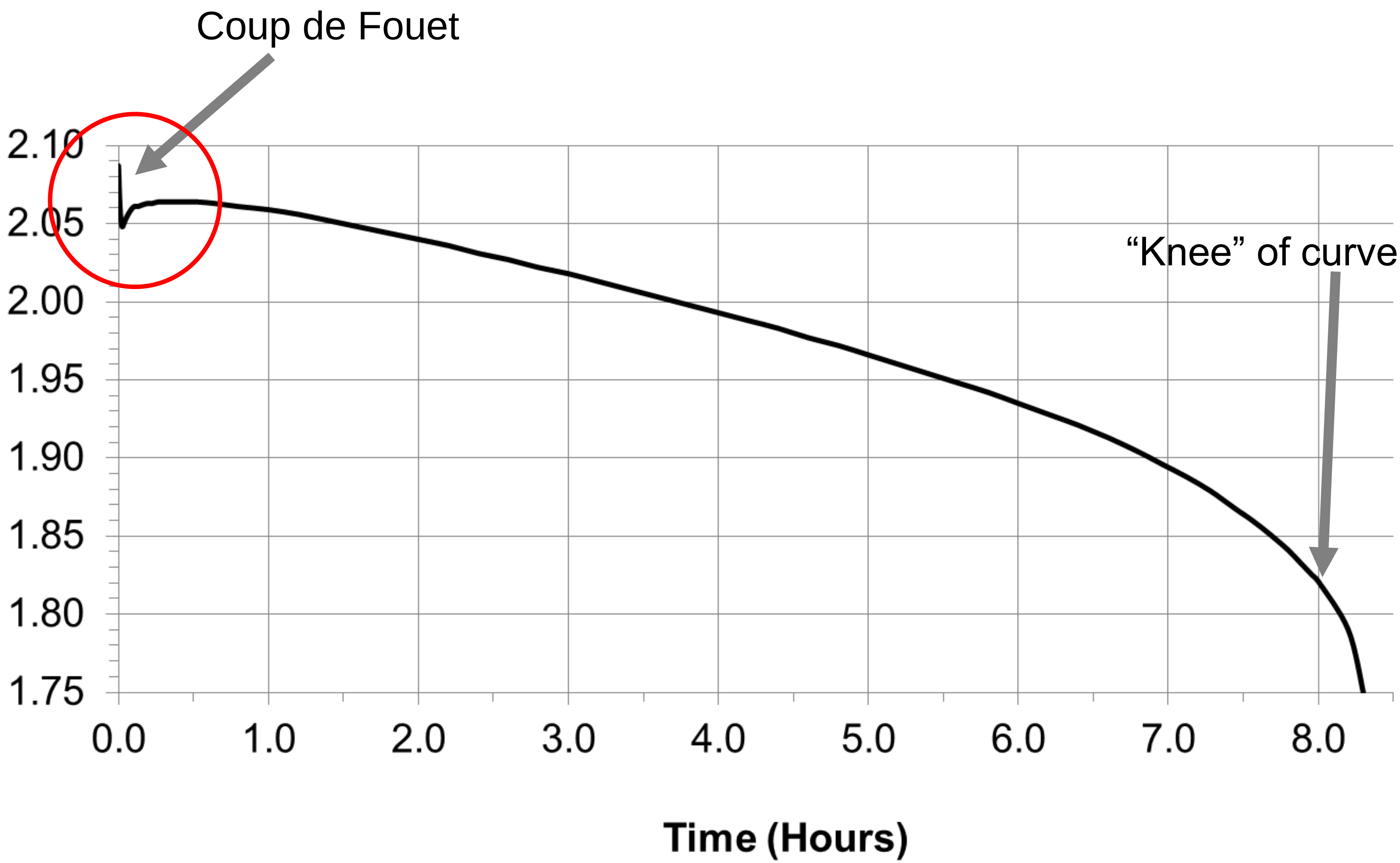
Typical battery discharge profile



Lead acid battery types

- **Standby type**
  - Batteries are on float charge until lose of power
- **Cycling type**
  - Car batteries
  - Fork lift batteries
  - Solar batteries

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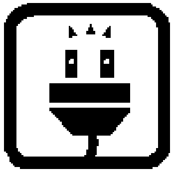
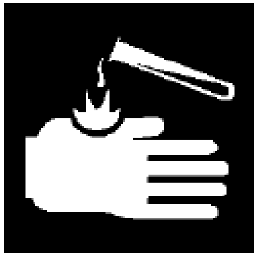
Basic lead acid battery chemistry

- 2 volts per cell
- Electric shock hazard
- Fully rechargeable
- Self discharge
- Sulfuric acid
- Over 98% recycled in North America





Lead acid battery glossary

- **Cell**: A unit part of the battery consisting of two dissimilar electrodes immersed in an electrolyte:
  1 cell = 2 volts

- **Battery**: An energy storage unit consisting of two or more connected cells where a conversion of chemical energy to electrical energy takes place – voltage varies depending on application

- **String**: Series connection of batteries of a required total cell quantity and capacity

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Types of standby lead acid battery

- **VLA (Vented Lead Acid) battery**
  - Also called Flooded or Wet
  - Common types are Lead-Calcium, Lead-Antimony, Lead-Selenium, and Pure Lead

- **VRLA (Valve Regulated Lead Acid) battery**
  - Also called Sealed or Maintenance-Free
  - Can be AGM (Absorbed Glass Mat), Gel, or hybrid

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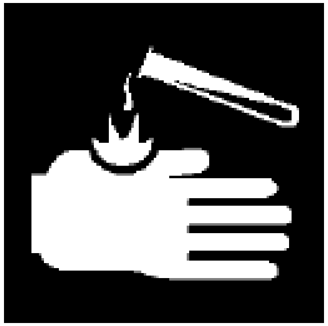
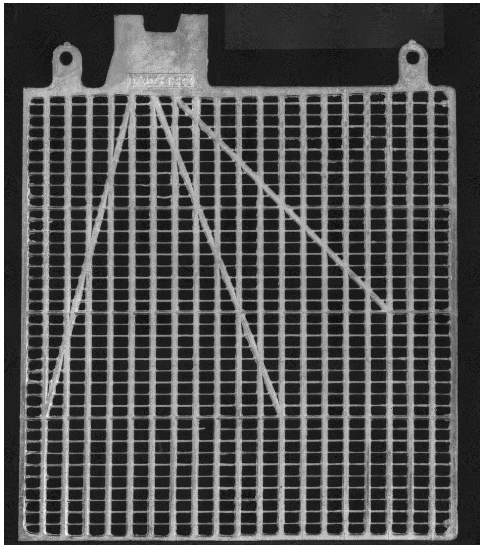
Battery glossary

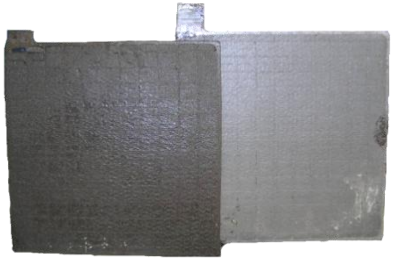
- **Specific gravity**: Acid concentration
  - Water = 1.000, Pure H_2SO_4 = 1.835
  - % concentration
    - 1.215 = 29.6%
    - 1.250 = 33.8%
    - 1.300 = 39.5%
  - Affects the capacity & grid corrosion rate
  - Strength: Higher strength acid has lower electrical resistance - the cell will therefore have a higher voltage curve
  - Volume: Larger volumes of acid will permit the discharge reaction to run for a longer period of time
  - Rule of thumb: Open circuit voltage: S.G. + 0.84
    - ex. 1.215 s.g. + 0.84 = 2.055 OCV



Flat pasted plate construction

- **Grid**
  - Collects and carries current
  - Provides support for active material
  - Tends to grow & corrode over time
  - EnerSys grids are double-hung to avoid cantilevering of plates
- **Active material (Paste)**
  - Positive = PbO_2 (black, when fully charged and healthy)
  - Negative = Pb (gray)
  - Primary source of chemical reaction (electricity)
  - Tends to degrade (soften) with heavy use or deep cycling
- **Plate = Grid + Paste**





Shown: 12V VRLA plates

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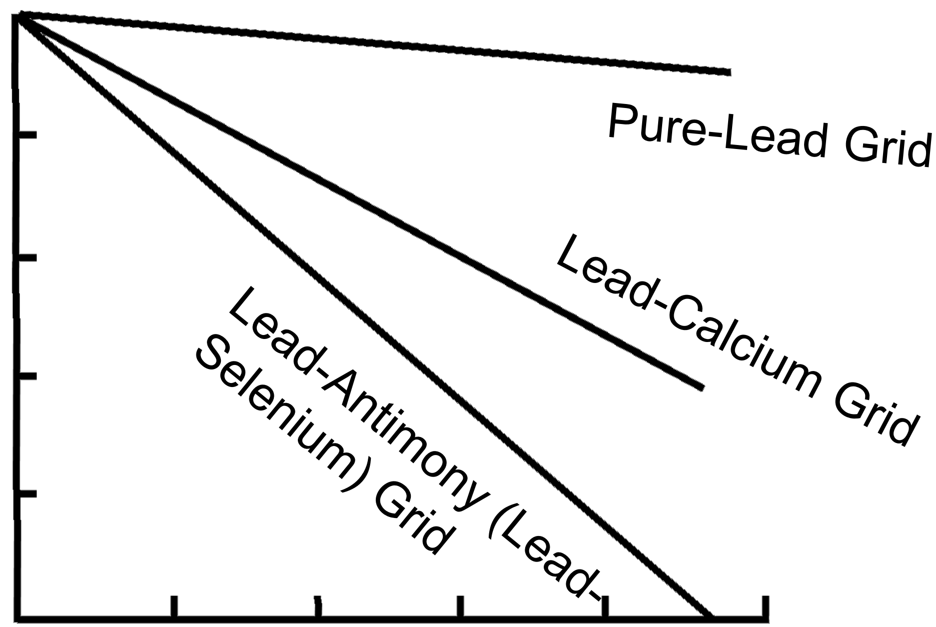
Self discharge

- Internal Resistance of battery acts as a small load
- Battery slowly discharges if left uncharged for an extended period of time
- Because of this phenomenon, batteries must be recharged periodically when left on open circuit



The storage time is significantly reduced for selenium (PbSe) and antimony (PbSb) alloy products due to the faster self discharge

Battery storage & shelf life

- Freshening charges are required at the following intervals at 77ºF:
  - Lead-antimony/selenium: Every 3 months
  - Lead-calcium: Every 6 months
- Indoors and dry location is ideal
- Batteries must be stored away from any harmful chemicals (petroleum-based products, e.g.)
- Storage time and freshening charge intervals are directly dependent on temperature

General rule of thumb – for every 15F to 18F rise in storage temp above 77F will reduce the storage time by 50%

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Battery glossary

- Ampere-hour (Ahr): The capacity of a storage battery
  - Based on Amperes X Hours
  - Typically used in Telecom and Utility and expressed in amp-hours at the 8hr rate to 1.75 end voltage @ 25C (77F)
  - Example:
    - 3CC-9M will provide 25 amps for 8 hours

      (25 amps x 8 hours = 200 amp-hours)

- Watts-per-cell: The power rating of a storage battery
  - Typically used in UPS batteries
  - Example: uses WPC @ 15 min rate to 1.67 vpc @ 25C (77F)

Ratings tables

End Voltage 1.75 Vpc Time in minutes								
Cell Model	60	120	180	240	300	360	420	480
CC-03M	26.9	17.2	12.8	10.4	8.8	7.7	6.9	6.3
CC-05M	53.9	34.4	25.7	20.8	17.7	15.5	13.8	12.5
CC-07M	80.8	51.6	38.5	31.2	26.5	23.2	20.8	18.8
CC-09M	107.8	68.9	51.4	41.6	35.3	31.0	27.7	25.0

Discharge rates in Amperes with 1.215 specific gravity acid at 77F (25C)

Battery ratings are NOT linear!

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Lead Acid Batteries

Grid Alloy Choices

Grid alloy history

- Before 1950's – Lead Antimony
  - Telephone network, Utility plants
  - 8 hour reserve times
- Bell Labs developed Lead Calcium
  - Deployed starting in 1950's, popularity grew
    - Longer life, Less watering, Less maintenance
- By 1970's, lead calcium became the standard in standby industry

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Grid alloy history

- Original Lead-antimony (>5% Sb) alloy evolved into “Lead-selenium” (approx. 2% Sb) alloy
  – Antimony level reduced from >5% to approx. 2% and selenium added as a grain refiner
  – This reduction delays the antimony poisoning of the negative plate
  – Batteries should be stable for first 5 to 6 years of service life
  – After this, normal antimony poisoning will occur
    - Float voltage requirement will increase
    - Gassing level will increase
    - Water consumption will increase
  – Minor threat of poisonous “STIBINE GAS” as a byproduct during severe, uncontrolled overcharging

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The Lead-Acid Battery alloys

Lead-selenium (PbSe)

- Contains 1.6 – 2.8% Antimony / 0.02% Selenium
  (Sometimes called Low-Antimony alloy)
- Advantages
  - Is an antimony alloy, so has the high cycling benefit of antimony
  - Float voltage range
  - Postpones antimony poisoning by 5 to 6 years
  - Initial infrequent water additions – due to large watering space
- Disadvantages
  - Older cells experience antimony poisoning with all associated disadvantages (increased water consumption, difficulty in float matching, increased positive grid corrosion)
  - Older cells don’t float well with new replacement cell

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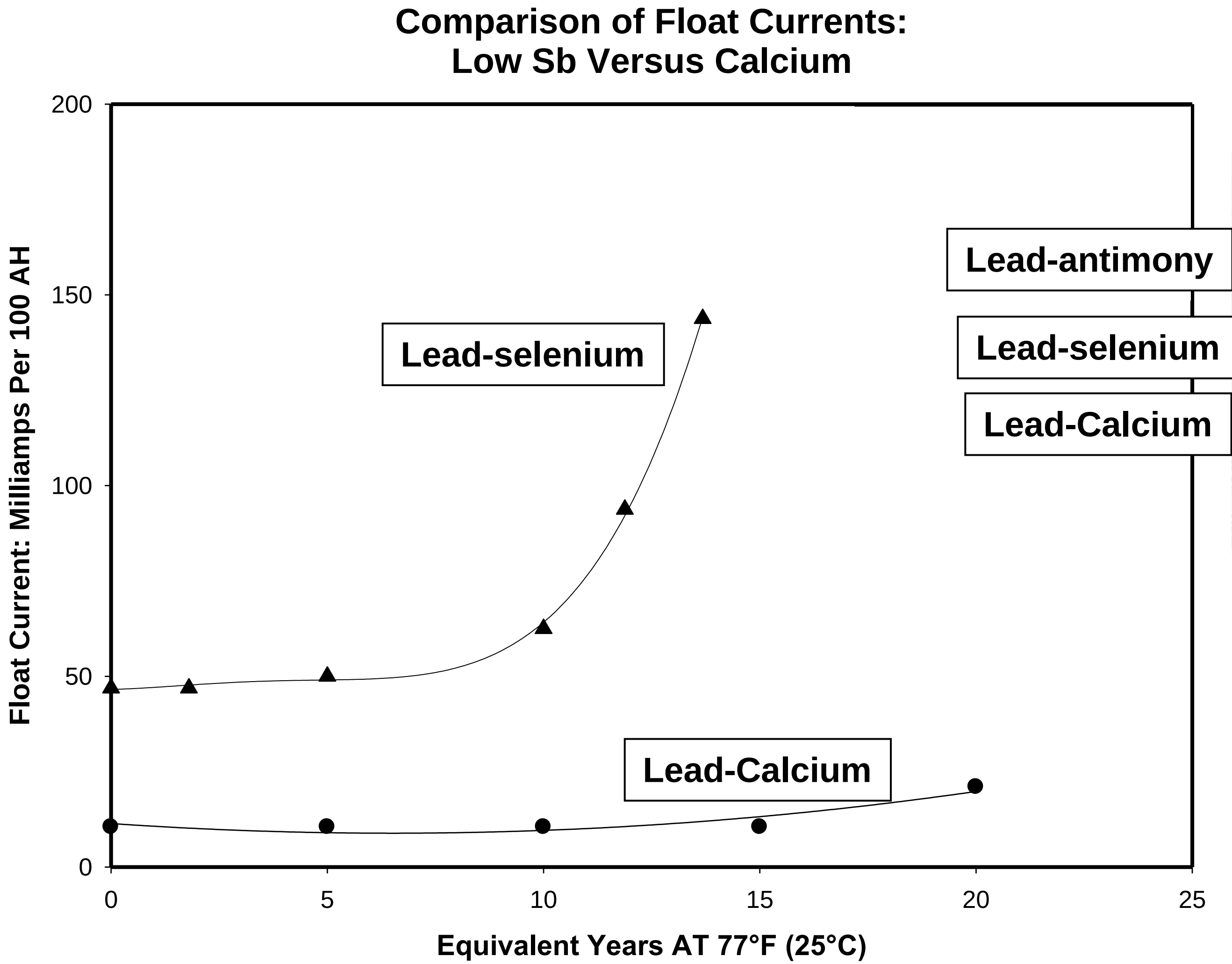
The Lead-Acid Battery Alloys

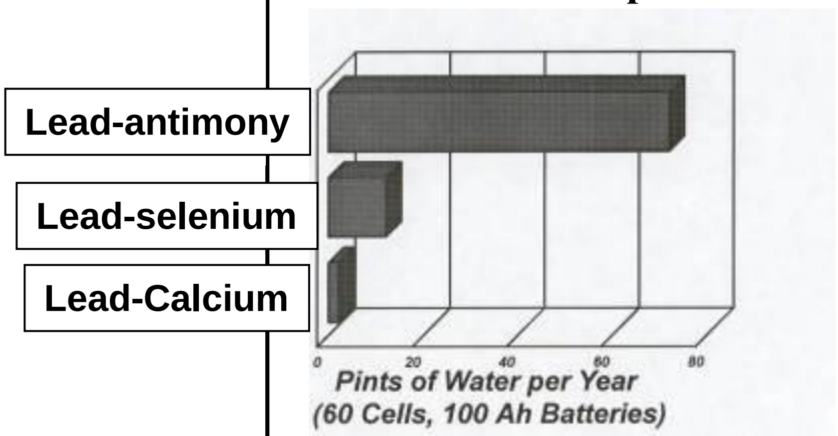
Lead-calcium (PbCa)

- Advantages
  - Calcium is stable in lead-acid battery – no poisoning
  - Initial float currents are low and remain low throughout life
  - Water consumption is lower than antimony
  - Replacement cells easily matched to older strings
  - Positive grid corrosion lower due to low float currents
  - Self-discharge rate lower – longer shelf life
- Disadvantages
  - Not suited for daily or high cycling application
  - Careful alloy control required to control long-term grid growth
  - Float voltage range control via depolarization

Lead alloy comparison



Water consumption



Lead Acid Batteries

Standby Application Differences

Typical standby battery applications

3 Major Markets Served: Telecom/UPS/Utility

- **Telecom/Broadband - 24/48 volt DC, 4 or 8 hour rate**
  - Wireless: Mobile Telephone Switching Office (MTSO) and Cell sites
  - Wire-line: Central Offices (CO) and Outside Plants (OSP)
- **UPS - 480 volt DC, 15 minute discharge**
  - Computer backup - Inside, clean, controlled installations
- **Utility - 120 volt DC with various duration discharge with 1 minute initial and final spikes**
  - Generation plants, transmission & distribution substations

Standby applications

- **Telecommunications**
  - DC Power backup for local telephone service providers, long distance, fiber optic transmission, cellular telephone service providers and outside plant broadband (bundle)

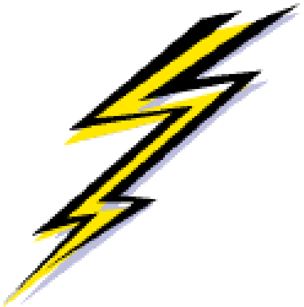
  - Product lines:
    - Larger capacity VLA batteries
    - Valve-regulated VRLA (AGM & GEL) batteries
    - Racks, Cabinets electronic monitors
    - **Customers:** Triple play or bundle packages as well as land line and wireless providers

Standby applications

- **UPS (Uninterruptible Power Supply)**
  - AC Power backup for a wide-range of commercial, industrial, and government facilities
  - <u>Product lines:</u>
    - Large flooded batteries
    - Large and Small Ah valve-regulated batteries
    - Racks, electronic monitors
    - **<u>Customers:</u>** UPS OEM, Data Centers, Government facilities

UPS application

- UPS service – factors that affect battery life
  - High current for shorter reserve time
    - High current density
  - Battery sized for reserve time closer to actual usage
    - Typical outage 2-3 minutes vs. sizing to 15 minutes
  - More cells per string
  - Exposure to more discharge cycles
    - Blackouts, Brownouts, Generator testing



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UPS application

- UPS applications are more stressful to batteries than telecom & Utility applications
  - Higher current density due to typical reserve times of 10-15 minutes vs. 8 hours in telecommunications
    - Less efficient utilization of active material
    - Internal resistance more of a factor due to higher discharge currents through each plate and post

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System Comparisons

HX-F - Front Terminated 16V Bloc

DXC – Wrapped Plated Flooded 2V Cell

HX - Top Terminated 12V Bloc

DDm – Stackable VRLA

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UPS System size comparison

750kVA (0.9 Power Factor, 95% Efficiency, 240 Cells)

kWB = 710.5kW (2961WPC)

Based on 15 Minutes to 1.67VPC @25°C

Solution	Model	Est Run Time	# of Strings required	# units/ string	Cabinet/Rack Description
HX-F	16HX800F-FR	15	4	30	4 cabs, 30 units (120 Total)
HX	HX500	15	6	40	6 cabs, 40 units (240 Total)
DXC	4-DXC-21B	17	1	60	2x13ft 2Tier, 2x14ft 2Tier
DDm	100-33	17	1	240	5 stacks, 6 wide and 8 high

Solution	Model	Estimated Footprint Length (ft)	Width (ft)	Description	Total sq ft	
HX-F	16HX800F-FR	16.67	5.67	50" x 32" each cab	94.44	
HX	HX500	21.50	5.67	43" x 32" each cab	121.83	
DXC	4-DXC-21B	27.00	7.00	2x13ft 2Tier, 2x14ft 2Tier w/ one 3' aisle	189.00	
DDm	100-33	34.42	5.19	5 stacks, each 6 wide and 8 high	178.54	

Notes: Cabinet and DDm footprint includes a 3 foot aisle allowance for the front
Rack footprint for DXC assumes 2 racks end to end with a 3 foot aisle

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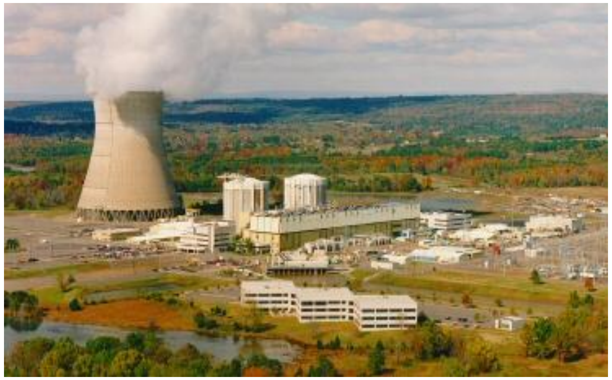
Standby applications

- **Utilities (Switchgear & Control)**
  - AC Power backup for Utility companies, generally in generating plants, and substations



  - Product lines:
    - VLA (flooded) batteries
    - Large and small Valve-regulated batteries
    - Chargers, racks, electronic monitors
    - Customers: Utility companies (Generation, Transmission, Distribution), engineering houses, nuclear power plants, oil & gas companies

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Standby applications

- Switchgear Requirements
  - Power for intermittent outages
    - 2-20 outages/year
    - Not considered a high cycling application, but must be able to handle 20 year's worth of cycles
  - Critical uptime issues
    - Loss of electricity not tolerated

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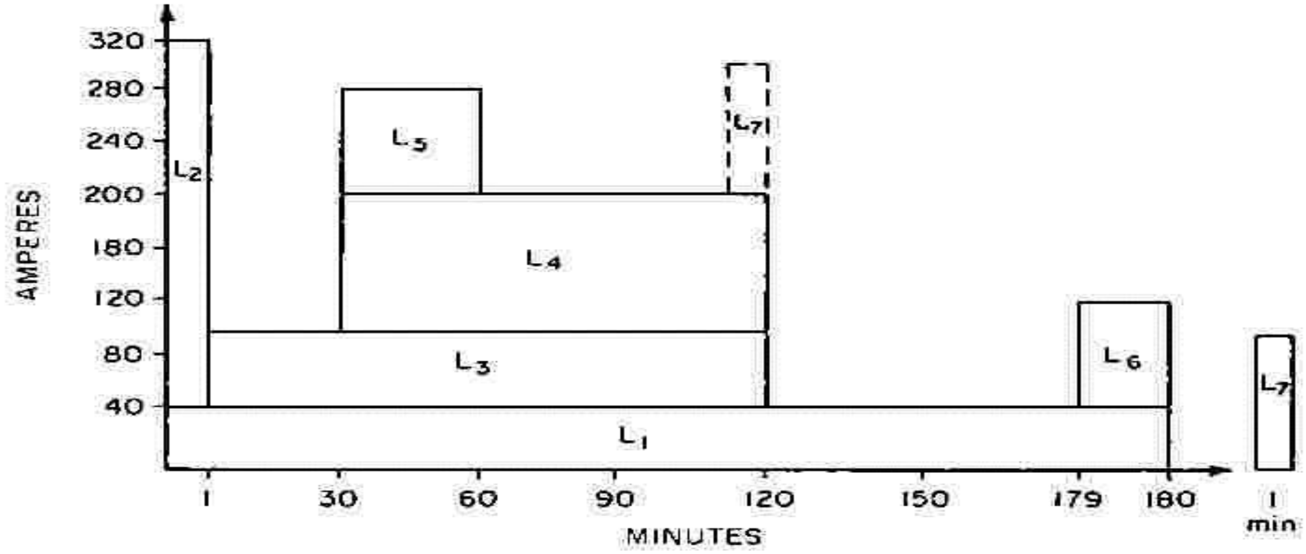
Utility application

- Duty Cycle
  - Battery current required over time at a given temperature and specific gravity and to a specified end voltage
  - Typically varies over time in order to perform several different operations, such as:
    - Breaker Tripping and Closing
    - Lights and Alarms
    - Control Circuits
    - Communications Circuits



Utility application

- Utility battery selection should not be based on Ah rating alone

  Think entire duty cycle

Typical application differences

Telecom Battery	UPS Battery	Utility Battery
Standby float application	Standby float application	Standby float application
Typ. 8hr discharge rates	Typ. 15 min discharge rates	Typ. 1hr discharge rates
Constant current discharge	Constant power discharge	Multi-step duty cycle discharge
Few cycles <10 cycles/yr	Moderate cycles 10-20 cycles/yr	Very few cycles 2-5 cycles/yr
Long duration, deep discharges (to 1.84vpc or 1.75vpc)	Short duration, high rate discharges (to 1.67vpc)	Short & long duration deep discharges (to 1.75vpc)
Poor high rates	Very good high rates	Good high rates
CO: temp. OK OSP: high temp	Typically temp. OK	Varying temp environ.

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Typical battery design differences

Telecom Battery	UPS Battery	Utility Battery
Nominal 8 hr discharge rate	Nominal 15 min. discharge rate	Combination of long & short duration rates
Thicker pos plates	Thinner pos plates	Moderately thick plates
Plates farther apart	Plates very close	Moderate plate center
High electrolyte to plate ratio	Low electrolyte to plate ratio	Moderate electrolyte to plate ratio
Minimal cycling	Improved cycling	Moderate cycling
Poor high rates	Very good high rates	Reliable high rates
Good long rates	Poor long rates	Reliable long rates

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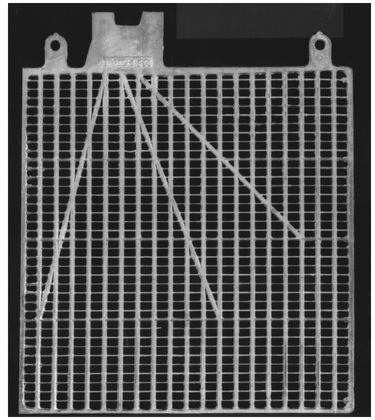
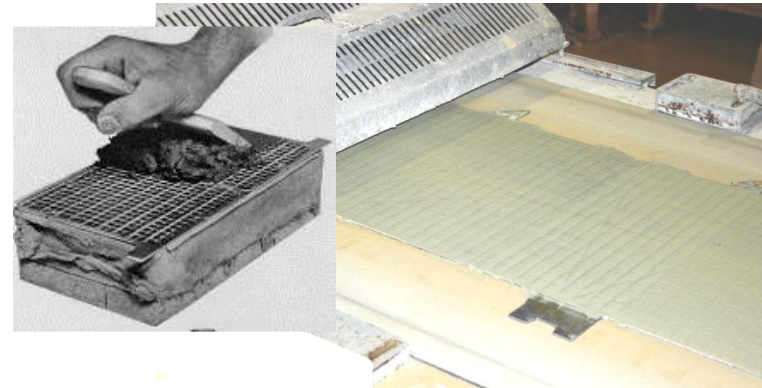
VLA vs. VRLA

Similarities and Differences

Similarities



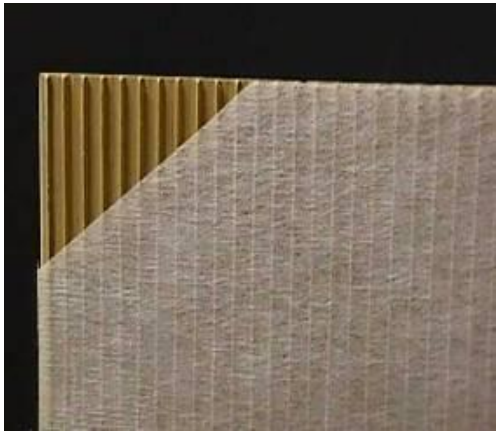


	VRLA	VLA (Flooded)
Alloy	Lead alloy	Lead alloy
Grid	Lead alloy, solid frame	Lead alloy, solid frame
Paste	Mixture of lead oxide, acid, and additives	Mixture of lead oxide, acid, and additives
Plate	Paste filled grid	Paste filled grid
Electrolyte	Sulfuric acid	Sulfuric acid
Chemistry	Positive plate is the life limiting member	Positive plate is the life limiting member

What is the design difference?

Separator - difference is noticeable

- Flooded: microporous membrane
  - Grooved for acid and gas movement
  - Provides good short prevention
  - Glass mat added to hold paste for improve cycle life



- VRLA: Absorbent glass fiber mat
  - Acid is fully absorbed - no free acid
  - Must maintain contact with plates - provides acid to plates
  - Compression level is critical
  - ~95% saturated to allow gas exchange

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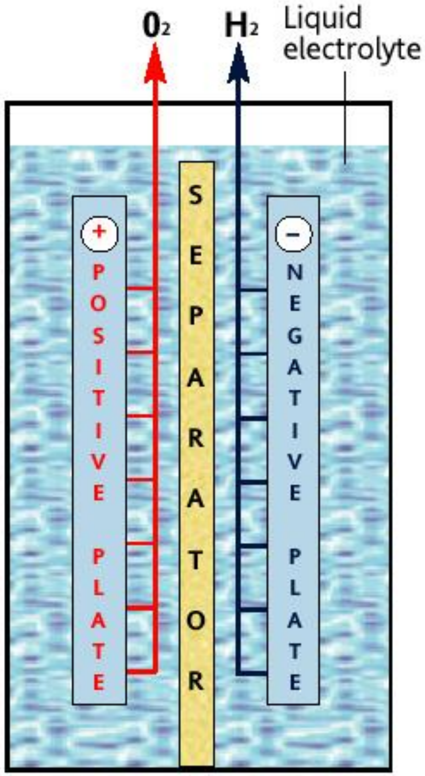
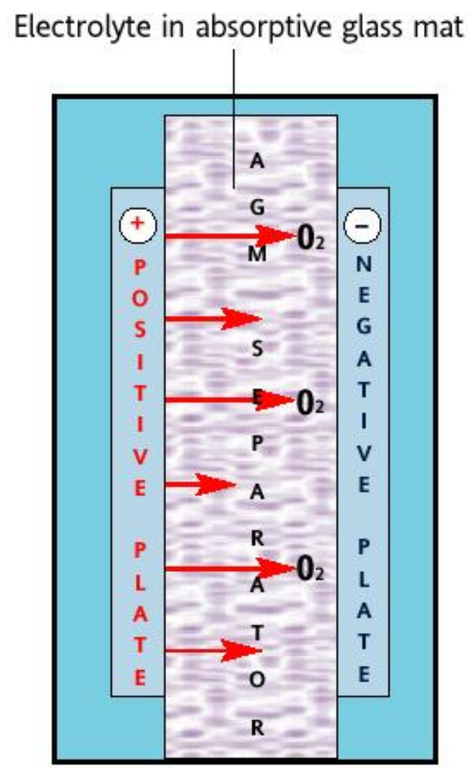
VLA (flooded) vs. AGM VRLA

VLA
(flooded)



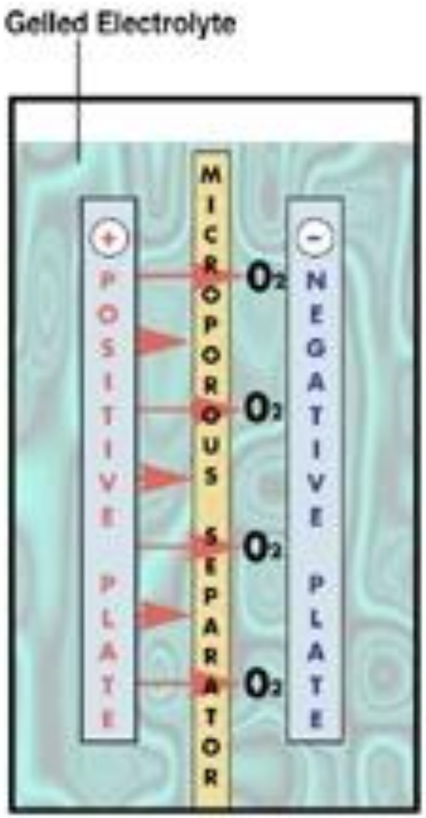


VRLA
(AGM type)

- O_2 and H_2 generated during reaction leaves the cell through open vent
- Recombination rate: ~ 20-25%
- Room ventilation must be considered - regular room air exchange via HVAC is NOT sufficient

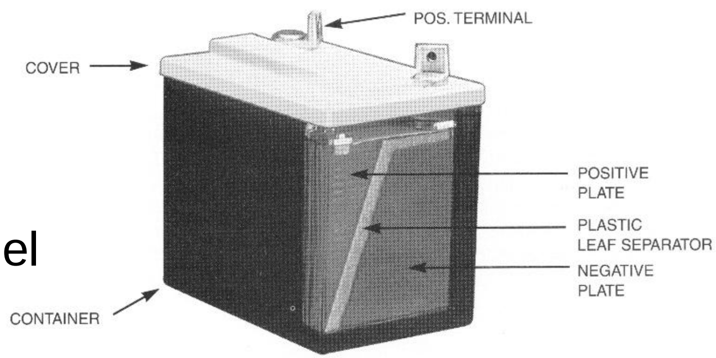
- O_2 and H_2 generated during reaction recombines into water and stays in the cell
- Recombination rate: ~ 98-99%
- Ventilation required - regular room air exchange via HVAC may be sufficient

Gel VRLA



Gel VRLA

- Electrolyte held in a solid gel mass
- Sulfuric acid and silica in VLA type micro-porous separator – NOT AGM
- Micro fissures within gel mixture for gas transfer
- Oxygen recombination – no watering
- Upon agitation gel reverts back to liquid
- Ground transportation – similar to liquid batteries



Gelled Electrolyte VRLA Battery Construction

Benefits of AGM VRLA

- Space savings
- No water addition or monitoring of electrolyte
- Higher energy & power densities
- Low hydrogen venting (gassing) due to 98-99% recombination rate
- Better cycling capabilities (no sediment)
- No free acid - “Nonspillable”

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Benefits of Flooded

- Typically a longer float life
- Easier to recover from abuse
  - Overcharging still results in gassing & water loss
  - In VRLA, water cannot be added back. Once water is gassed, it is gone for good
- Better indication of battery's health via visual inspections
- Less power consumption (lower float current)
- No dependence on pressure vents
- Typically built larger (more Ah – up to 4000 Ahrs) than VRLA
- Less sensitive to heat issues
  - electrolyte acts as "heat sink"
  - space between cells helps with heat dissipation

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How to choose between VLA and VRLA?

Must consider the following:

- Application
  - Cycle vs. float
  - Discharge rate
  - Estimated service life
  - Temperature
- Space & Accessibility
- Maintenance & Monitoring

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How to choose?

- Application - Cycle vs. Float
  - VRLA
    - Element compression aids in cycling
    - Overcharge & undercharge more critical
    - Better cycling than Flooded
    - In most cases, VRLA batteries are made with lead-calcium alloy
  - Flooded
    - Wrapped plate improves cycling
    - Better able to withstand extreme usage
    - Visually able to detect over / undercharge

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How to choose?

- Application - Discharge rate
  - Flooded
    - Able to vary acid volume ratio depending on application
    - Plate thickness and acid volume play a role
  - VRLA
    - Lower resistance of AGM aids in high rates
    - Limited acid volume affects duration
    - Higher concentration acid (1.300) used
    - More sensitive to low cutoff voltages
      - Leading to development of dendrite shorting

How to choose?

- Application - Service life
  - Flooded
    - Been around a long time
    - Proven history of batteries with longer than 20 yr service life
    - Modes of failure are well understood
  - VRLA
    - Relatively short history compared to flooded
    - Modes of failure are being studied and making improvements
    - Selection also depends on site accessibility
  - Depth of discharge is critical to service life

How to choose?

- Application – Temperature
  - Flooded
    - Better at temp variation than VRLA
    - High temp results in higher grid corrosion & grid growth
    - Higher grid corrosion results in increased gassing - results in higher water loss and shorter life
  - VRLA
    - Sensitive to high temperature
    - High temp = high grid corrosion/grid corrosion = high gassing = higher water loss
    - Excessive water loss results in premature failure

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How to choose?

Space / Maintenance Considerations

- Flooded
  - Requires larger foot print for same energy density
  - Must consider access space for maintenance
  - Must consider ventilation requirement & spill containment
  - Proven reliability

- VRLA
  - Takes up less space for same energy density
  - Reduced maintenance
  - Regular room air exchange is sufficient; however, avoid air tight rooms
  - Do not turn off HVAC system while the batteries are on charge

Material & Battery Selection Guidelines

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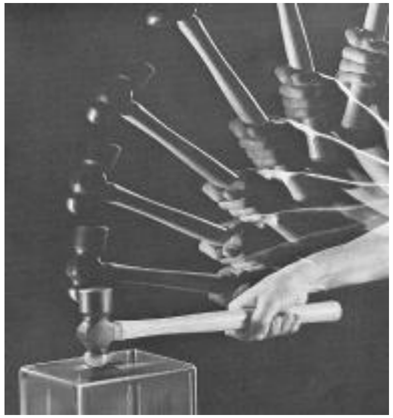
Plastics choices

- Limited Oxygen Index (LOI)
  - Used to rate the ability of material to support a flame
  - LOI refers to the minimum oxygen level required to sustain a flame. If the LOI is above ~20, the plastic will be self-extinguishing
    - Typical atmospheric level LOI is approx. 18

	PC-ABS	PVC	FR-PP	PC	SAN	Styrene
LOI:	32	32	28	25	18	18

Plastics choices



- Common jar material choices

	SAN	FR-PP	PVC	PC
Cost	$	$$	$$	$$$
Strength	1	2	2	3
LOI	18	28	>32	25

- **SAN, PVC & PC available in transparent mat'l & used in flooded cells**
- **PP & PVC available in opaque material & used in VRLA cells**

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Jar material choices - Flammability

- Flammability plays a big factor in preventing battery fire

Battery selection

- There are many items to be considered when selecting a battery for stationary use
  - Application
  - End Voltages
  - AH Sizes
  - Power Density
  - Ventilation
  - Temperature
  - Space (room/cabinet) limitations
  - Budget
  - Expected service life of the installation
  - Experience level of maintenance personnel

Battery sizing

- Some customers have internal battery-sizing computer programs
- EnerSys provides an online **B**attery **S**izing **P**rogram (BSP) for flooded batteries
  - https://bsp.enersys.com/bsp/globalLocations.do
- IEEE 485 provides guidelines for sizing batteries
  - Temperature correction
  - Design margin
  - Aging factors
  - Initial capacity vs. Peak capacity
- Battery system requirements typically dictated by equipment in place
  - Runtime based on Ah rating
  - Single Cell (2V) vs. Multiple Cell (4, 6, or 8V)

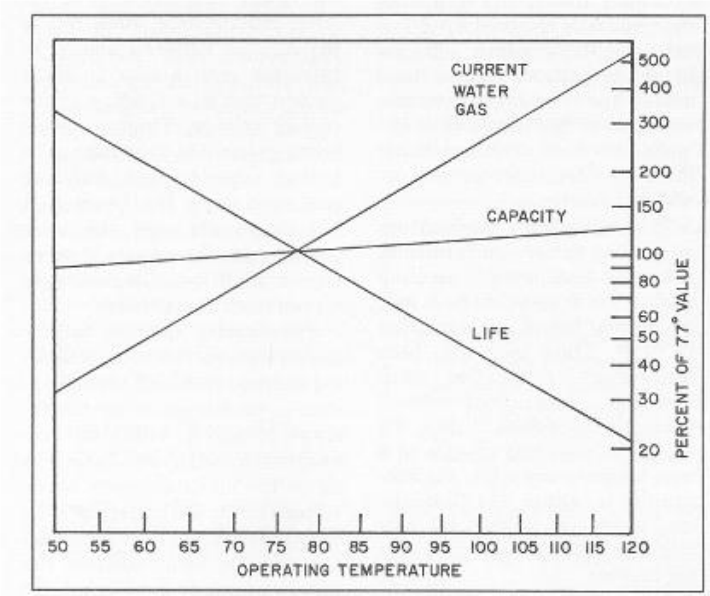
Battery sizing

- Design margin
  - How much do you want to oversize the battery?
  - Default design margin is 1.0
  - Typical design margin value is 10% or 1.1

- Aging factor
  - Where do you want the battery capacity at the end of life?
  - IEEE says the batteries are at the end of life at 80% capacity
  - If you want the batteries to be at 100% capacity at the end of life, then the aging factor has to be 1.25

Temperature effect

- Heat accelerates chemical activity and cold slows it down
- Low temperature will reduce available battery capacity by approx. 0.5% per degree F
- High temperature will
  - Increase capacity
  - Shorten life
  - Increase internal discharge rate
  - Raises charging current
  - Increases the watering interval



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Temperature correction factor

Sizing correction

- Must consider temperature effect on capacity
- Lead-acid batteries are typically rated at 25C (77°F)
- Size batteries larger (higher Ahrs) if operated at colder temperatures
- IEEE recommends using the factor of 1, when sizing at higher than 25C (77F)

Electrolyte Temperature (°F)	Cell Size Correction Factor
25	1.52
30	1.43
35	1.35
40	1.30
45	1.25
50	1.19
55	1.15
60	1.11
65	1.08
70	1.04
77	1.00
80	.98
85	.96
90	.94
95	.93
100	.91
105	.89
110	.88

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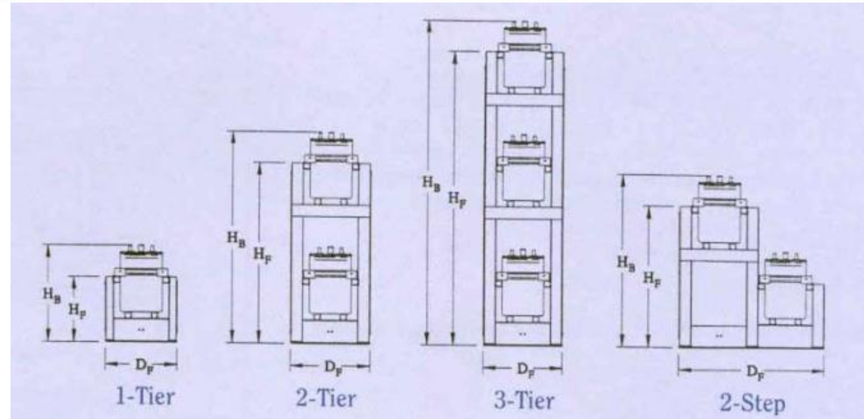
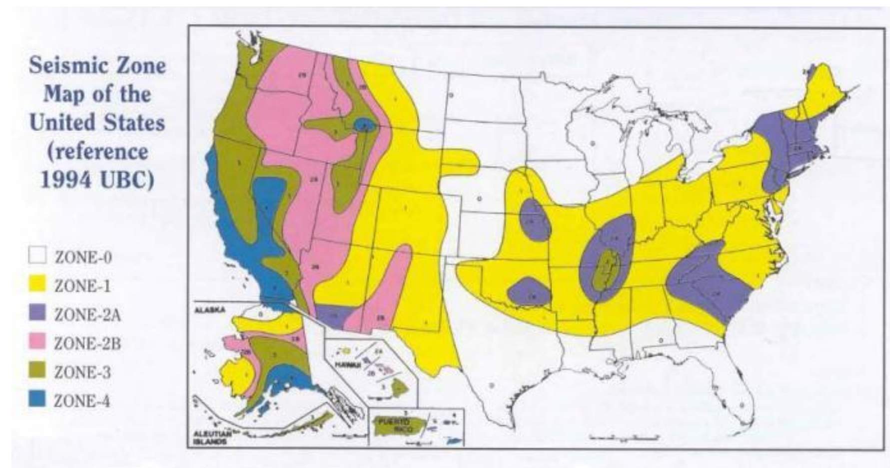
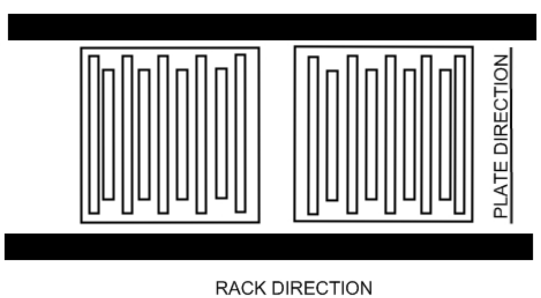
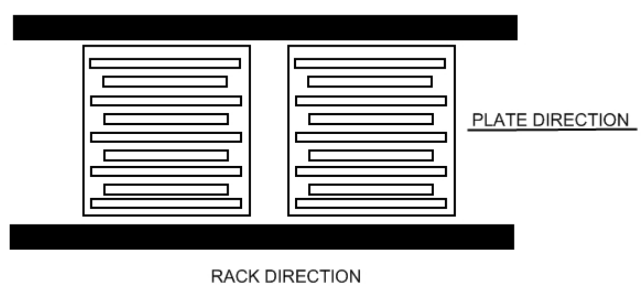
VLA Configuration & Terminology

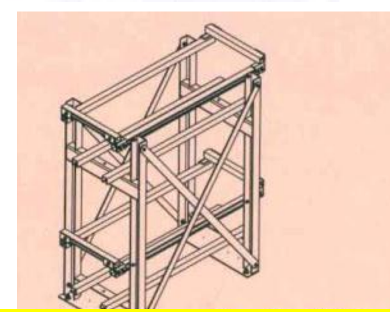
- Non-seismic
- Seismic – Zone 2, Zone 4
- 2-Tier, 2-Step, etc.
- Single string
- Parallel string
- Terminal Plates / Overhead Buss Bar
- Perpendicular & Parallel Configurations











Two-Tier Seismic Rack

Battery Charging

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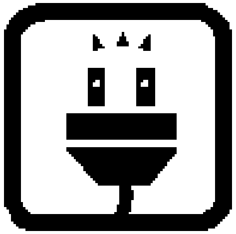
Types of Charging

- Charging – keeps the batteries at full state of readiness so they can deliver the expected capacity at the time of need
  - Recharging following a discharge
  - Float charging
  - Equalization charging



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Types of Charging – Recharge Following A Discharge

Recharging following a discharge

– Approx. 105 to 110% of the Ahr removed on discharge should be returned to fully recharge the battery

– If not fully recharged, the residual lead sulfate remains on the plates (white residue, which may be hard to detect in the early stages)

– If the cell is not recharged or undercharged for an extended period, the lead sulfate hardens

– Hardened lead sulfate will permanently kill the capacity and can result in cell shorting

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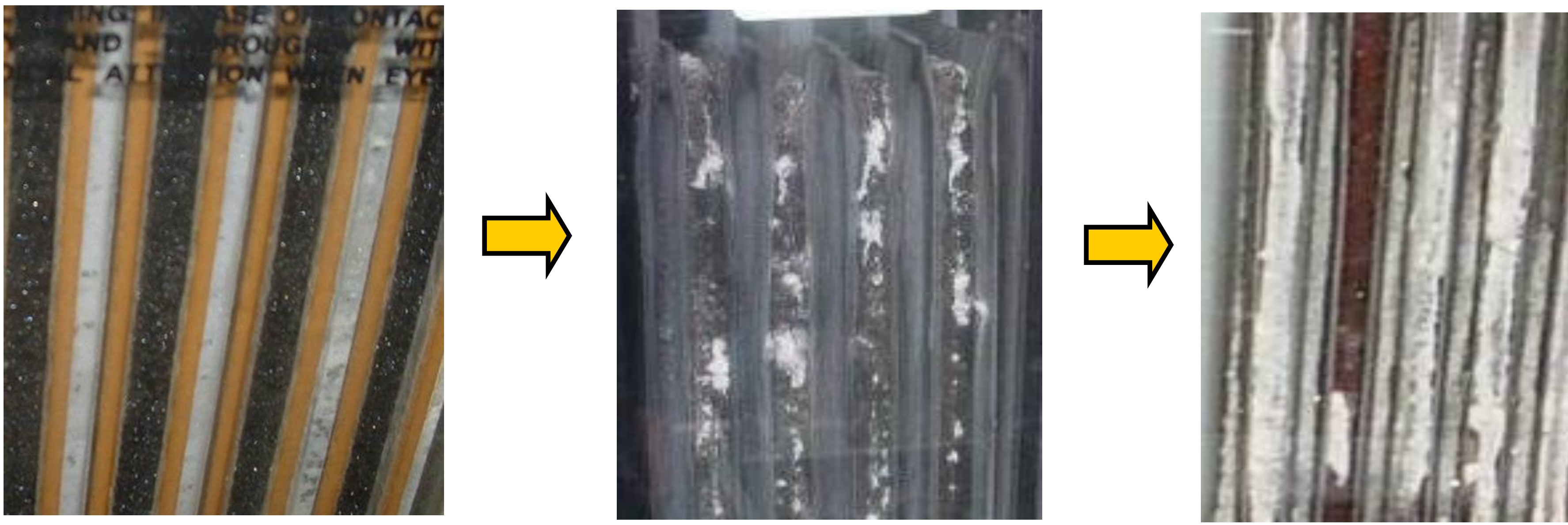
Plate Sulfation Progression



Types of charging – Float Charging

Float charging

- Necessary to keep the battery at 100% state of charge
- Counters the battery’s self discharge reaction
- Too low float voltage
  - undercharged battery
  - can cause plate damage
- Too high float voltage
  - overcharges the battery
  - excessive grid corrosion and loss of water
- Temperature compensated charge voltage recommended to prolong battery life
- Float charging does not result in temp. rise

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Types of charging – Float Charging

- DC power supply will keep the batteries fully charged – adjust the power supply to proper float values

- Float voltage – Correct float voltage maximizes battery performance and service life

Nominal Acid Specific gravity	Allowable float voltage based on total battery voltage	Allowable individual cell voltage
1.215	2.20-2.25	2.12-2.29
1.250	2.22-2.27	2.15-2.32

Note: Above table is for lead calcium flooded batteries

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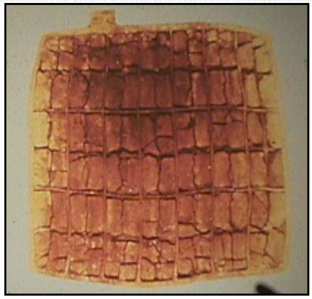
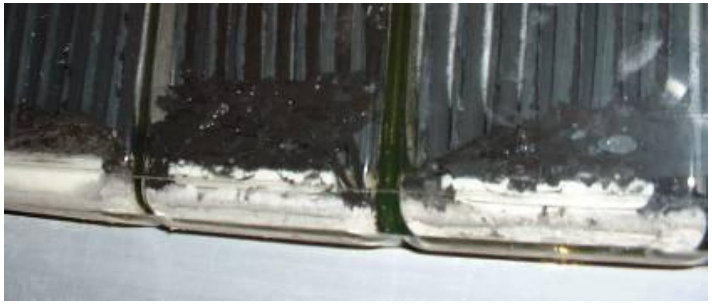
Charging Issues

- Overcharging causes:
  - Accelerated aging
  - Excessive polarization of the positive plate = accelerated corrosion
  - Generates more free oxygen = accelerated corrosion
  - Excessive Gassing
  - Shedding of active material
  - Increased water consumption = frequent watering
  - Increase in heat generation





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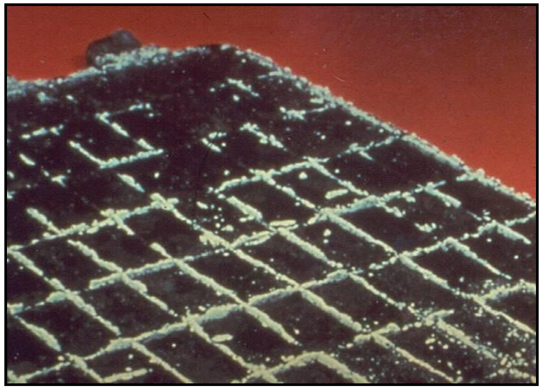
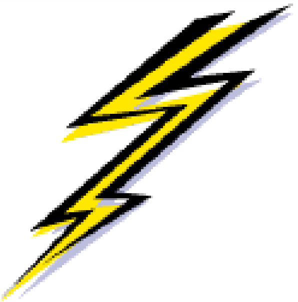
Charging Issues

- Undercharging
  - Means that the battery does not get fully charged
  - Causes plate sulfation
  - Build-up of lead-sulfate crystals on plates
  - Loss of capacity which could be permanent
  - Plate deformation
  - Equalize or boost charge may fully or partially recover depending on severity of undercharging



Types of charging – Equalization Charging



- Equalization charging
  - Used to bring batteries up to full state of charge
  - Needed if charged to less than minimum float voltage – equalization will restore the proper float voltage
  - Results in gassing which in-turn mixes the stratified acid
  - Used to even out cell to cell float voltages and capacity differences that may develop over time
  - Too frequent equalization shortens the battery life
- Need to equalize does not imply malfunction or failure to support the load

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Types of charging – Equalization Charging

- Equalizing charge - follow manufacturer's recommended voltage
  - If the lowest cell in string on float reaches the below voltage
  - If subjected to frequent discharges
  - Unless trouble shooting, <u>equalization charges are unnecessary</u>

Nominal acid Specific gravity	Equalize when lowest cell in string reaches this voltage	Equalize voltage per cell
1.215	2.12	2.33-2.38
1.250	2.15	2.38-2.43

Note: Above table is for lead calcium flooded batteries

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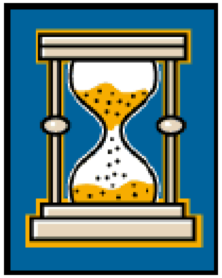
Types of charging – Equalization Charging

- Equalization charge duration
  - Charging time varies depending on condition of the battery
    - time on open circuit
    - storage temperature
    - charge voltage



  - When equalized as a string, it usually takes between 8 to 24 hours, but may take up to 100 hours
  - Stop equalizing
    - 3 successive voltage readings are the same
    - the lowest cell is less than 0.05 volts below the average of the string

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Battery Maintenance Checks

- In general the types of checks to be made during the periodic maintenance include:
  - System charging voltage
  - Ambient / Battery temperatures
  - Inter-unit connection hardware resistance or tightness
  - Individual battery float voltage
  - Battery system capacity test

- Have a consistent maintenance program
- Follow manufacturer’s recommendations or IEEE guidelines
  - IEEE-450 (VLA), IEEE-1188 (VRLA)

Types of charging – Single Cell Charging

- If the charging equipment does not have the required equalizing potential
  - Single cell charger may be paralleled across the affected cell while still part of the overall battery
  - It will provide an over-voltage to the subject cell
  - This type of charger requires AC isolation from DC to prevent possible ground faults and shocks
    - Buy chargers with transformer isolation feature

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Charger selection

- Battery charger must have at least two capabilities:
  - Electrical filtering to protect the cells from AC ripple
    - may lead to shedding where active material from flooded battery falls to the bottom as sediment
    - too much will cause cell shorting
  - Temperature compensation to prevent overcharging or undercharging

Temperature compensate by 2.8mV (0.0028V) per degree F deviating from 77F

- **Add 2.8mV per degree F below 77F**
- **Subtract 2.8mV per degree F above 77F**

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Specification Writing

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Writing battery specifications

- Simple and relevant battery specification will facilitate the selection of the right battery

- It results in ……..
  - Satisfactory life
  - Less remedial maintenance
  - Capital savings
  - Most reliable back-up power system

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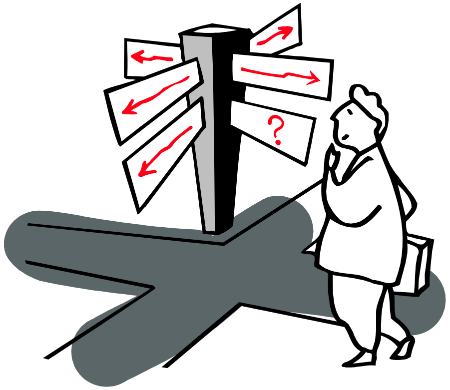
Common Pitfalls

- Do not simply cut & paste existing documents

"Lead acid batteries shall be AGM VRLA type with battery containers clearly marked with high and low acid level lines."



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Common Pitfalls

- Do not leave it up to individual interpretation

"Battery jars must fit comfortable, within battery building, with plenty of room for servicing and replacing cells."

Common Pitfalls

- Define the load, duration, end voltage, and temperature

"Number of cells is 60 with a minimum of 280 AMP HOUR capacity of each cell."

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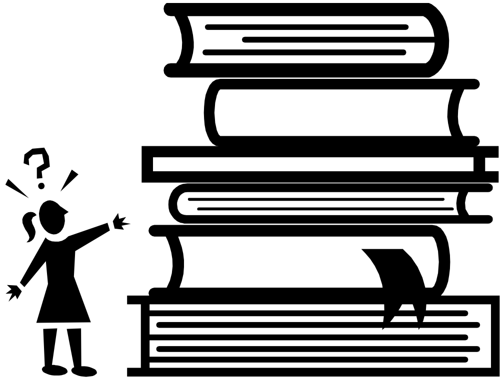
Writing Style

- Avoid using ambiguous and wasteful phrases

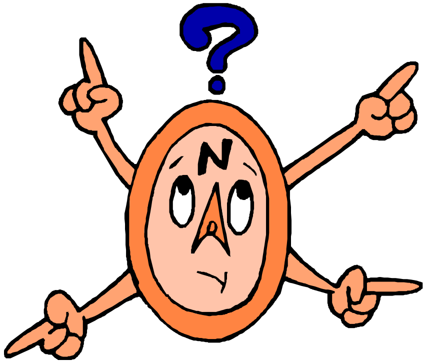
“except as otherwise specified”

“unless otherwise shown or directed"



Writing Style

- Use present tense



Try to avoid "will, shall, should, & may"

- Above words brings into question whether the parameters are mandatory or not
- Present tense makes language clear and direct & prevents 'specification creep'

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Technical Aspects

- Three major areas

1. Application definition
   - Describe the battery and its usage fully
2. Battery system preference
   - Summarize the customer’s preferences in terms of the battery type and features
3. Requirements
   - Define specific features or criteria that the battery must meet as determined by the customer

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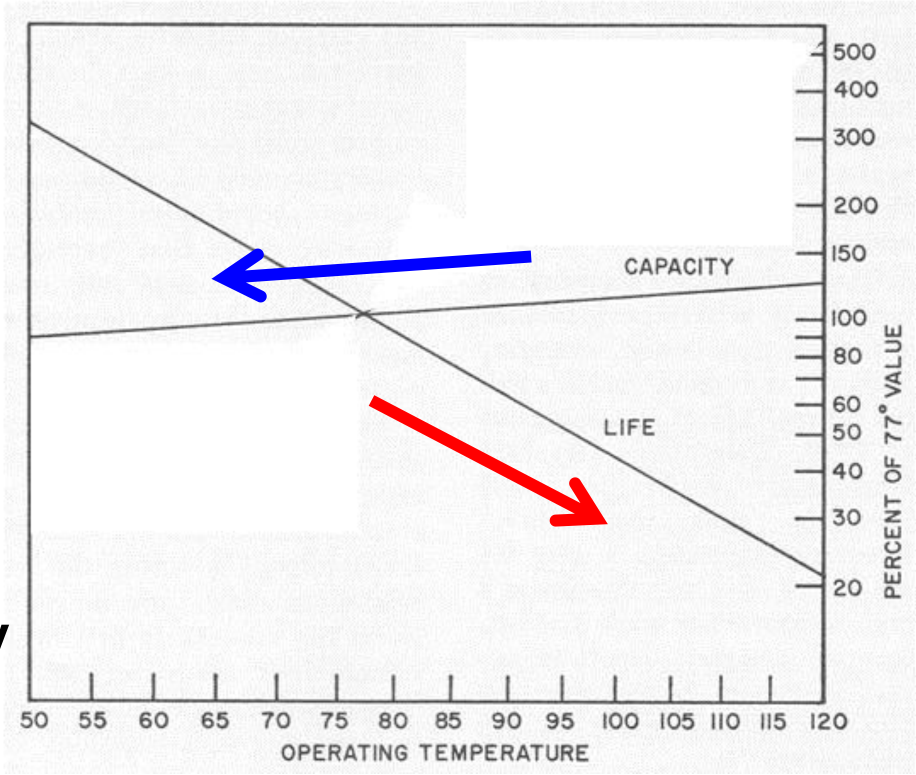
Technical Aspects

- Application definition
  - Describe application
  - Become familiar with IEEE standards for stationary batteries
  - Areas to define
    - Environment
    - Duty cycle
    - Recharge method
    - Maintenance issues

Technical Aspects

- **Environment – temperature, seismic, vibration, etc.**
  - **Ambient temperature – why it is important**
    - **Cold = Larger battery**
    - **Hot = Shorter life**
  - **Options based on temperature**
    - **High temperature plastic cover/container material**
    - **Outer steel sleeve**
    - **Electrolyte specific gravity**



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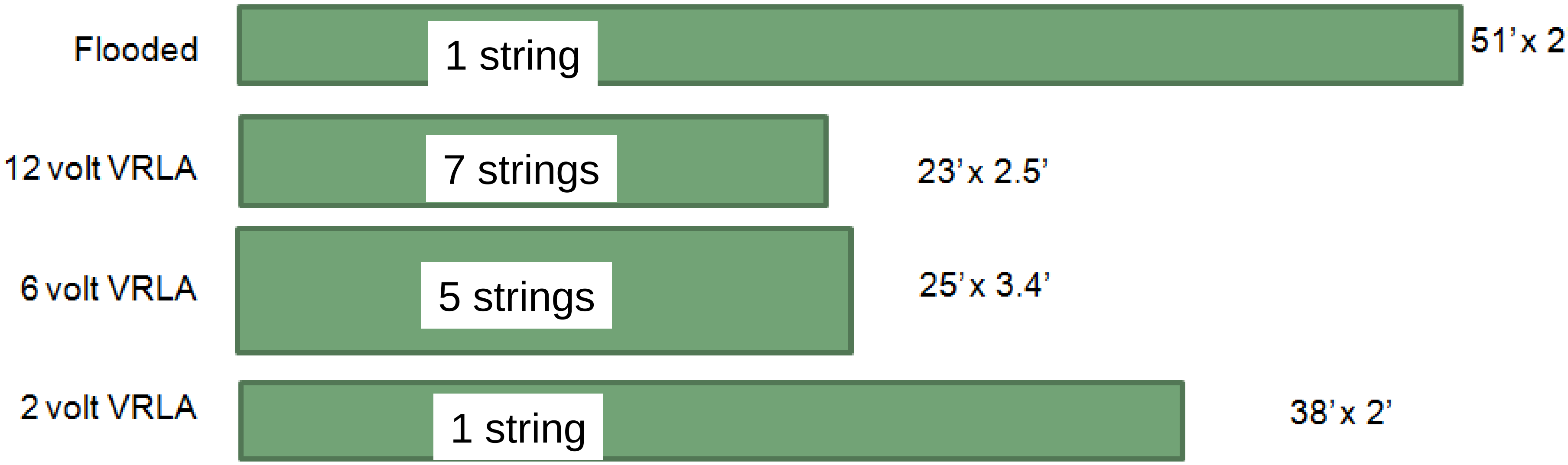
Technical Aspects

- Battery system preferences
  - Identify customer preferences
    - VLA vs. VRLA
    - Single cell vs. Multi-cell jars
    - Parallel string vs. Single string
    - Ancillary equipment

Technical Aspects

- **Battery system preferences**
  - **Example of a 15 minutes, 750 KVA battery choices**
    - **All will meet a general performance specification – user preference is required**



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Technical Aspects

- Specification requirements
  - Space limitation
  - Floor loading
  - Battery life
  - Jar & cover materials
  - Application specific design features
  - Warranty

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Factors affecting performance and life

Storage
troubleshooting
AC ripple
Design
voltage
equalization
AGING
Temperature
testing
cycles
Load changes
Manufacturing
Location
Maintenance
selection
installation
Charging
SIZING

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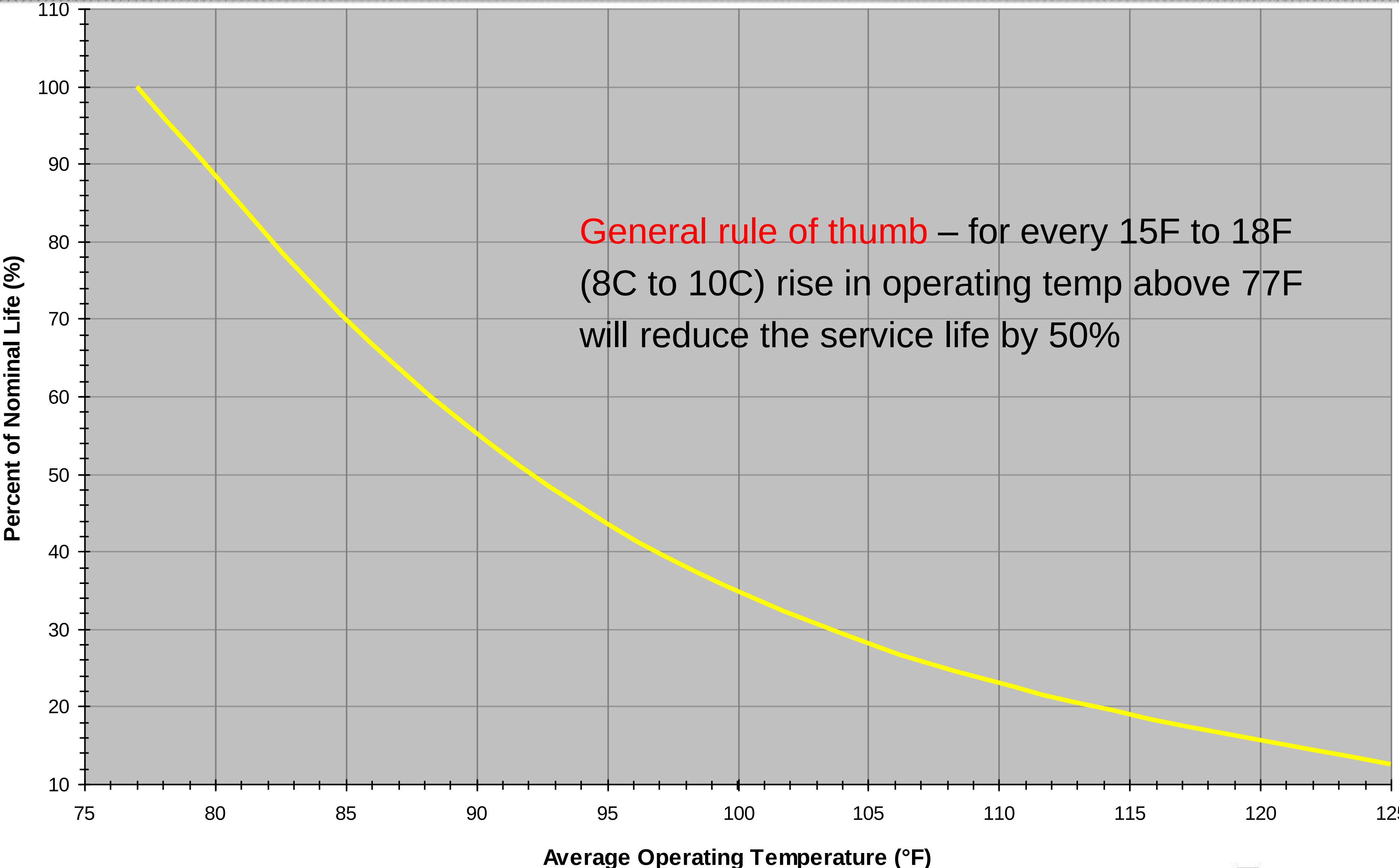
Temperature - battery life relationship



Inspection & maintenance guidelines

- IEEE 450 (VLA) & IEEE 1188 (VRLA) outlines inspection & maintenance guidelines
- Obtain the latest document at www.ieee.org

Handling cells

- Do not over estimate your strength
- Have proper tools to handle cells
  - Two wheeled carts tip forward and backward – causing acid spills with flooded cells

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Battery inspection

- Preliminary external inspection should occur upon arrival of battery shipment:
  - BOL matches expectation
  - Damage to packing material
  - Wetness or stains indicating electrolyte leakage
  - Issues found at this point should be noted to freight carrier before signing for product
- Secondary (detailed) Inspection to occur within 15 days of receipt
  - If electrolyte is below proper levels, contact EnerSys representative
  - Check the received materials match the packing list
  - Carrier should be contacted for any “hidden” damages
- Beware of Static Electricity!

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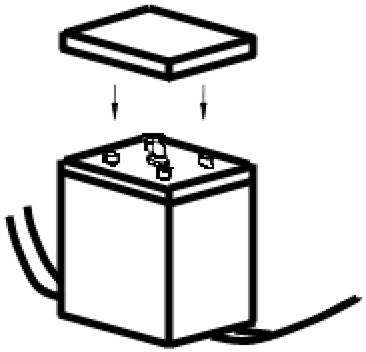
Key points to check during installation



- Batteries being lifted / moved using approved battery straps
  - Lifting / moving batteries by the terminals is NOT recommended and will VOID the warranty
  - Failure to use Styrofoam block (provided) may damage cells and lead to short-circuit

- Rack lubricant is to be EnerSys **Pro-Slide** or Dow Corning Silicon Compound #111
  - Petroleum-based lubricants will **CRACK** the jar

- Cells should be carefully positioned
  - Banging of jars can cause irreparable damage

- NO tools are to be used to pry cells into position

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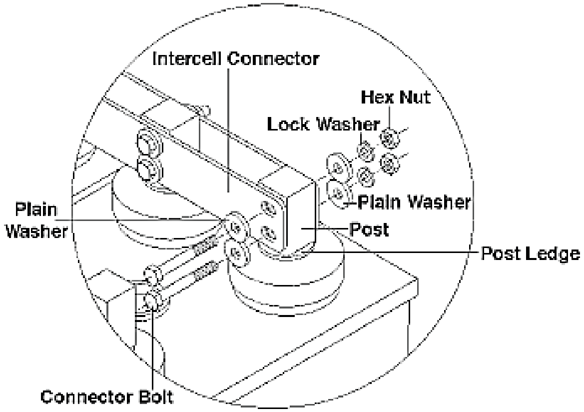
Installation of intercell connectors

- Remove grease & inspect terminals posts
- Any tarnishing or discoloration of posts requires cleaning
- Intercell connectors are to be cleaned prior to installation
- NO-OX-ID grease must be applied to each post/connector prior to connection
- Each connection (bolts, washers, connectors, and nuts must be properly torqued using a calibrated torque wrench
- **<u>All</u>** specified washers & other hardware must be used
- “Rounded” edges of washers are to face intercell connector / battery post
- Read connector resistance to ascertain connection quality



An improper connection could result in catastrophic battery failure

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Catastrophic failures

Caused by improper connection torque!

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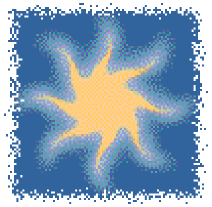
Installation location

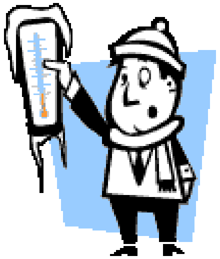
- Do NOT place the cells near radiant heat source (ex. portable heaters, heating ducts, etc.)

- Do NOT expose cells to the direct sunlight



  - UV rays will react with plastic jar and cover
  - Sunlight will heat the exposed cells

- Do NOT allow electrolyte to freeze (fully charged battery may not freeze, but discharged battery may freeze) – do not store or operate below 32F (0C)



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Impedance & conductance

- The objective of ‘impedance’ testing is correlating the change in the output signal to changes in the components of the actual cell

- The desire is to detect physical changes and chemical changes in the cell
  - Physical changes – want to determine mechanical defects, temperature effects, decrease in grid wire diameters, etc.
  - Chemical changes – want to determine changes in the paste, changes in acid concentration, changes in amount of lead sulfate, change in crystal structure of the plates, etc.

Impedance & conductance

What do these values mean?

- **Cells are measured and a value is given. This value is a combination of all impedance measurements: resistance + capacitance + inductance** **(This is the easy part)**
- **This combination value must then be interpreted to determine if a cell is good or bad** **(This is the hard part)**
- **This value is also used to 'predict' if a cell is going to be good or bad in the future** **(This is the unrealistic part)**

Maintenance – Internal resistance (impedance /conductance)

- Internal ohmic measurement is a tool that can be useful for trending batteries
  - Use with flooded batteries is questionable because internal resistance change may not be observable
- Taking a baseline reading at the time of installation is very important
- Capacity testing is the only surefire way to verify cell performance

Impedance changes due to:

- Gassing:
  - Gas (H_2 and O_2) bubbles develop on plates during charge cycles creating less surface area
- Sulfation:
  - Deposits of sulfur ions on Plates and become harder (crystallized) over time, more difficult to remove
- Electrolyte volume:
  - Loss of electrolyte due to gassing
  - Recent water addition to flooded cells
  - Dryout for VRLA batteries
- Probe location & Meter model
  - Measurement location & meter type can make difference

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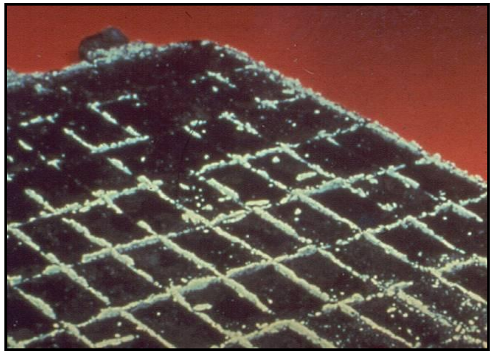
Battery aging

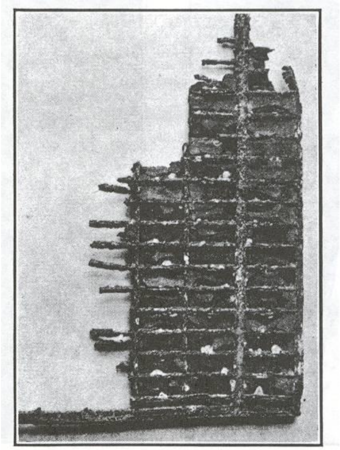
- Lead-Acid Battery is a sacrificial design with unavoidable degradation over time
  - Highly chemically active environment
  - Corrosion of positive plate grid structure
  - Converts base material to:
    - Lead dioxide
    - Lead peroxide
    - Lead sulphate
    - Even under ideal conditions



- Positive Grid Corrosion commonly results in "Positive Plate Growth"

Battery aging

- Effects of Positive Plate Grid Corrosion:
  - Expansion of the positive plate
    - Occupies more volume
  - Decrease in grid cross-sectional area
  - Weakening of grid and straps
  - Loss of electrical contact with active material
    - Higher resistivity & Lower conductance
  - Active material shedding (sediment)
  - Loss of conductance
  - Reduced capacity



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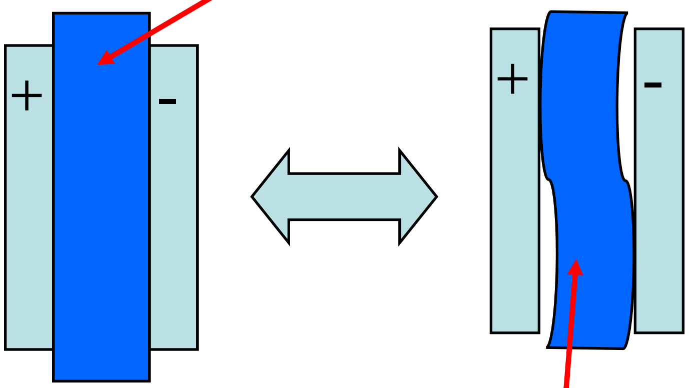
Battery aging

- Failure modes due to aging:
  - Permanent Loss of capacity
  - Increased internal resistance
  - Obstruction of active material in discharge reaction
  - Post seal leakage
  - Cracked cover
  - Internal short circuit
  - Loss of physical strength
  - Failure of conduction path

Failures unique to VRLA

- **Dryout:**
  - Loss of water ($H2$ & $O2$ gas) is irreversible
  - Results in loss of compression & immediate effect on capacity
  - Premature failure (#1 failure mode for VRLA)

Saturated AGM
Full contact with + & - plates



Dried AGM
Lost contact with + & - plates, thus losing capacity

- **Dryout may be caused by:**
  - Pressure relief valve failure
  - Post seal or case leaks
  - Overcharging
  - High operating temperature

Charger selection

- Battery charger should have at least two capabilities:
  - Proper charger output filtering to protect the cells from AC ripple - which may lead to shedding where active material from flooded battery falls to the bottom as sediment – too much will cause shorting
  - Temperature compensation to prevent overcharging or undercharging
  - The consensus is that AC ripple will prematurely age the batteries and accelerate corrosion & shedding

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Installation & Maintenance

- Proper installation & maintenance will make batteries last longer and perform to its requirements

- Battery installation & maintenance should be done by personnel knowledgeable of the battery and the safety procedures involved

- Installation & maintenance must be done in consistent manner to avoid discrepancies

Improper installation

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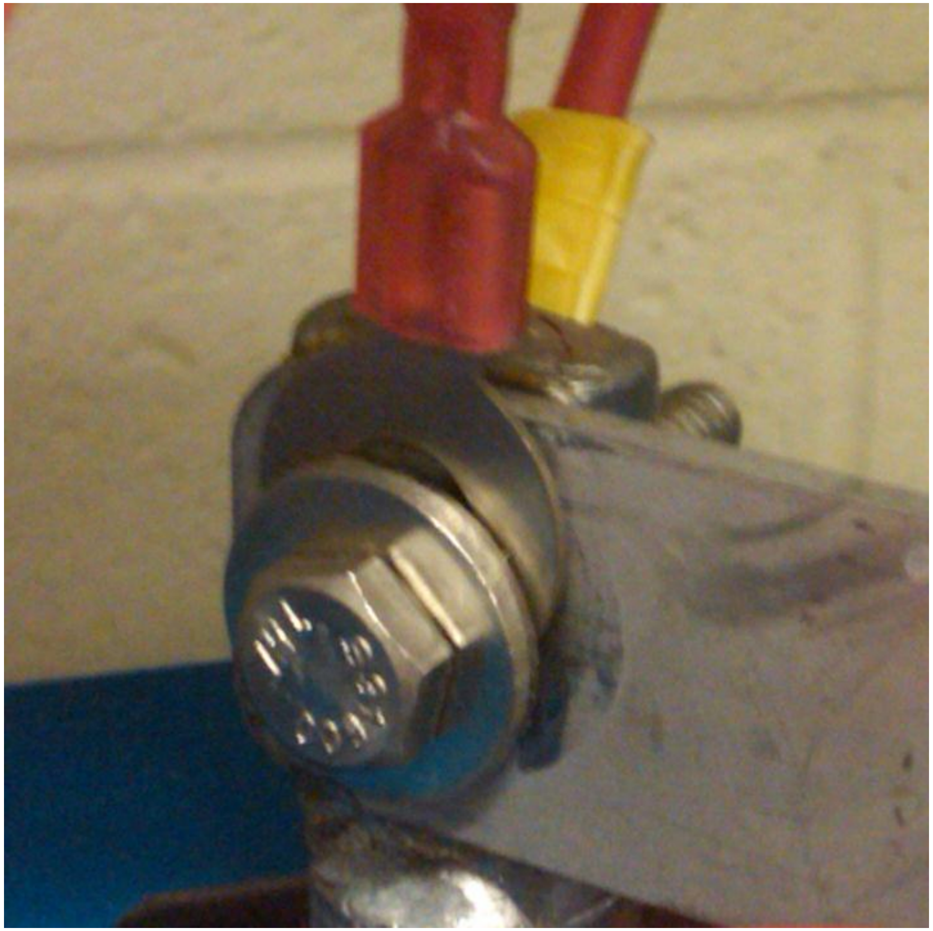
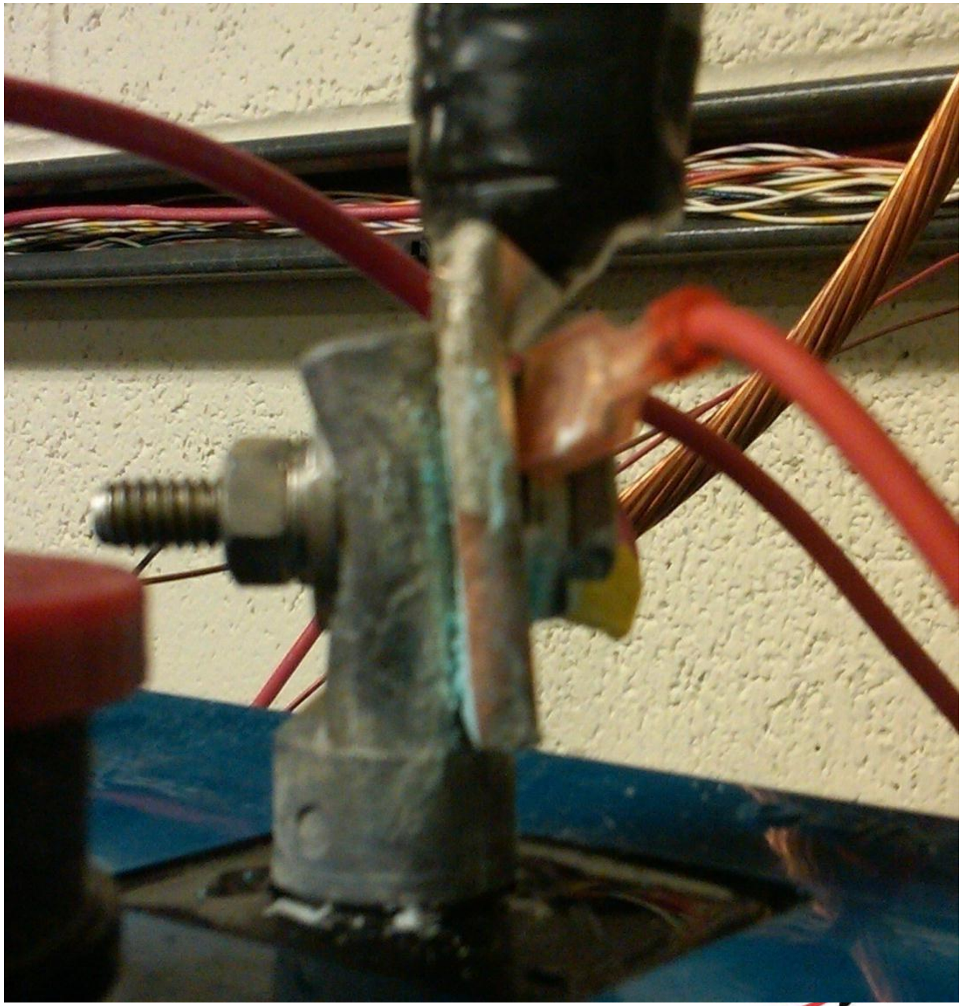
Improper installation

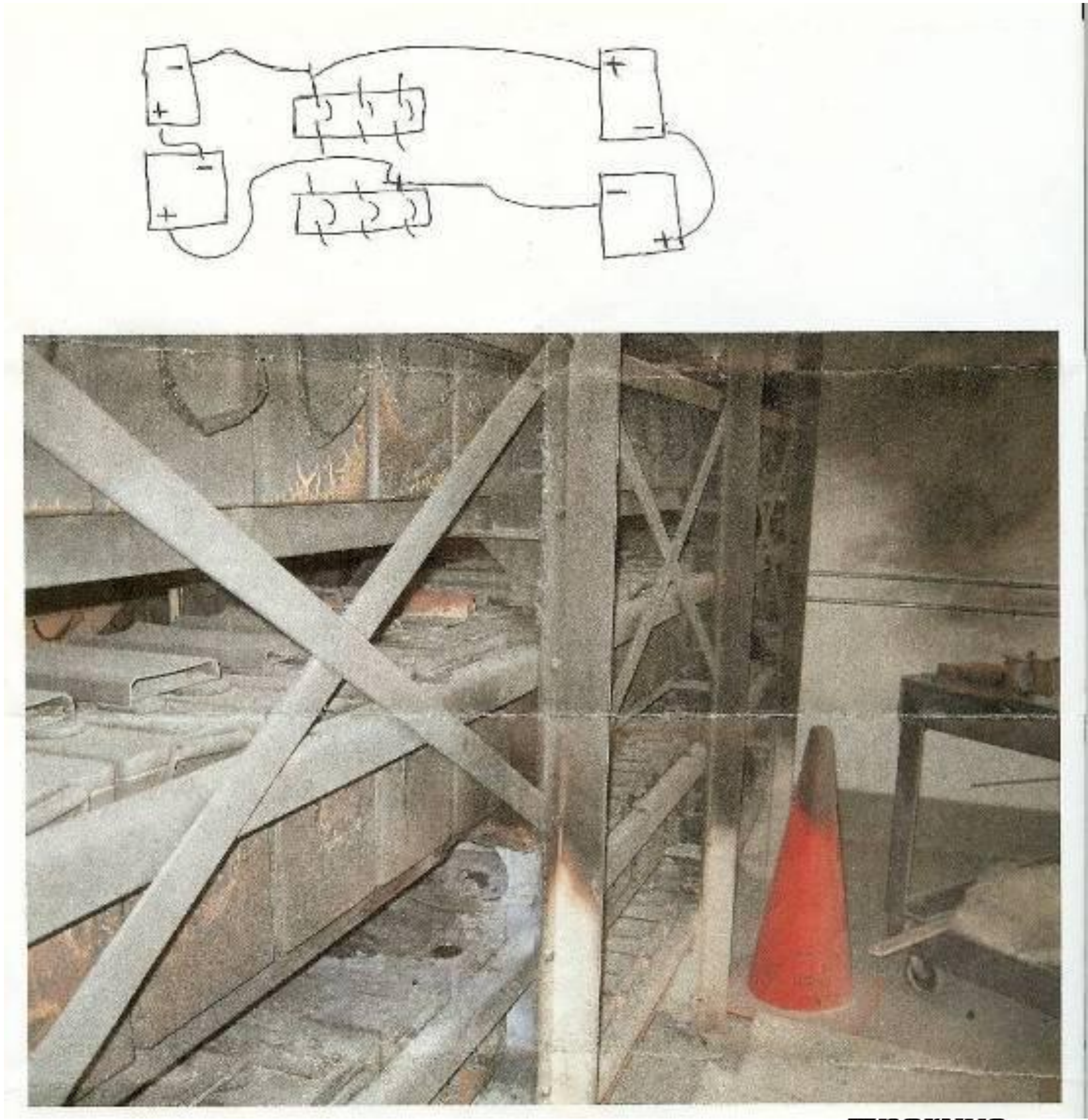




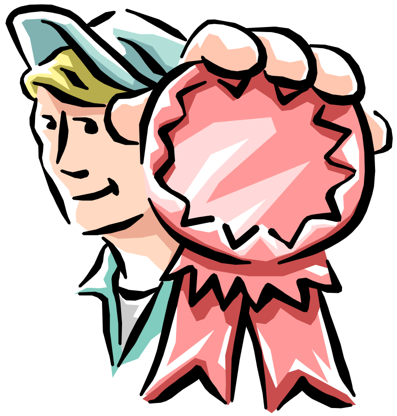
Improper installation

Results of using “inexperienced installers”

- Result of connecting 240 cells in series



Why do the battery system maintenance?



Periodic Maintenance assures:

☺ Maximum System Reliability

☺ Longest Battery System Life

☺ Indication of When to Adjust the “System”

☺ Indication of When to Replace a Cell

☺ Indication of When to Replace the System

Hydrogen gas emission

- ALL batteries emit gas (H_2 & O_2) during charging
- Hydrogen concentration above 4% is explosive
  - Hydrogen monitors available
  - Never ignore hydrogen alarm
- NEVER place ANY batteries in air tight area with no ventilation
- Charging current determines the amount of gas generated
  - Limit charge current
  - Float charging produces little gas

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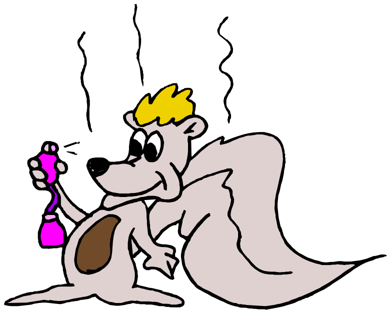
Sensory checks

- ☹ Hearing
  - ☹ “sizzle” is not good

- ☹ Visual
  - ☹ distorted labels or case, melted terminal grease, damaged containers or cracked cover, visible leaks

- ☹ Smell
  - ☹ odor of rotten egg (H_2S)



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Maintenance – visual inspection

- A set of eyes and a flash light are very important tools in detecting any abnormalities
  - Acid level
  - Sulfate crystals
  - Seal conditions
  - Debris inside cells
  - Sediment level
  - Presence of acid on cover & container (VRLA)
  - Discoloration (VRLA)
  - Bulging (VRLA)

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Maintenance – visual inspection

- Visual inspection
  - Inspect the battery rack for possible structural deterioration (rusting, corrosion, bending, etc.….)
  - Check electrolyte level on VLA cells
  - Inspect each battery jar, cover, posts and seals for deterioration
  - Examine the color of plates (pos plates should be dark chocolate to black color)
  - Look for sulfation with a flash light
  - Check the sedimentation level

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Battery disposal

- Dispose cells in accordance with Federal, State, and Local ordinances – DO NOT THROW AWAY LEAD-ACID BATTERIES WITH COMMON TRASH

- Contact EnerSys for proper methods and approved disposal handlers

Maintenance - Calibration

- Calibrate meters to avoid misreading
- Calibrate torque wrench to minimize damage to posts and connectors

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Maintenance - Capacity testing

- The actual measurement of battery’s ability to provide back-up power for a predetermined amount of time
  - Specified amount of current (amperes) to a certain end voltage for a determined period of time
  - Examples
    - UPS (15 min rate to 1.67vpc)
    - Substation (1 hour rate to 1.75vpc)
    - Telecom (8 hour rate to 1.75vpc)

- Verification of manufacturer’s published rating or system design performance parameters

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Maintenance – Capacity testing

- Capacity testing requires ….
  - Equipment (load bank, data collection devices, back-up power – generator or temporary battery bank, etc…)
  - Battery knowledge
    - Ability to detect and jump out a bad cell during testing
    - Verification of load current
    - Decision to interrupt testing
    - Once a cell voltage falls below 1.75 volts, it will decline at a rapid rate, and the testing should be interrupted before that particular cell goes into reversal
    - Test can be halted while the cell is bypassed – for 10% of total test time

- Capacity testing should be done by battery knowledgeable professionals

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Maintenance – Capacity testing

- Capacity testing requires ….
  - A fully charged battery properly floated at recommended voltage, balanced cell potentials, and acid gravities – some cases may require equalize charge
  - Battery must be on float for at least 72 hours prior to test – especially important following equalization
  - All connections (intercell, inter-row, and inter-aisle) must be optimized to lowest resistance
  - Usage of proper discharge load

Maintenance - record keeping

- Trending - Keep maintenance record to track changes
  - Connection resistance
  - Float current
  - Float voltage
  - Temperature

- Capacity testing – IEEE recommendation
  - A performance test should be made within the first 2 yrs of service
  - The interval should not be greater than 25% of the expected life
  - Annual testing should be made on any battery showing signs of degradation or has reached 85% of the expected life

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Maintenance - record keeping

- Good record keeping is a valuable tool
  - Use manufacture's form or your company's record log
  - Keeps track of trend
  - Needed for warranty verification
- Follow maintenance recommendations from the manufacturer
- May follow IEEE-450 and IEEE-1188's recommended maintenance practices
- Review maintenance data
- Early detection is key!

Battery replacement

- If battery capacity falls below 80% of the manufacturer's rating

- Physical conditions should prompt investigation into the need for replacement
  - Cracked jar
  - Deformed jar / cover
  - Wetness around cell
  - Overly grown plates
  - Frequent watering on flooded cells

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Battery replacement

- Removing a cell from string
  - String voltage must be adjusted properly
  - Identify and replace the cell in question through early detection of possible problem – importance of regular maintenance

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Battery replacement

- If cell voltage is below 2 volts on float and can't raise the voltage through equalization,
  - Replace as soon as you can
  - Cell may have internal short and have substantially self-discharged
  - Will limit the string performance
  - Regular maintenance check should minimize the length of time you are exposed to the risk

Battery replacement

- Mixing different size batteries within a string is NOT recommended due to uneven float voltage – may lead to long term damage
- Mixing different specific gravity and different alloy batteries within a string is NOT allowed because they float at different voltages
- Mixing different manufacturer's batteries within a string is NOT recommended
- Mixing VLA and VRLA within a string is NOT recommended

Battery replacement – what not to do!

Summary

- Understand lead acid battery fundamentals
- Know different applications
- Choose the right battery for the application
- Size the batteries properly

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Thank you! Any Questions?