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INDUSTRIAL LEAD ACID BATTERIES: TYPES AND THEIR SELECTION

1. Basic theory of lead acid batteries

Refer figure 1 below:

The lead acid battery comprises of two chemically dissimilar lead based plates in a dilute sulphuric acid solution. The positive plate contains lead dioxide PbO_2, and the negative plate pure lead in a spongy form. When immersed in dilute sulphuric acid, the nominal electric potential between the two plates is 2 volt. This voltage is universal for all lead acid batteries.

During discharge, the sulphite ions in the electrolyte interact with the negative and positive plates, forming lead sulphate on both. The loss of sulphite ions in the electrolyte reduces its specific gravity in proportion to the charge delivered.

During recharge, the electric current converts the plates back to their charged state, and the sulphate back to sulphuric acid. The specific gravity of the electrolyte likewise rises again as a result.

The chemical formula for these processes is shown in figure 1. From this the following is evident:

- The process is reversible, i.e. a lead acid battery can be discharged and recharged many times.
- The capacity of the battery (in ampere hours) depends on the amounts of lead dioxide (on the positive plate), spongy lead (on the negative plate) and sulphuric acid (in the electrolyte) present in the battery. These are applied in a specific ratio, and a loss of any one will result in a drop in capacity of the battery.

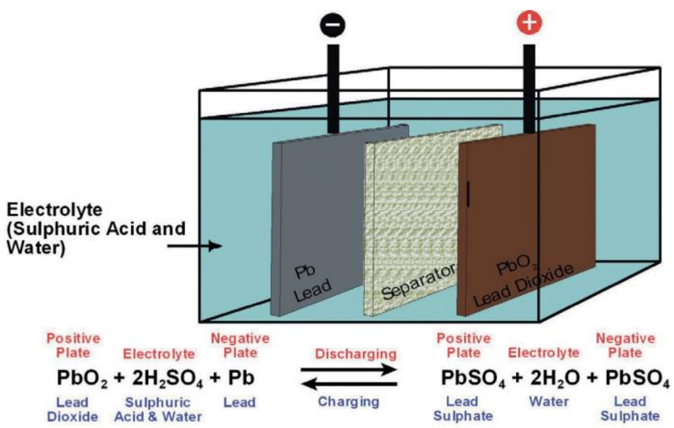

Figure 1. Basic operating principle of a lead acid battery

2. Types of lead acid batteries

Table 1 below contains the range of lead acid batteries commonly available in the market. There are other purpose specific lead acid designs not covered in this article and information on these can be obtained from manufacturers.

The two basic battery groups discussed herein are briefly explained as follows:

> *Vented lead acid (VLA)* group batteries are all "open", allowing gas to escape without any positive pressure building up in the cells. They can be topped up when required and are therefore more tolerant to high temperature operation and over charging. The free electrolyte also facilitates cooling of the battery.

Group		**Vented lead acid** (VLA)			**Sealed lead acid** (SLA or VRLA)	
Type		**Planté**	**Pasted plate**	**Tubular**	**Pasted plate**	**Tubular**
Positive plate	Construction	Pure lead Lamellae	Lead antimony /calcium alloy grid	Lead antimony /calcium alloy spines	Lead calcium alloy grid	Lead calcium alloy spines
	Active material	PbO_2 grown from pure lead plate	PbO_2	PbO_2	PbO_2	PbO_2
Negative plate	Construction	Lead antimony alloy grid	Lead antimony alloy grid	Lead antimony alloy grid	Lead calcium alloy grid	Lead calcium alloy grid
	Active material	Spongy lead	Spongy lead	Spongy lead	Spongy lead	Spongy lead
Electrolyte	Chemical	Sulphuric acid solution in pure water			Sulphuric acid solution in pure water	
	Containment	Free liquid			Immobilised liquid, using:	
					Absorbent glass mat (AGM)	Silica based gel (Gel)
	Venting	Free to air			Low pressure valve regulated (VR)	

Table 1. Simple classification of lead acid batteries by type

> *Sealed lead acid (SLA or VRLA)* group batteries, also known as maintenance free batteries, are sealed with a pressure release valve, which limits the escape of gas to above the release pressure. Hence the term "Valve Regulated Lead Acid", or VRLA for short. The electrolyte is immobilised to prevent spillage and facilitate gas recombination within the battery. These batteries are usually more compact in size than vented lead acid batteries and typically used in areas where ventilation is insufficient to accommodate vented batteries. They cannot be topped up and are more susceptible to failure due to high temperature than vented lead acid batteries.

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3. Application features of various battery types

3.1 Common features

The following features apply to all lead acid batteries, irrespective of their type.

a. The ampere hour capacity in a battery depends on its discharge rate. The higher the current, the less the capacity and vice versa. The reason for this is that the chemical reaction during discharge limits the rate at which power can be drawn from the battery. This is illustrated by the graph in figure 2 which gives capacity realised from a vented Tubular battery versus discharge current. This shows that the 100 hour discharge current gives 100% of capacity but the 1 hour discharge current only 60% of capacity.

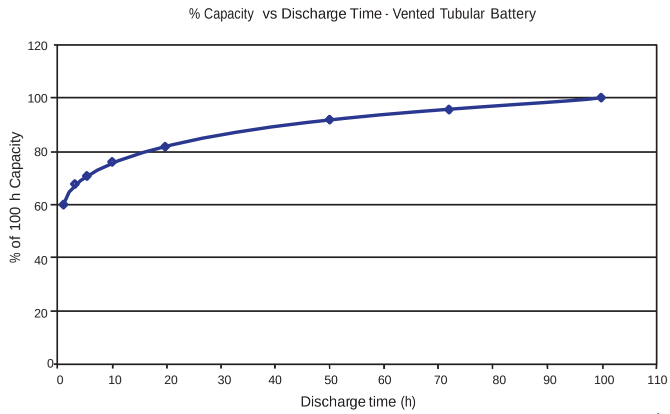

Figure 2. % Capacity (Ah) vs. discharge current of a typical solar battery

b. Battery life depends on temperature. The rate at which the chemical reactions, such as corrosion, takes place within the battery is expressed in the formula:

$$k = C^{-\frac{E_A}{R \cdot T}}$$

Where C is a constant, E_A the activation energy and R the molar gas constant (8.3143 J/mole K). This means that the rate roughly doubles for every 10^{O} Celsius increase in temperature; and in practice that the life of the battery life is halved as a result, as shown in Figure 3.

Furthermore, elevated temperatures in excess of 55^{O} Celsius are harmful to the separator and tube material, causing brittleness and loss of porosity. This leads to premature battery failure.

c. The efficiency of charge and rate of charge acceptance drop off as the battery approaches top of charge. Near top of charge the charger voltage rises to a level where the battery starts gassing. This reduces the charge acceptance and the difference between charge energy and accepted energy is expressed in heat and gassing. To fully charge a vented battery within a time limit will therefore result in some loss of electrolyte from gassing, and will over time require topping up. With a sealed battery the charger

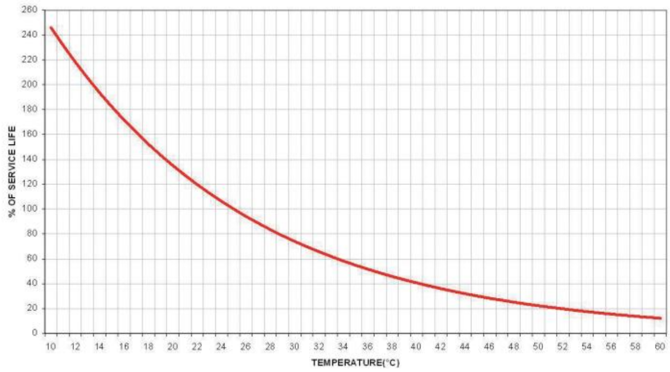

Figure 3. Typical life vs Temperature - Vented Tubular Batteries

voltage is limited to just below the gassing voltage to prevent dry out. As a result, the time to fully recharge can be substantially longer than with a vented battery. This is relevant in applications where the battery is discharged regularly, such as in solar installations.

d. Old lead acid batteries are recycled. The lead and plastic from spent batteries are recycled for reuse in the manufacture of new batteries. Lead acid batteries are therefore environmentally safe from the point of view of industrial waste.

3.2 Type specific features

Key features of specific types of lead acid batteries are given in table 2 below.

Group	**Vented lead acid** (VLA)			**Sealed lead acid** (SLA or VRLA)		
Type	**Planté**	**Pasted plate**	**Tubular**	**Pasted plate**		**Tubular**
				AGM	**Gel**	
Automotive	N/A	**Excellent**	N/A	Good	Good	N/A
Standby power	**Excellent**	Good	Fair	Good	Good	Good
Solar power	Poor	Fair	**Excellent**	Fair	Fair	Good
Traction duty	Poor	Fair	**Excellent**	Fair	Fair	Good
Cost	High	Moderate	Moderate	Moderate	High	High
Float life	>20yrs	15yrs	10yrs	5 to 10yrs	10yrs	10 to 15yrs
Cycle life	300	600 to 800	>1250	500	500	>1250

Table 2. Application features of different lead acid battery types

3.3 Vented lead acid group

a. Higher temperature-withstand capability. The free electrolyte facilitates convection cooling within the battery which helps reduce temperature. This advantage is most evident in designs where the amount of electrolyte is deliberately increased, and the specific gravity of the cells thus reduced, commonly called “tropical S.G.”

b. VLA batteries can be topped up. The most common mode of failure of VRLA batteries is drying out. Because VLA batteries can be topped up, this condition is prevented from developing.

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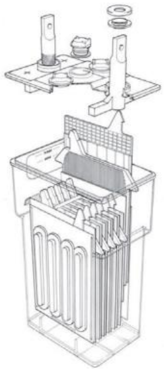
3.3.1 Planté

This battery is named after Gaston Planté, the Eighteen century French scientist who first developed it. The positive grid comprises pure lead with fine lamellae, giving a surface area over 12 times the apparent area. The active material is grown from the surface lead, and is replenished over the life of the battery. As a result, this battery maintains its original capacity for the duration of its life.

This large surface area and the ability to regenerate its own active material makes it ideal for high reliability, long life and high discharge currents. It is therefore used in mission critical applications where the cost of failure is very high, such as large power stations, switch tripping in critical switch gear and large standby power applications. Its cycling capability is however limited, as shown in figure 4.This battery is also expensive. Considering its high float life however, it often proves the cheapest in terms of ownership cost.



Exploded view

Cast positive plate

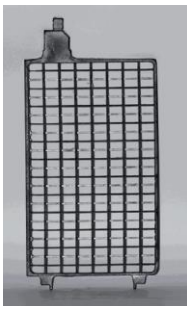
Formed positive plate

Figure 4. Planté battery

3.3.2 Flat plate

This battery is less expensive than Planté but has a shorter float life. Some designs also offer higher cycling capability, which makes it a good compromise between pure standby duty and high cycling. The positive plate is a lead alloy grid into which lead oxide is pressed, which is a less expensive manufacturing process. The positive plate is also thinner than that of Planté, which reduces life. During operation, there is a gradual drop off in capacity and end of life is when capacity drops below 80% of nominal.

Exploded view



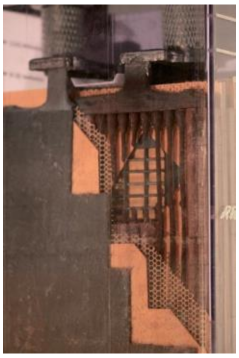
Cast grid

Pasted plate

Figure 5. Flat plate battery

3.3.3 Tubular

The positive plate consists of lead alloy spines surrounded by synthetic fibre tubes filled with active material. This makes them ideal for any application requiring frequent charge/discharge cycles, such as solar systems and traction duty. In certain standby applications where the grid is unstable and frequent discharges occur, the tubular battery is preferred over flat plate or Planté. Like the flat plate, the capacity of this battery also drops off over time, and the same 80% measure of end of life applies.



Cutaway

Cast positive spine

Complete positive plate

Figure 6. Tubular battery

3.4 Valve regulated lead acid (VRLA)

Sealed lead acid batteries have the following key characteristics:

- ***Very low gas emission.*** VRLA batteries have positive plates of a lead calcium alloy which elevates the voltage level at which gassing starts. This combined with voltage limited chargers reduces the gassing rate to less than 5% that of VLA batteries. As a result, these batteries do not require special vented rooms and are often placed alongside UPS and electronic cabinets in offices and the like.
- ***Not orientation bound.*** Because the electrolyte in these batteries is immobilised and they do not have removable caps, they can be stacked in racks on their sides to minimise space. This is useful in areas where space is at a premium.
- ***No topping up required.*** As explained above, low gas emission results in low water loss, and hence these batteries do not require topping up over life.

Flat plate AGM

Flat Plate Gel

Tubular Gel

Figure 7. VRLA Group

3.4.1 Flat plate absorbent glass mat (AGM)

These batteries have the same basic construction as the VLA flat plate, but use different lead alloys, separators and containers. The separators comprise a highly absorbent glass mat that immobilises the electrolyte and facilitates gas recombination. It has a relatively high rate discharge capability, limited cycle life and is the cheapest of the VRLA range to manufacture. It is therefore the most commonly used VRLA battery type. As with its VLA counterpart, this battery also has good discharge (standby power) performance, but limited cycle life. Its capacity likewise drops off over time.

3.4.2 Flat plate gel (Gel)

These batteries are the same as the AGM type but with the electrolyte immobilised in a silica based gel. This helps to improve the temperature withstand capability of the battery, and is therefore considered to be more robust. Gel batteries are generally more expensive than AGM, because of the manufacturing process involved. This flat plate type also has good discharge (standby power) performance, but limited cycle life. Its capacity likewise drops off over time.

3.4.3 Tubular gel (Gel)

The basic construction of this type is the same as the VLA tubular type, but uses different lead alloys and separators. The electrolyte is immobilised in a silica based gel, which offers the same higher temperature withstand capability as the flat plate gel. This battery offers the high cycle life of its VLA counterpart, good discharge performance and the same capacity drop off over time.

4. Considerations in the choice of the correct battery for different applications.

It is important that a full understanding of the required duty be gained and specified before deciding on the appropriate battery type. This includes the following:

a. How frequently is the battery to be discharged and recharged?

Is the battery to be used for back up power in the event of loss of power from the grid, or is it to be cycled daily as in a fork truck or a solar system?

b. If the battery is to be used for standby power:

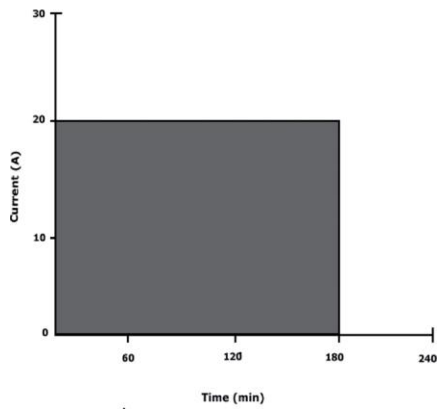
1. What is the probability of power failure? This defines the expected number of ***discharges/cycles*** that the battery is required to perform over its life.
2. What is the likely duration of the discharge? In some instances a user only wants sufficient time to shut down its system safely, or start a generator set, whilst in others the battery is required to deliver power until the grid comes back on line. This determines the required ***capacity*** of the battery.
3. How critical is it that the load remains operational, i.e. what costs or other risks are involved should the load fail due to a loss of power? This determines the ***level of reliability*** required from the battery.
4. Where is the battery to be installed? This will assist in determining whether a ***vented or sealed*** battery is required.
5. What ***regulations*** have to be complied with? These would typically cover building, health and safety requirements;
6. What is an acceptable life expectancy for the battery? Often the load may have a finite planned life expectancy that is known and can help to decide the ***allowable cost*** of the battery system.

c. If the battery is to be used for cycling duty

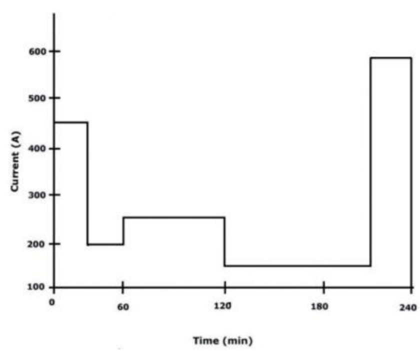
1. What is the ***amount of energy*** that the battery is expected to deliver during a single discharge period? In solar duty, the expected daily load and the period that the battery is required to power the load. In fork truck duty, the energy required by the fork truck to perform its duty during the shift.
2. The actual ***discharge current*** at which the battery must perform. Since the higher the current, the lower the available battery capacity, it is important to define the capacity in terms of the value of the discharge current and the applicable time. Since these batteries lose some capacity over life, the actual sizing of the battery should include a 25% margin for capacity drop off, i.e. no more than 80% of nominal capacity should be used during operation.
3. What is the ***available space*** in which the battery must fit? Most fork trucks are space constrained and it is advised to make the maximum use of the allocated space for the battery to ensure the battery can perform for the duration of the shift. This is less of a problem in most solar applications.
4. What ***regulations*** have to be complied with? These would typically cover building, health and safety requirements and will assist in determining whether a sealed or vented battery is required.

From the above questions the battery capacity and type can be selected.

Figure 8. Typical discharge curves for standby duty



a. Fixed discharge rate



b. Variable discharge rate

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Warehousing

Solar

Figure 9. Typical applications for cycling duty

5. Factors influencing battery life

An industrial battery is a large investment and it is in the user's interest that maximum life is realised from this investment. The following factors have a major impact on actual life realised in operation:

Temperature. From Fig 3 above, battery life approximately halves for every 10^{O} Celsius increase in electrolyte temperature. Above 55^{O} Celsius, the separators and tubes are irreparably damaged.
It is therefore important to keep the battery temperature at room temperature wherever possible.

Overcharging. As described above, charge acceptance drops and losses increase at the end of charge. Extended charging beyond this stage will increase battery temperature and reduce battery life considerably. Excessive charging can lead to excessive gassing and destruction of a battery.

Impure topping up water. Water containing salts, chlorides, metals and other impurities will react with the plates and can render them useless within days. Using only approved water for topping up is therefore essential. A typical specification for topping up water is:

- It shall be clear, colourless and odourless.
- The pH shall be between 5 and 7.
- The impurities shall not exceed the limits in the table below.
- It shall, whenever possible, be stored in a glass or plastic container.
- Conductivity shall be less than 30 µS/cm

Impurities	Milligrams per litre
Dissolved solids	25
Arsenic (As)	1
Chloride (Cl)	5
Copper (Cu)	0.1
Iron (Fe)	0.2
Manganese (Mn)	0.1
Nitrogen (as NH_4)	5
Nitrogen (as NO_3)	5
Heavy metals (as Pb)	5
$KMnO_4$ reducing substances*	10

* as determined by FNB test method LTM - 01 (25.09.2003)

Over discharging. Discharging a battery regularly beyond 80% of its capacity without regular equalising charges may result in reversal of some of the cells and this can seldom be corrected.

Excessive cycling. Every time a battery is cycled; discharged and recharged; a chemical conversion and volume change takes place on the positive plate. This ultimately leads to shedding of active material, resulting in a loss of capacity and reduced battery life.

6.0 Safety and environmental considerations

It is important when using lead acid batteries that the user is aware of the various risks involved. These include electrocution, poisoning and contamination. Users are advised to ensure they obtain the necessary documentation and advice from the manufacturer and that staff are fully trained in the safe practices relative to lead acid batteries. Manufacturers usually have Material Safety Data Sheets (MSDS) on all their products available to assist users in this regard.

The risk of electrocution by direct current is also not as commonly known as is the case with alternating current. Users should ensure that their operating staff are aware of, and properly trained in this area. Lead, like many other metals, poses an environmental hazard if not correctly disposed of. It is therefore important that all scrap batteries be returned to a reputable lead recycling facility.

Figure 10 shows the ISO 14001 certified lead recycle process used by First National Battery.

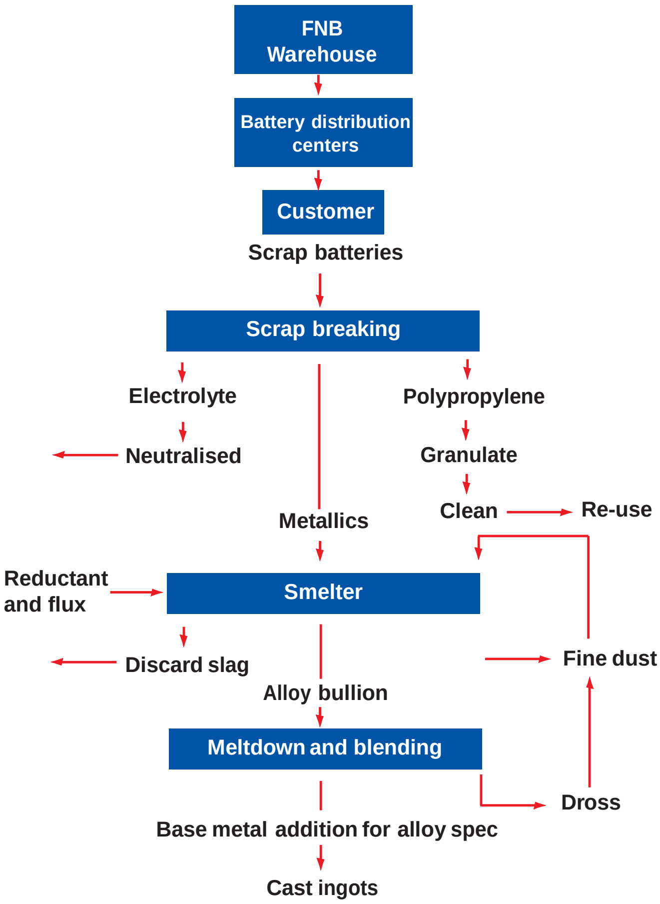

Figure 10. Typical lead recycling process