FUNCTIONAL REQUIREMENT OF LEAD ACID BATTERY SEPARATOR

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Abstract: *The separator is one of the most critical components of the lead/acid battery. The porosity and pore size distribution is important parameter in designing separator as it directly affects the performance and life of battery. Further, Resistance of the separators also affects battery performance. During discharging and charging process, separator gets de-saturated and saturated cyclically which changes its resistance consequently. In certain duties, such as cycling applications where faster charging is required, the water loss may be greater and the separator will de-saturate preferentially. This increases the resistance and promotes the risk of the development of a runaway situation which can cause permanent battery failure. This paper reviews functional requirement including mechanical and structural requirement of lead acid battery separator and deals with the parameters which measures the battery performance like electrical resistance, reserve capacity, cold cranking amperes etc.*

Keywords: *Separator, porosity, pore size, pore size distribution, acid retention.*

1. Introduction

The lead/acid battery is one of the most successful electrochemical systems ever developed. Although it was first demonstrated by Plante and many other storage battery systems have been developed since, the lead/acid battery is still the most widely used storage battery [1]. Although many years have passed since the invention of the lead/acid battery, it still represents the most important secondary chemical power source and still continuous efforts are made to improve the battery design and technology from production and application aspect. As a whole battery have a number of components and each have a specific role but in that separator is one of the most critical component. Traditionally, a wide variety of separator materials have been used e.g., wood, cellulose, resin-impregnated polyester fibre, sintered PVC, micro porous PVC, micro porous rubber, micro porous polyethylene, glass etc [2]. Currently micro porous polyethylene and glass based separators are widely used due to its micro porous structure, low electrical resistance and chemical purity.

The material and design of separator directly affects the battery performance. The primary function of the separator is to prevent electrical contact between plates of opposite polarity but at the same time it must allow the free movement of the sulfate ion through the electrolyte space to maintain continuous flow of electric current [3, 4]. A variety of separators have been used in batteries over the years. Starting with cellulosic papers and cellophane to nonwoven fabrics, foams, ion exchange membranes, and micro porous flat sheet membranes made from polymeric materials. Understanding of chemical reaction occurring inside battery during charging and discharging process is necessary in designing an appropriate separator which can function properly for long period of time. The basic chemical reactions which normally occur during charging and discharging of battery are:

At Negative Electrode: $$Pb + H_2SO_4 \underset{\text{Charging}}{\overset{\text{Discharging}}{\longleftrightarrow}} PbSO_4 + 2H^+ + 2e^- \quad (1)$$

At Positive Electrode: $$PbO_2 + H_2SO_4 + 2H^+ + 2e^- \underset{\text{Charging}}{\overset{\text{Discharging}}{\longleftrightarrow}} PbSO_4 + 2H_2O \quad (2)$$

Overall reaction: $$Pb + PbO_2 + 2H_2S0_4 \underset{\text{Charging}}{\overset{\text{Discharging}}{\longleftrightarrow}} 2PbS0_4 + 2H_2O \quad (3)$$

When the cell is charged, and the majority of $PbS0_4$ has been converted to Pb and PbO_2, the overcharge reactions begin. For flooded cells, these reaction produce hydrogen and oxygen gas, with subsequent loss of water. Scenario of modern separator design requires reducing this subsequent loss of water [5]. Now AGM (Absorptive-glass microfiber mat) based separator has been introduced in market which minimizes water loss through internal oxygen cycle and opened new application areas for lead-acid batteries.

2. Function of separator

The separator is one of the most critical components of the lead/acid battery. It has two basic roles. First, preventing the occurrence of short-circuits between electrodes of different polarity with facilitating free movement to sulfate ions through the electrolyte space and second, to serve as mechanical spacers between the electrodes and decrease the rate of shedding of active material.
Ideally, a separator should [5]:

- act as an insulatotor (50-70 mΩcm^{-2})
- possesses sufficient strength (0.875 to 1.75 kNm^{-1}) and elongation (0.5 to 10%) for processing
- sustain a high level of pressure at the positive plate
- conform to the surface of the plates at the required level of force
- provide a sufficient supply of electrolyte to the plates
- prevent acid stratification
- allow effective oxygen transport to the negative plate

3. Functional requirement of separator

There are many physical and thermal properties that can be used to characerize the separator. The key physical properties which provide information about the mechanical characteristics of separator are: composition , structure, resilience, tensile strength, elongation and porosity [5]. As the separator affects the battery performance, a number of properties must be considered during design of separator. Following are the details of some important thermomechanical properties which are required for a good separator:

3.1 Lower thickness

Having the thicker separator among the plates will impact the shock absorbing properties. In addition, having a thicker separator i.e. more acid, will slow the dry out aspects of the separator. If the separator thickness is doubled for a given amount of corrosion, the percentage change of the acid saturation of the separator is cut in half [6]. Further, thicker the separator, greater is the mechanical strength and lower the probability of punctures during cell assembly while thinner the separator lesser the internal resistance of battery. Therefore optimum thickness is required.

3.2 Low electrical resistance

Ideally, the separators should have negligible resistance; this is not possible, but the lower the electrical resistance the greater is the power developed at the battery terminals. Many factors like type of separator material, its thickness, contact with plates, porosity, average pore size and acid holding capacity of seaparaor can affect the cell resistance. Further cell resistance also varies with the electrolyte density inside cell [3,7]. Table 1 shows resistance of different commercially available separator materials.

Table 1: Resistance of various separators (in 1.280 sp. gr. acid at 25°C) [8]

Separator type	Resistance (ohm/cm^2)
Absorbent glass-mat	0.05
Absorbent glass-mat (60% saturated)	0.11
Microporous polyethene	0.07
Sintered PVC	0.15-0.25
Microporous rubber	0.17
Cellulosic	0.16
Resin-impregnated paper	0.15-0.25
Microporous PVC	0.2-0.3

3.3 High porosity and small pore size

The sub micrometer pore dimensions are critical for preventing internal shorts between the anode and the cathode and the pore-size distribution can affect oxygen-recombination rates and acid retention. A larger pore structure within the separator cause wick faster but not as high while a finer pore structure will support a greater fluid height but will wick more slowly. Therefore the capability of separators to fullfill functions associated with oxygen transport and electrolyte supply can be evaluated from studies of parameters such as porosity, specific surface area, pore-size, poresize distribution and wicking/acid absorption. Further acid holding and its distribution depend on these properties. If the porosity of separator is insufficient then less acid will be absorbed by the separator**.** The oxygen diffusion in cells through separator is influenced by both the separator saturation level and the tortuosity of the material itself. Large average pore size facilitates acid stratification which produce non uniform acid concentration in the cell and lead to poor active-materials utilization in some regions and hence causes capacity loss. High degree of electrolyte saturation in plate can be achieved by maintaining smaller pore size genrally 1 to 15 µm but if mean pore size is too large (>30 µm) , then the risk of dendrite growth and short circuit increases. The micro porous polyethylene separator with an average pore size of less than 1 µm is almost unknown with the polyethylene separator, whereas it used to be fairly common with the polyvinylchloride type of separator [5-7].

3.4 Sufficient mechanical property

Separator must have sufficient mechanical strength in respect of tear, tensile and puncture resistance. As these properties are required for preventing the short circuit and internal discharge due to dendrite growth and damage of separator through mechanical handling [3]. Greater tensile strength allows for faster processing during battery assembly and thus lowers manufacturing cost. It is well known that plate group pressure plays an essential role in constraining the expansion of positive active materials and maintain effective contact beetween PbO_2 particles during deep-discharge cycling and thus extend the cycle life [9-11]. The maintainance of adequate plategroup pressure against positive plate relies upon the elastic and resilience property of separator. Wet plate group pressure recommended to be maintained at a level of 40 Kpa or greater [5].

3.5 Mechanical and dimensional stability

The separator should not shrink when exposed to electrolyte and it should lay flat and not curl at the edges when unrolled, as this can greatly complicate cell assembly. Mechanically or dimensionally unstable separator causes reduction in battery performance as it fails in maintaining proper contact with the plates of the battery resulting in improper utilization of active materials and increasing the internal resistance of the battery.

3.6 Thermal, chemical and oxidation resistance

The environment in which separator has to opertate without serious degradation is about 35% H_2SO_4 and in temperature range 70-120^{o}C depending upon the area of application. In case of cellulosic based separator α-cellulose is highly purified and more resistant to oxidation in presence of sulfuric acid than other less pure celluloses. The greater the crystallinity of cellulose, the lower is the rate of attack while attack is approximately proportional to the specific surface [3]. The separators should be stable in the battery for a long period of time. They should be inert to both strong reducing and strong oxidizing conditions and should not degrade or loose mechanical strength or produce impurities, which can interfere with the function of the battery. The separator must be able to withstand the strong oxidizing positive electrode and the corrosive nature of the electrolyte at temperature of at least 75 °C. Polyethylene separator has melting point around 140^{o}C and will not deteriorate mechanically at this point but major potential; problem is oxidative degradation. Additional benefit of polyethylene separator is low acid dispalcement and thin backweb compared with overall thickness. Traditionally, for heavy-duty applications, leaf type separators with attached glass mat have been used. More recently, with the growth in polyethylene separator usage for standard automotive applications, the battery manufacturers are now also taking advantage of the benefits of polyethylene for heavy-duty applications. In these cases, a polyethylene envelope separator with a glass retainer mat is recommended [2, 7].

4. Battery performance and its measurement

Battery performance at high rates depends initially on: (i) the wetted area that is developed within the active material, and (ii) how the voltage at the cell terminals is modified by the resistance losses in the electrolyte and the separation [12]. Resistance of the separators can affect high-rate performance; low resistance of today's separators has contributed to the success of the battery industry. Pore size and pore size distribution- the properties that is measured and that relates directly to the life of the battery is pore size. The distribution of pore diameters determines the ability of the separator to prevent internal shorting. The pore-size distribution can also affect oxygen-recombination rates and acid retention. In fact, battery performance depends upon the cell design, the materials of construction, a complex interplay between the multitudinous parameters involved in plate preparation, the chemical composition/structure of the active materials, and the duty/conditions of battery operation [13-15]. Society of automotive engineers (SAE) has established two ratings (Reserve capacity and cold cranking amperes) for the measurement of batteries performance.

4.1 Reserve capacity (RC)

It is the time required in minutes for a fully charged battery at 80ºF under a constant 25 Amp draw to reach a voltage of 10.5 volts. This rating helps in determining the battery's ability to sustain in a minimum vehicle electrical load in the event of a charging system failure. It is also useful to measure the battery's ability to power a vehicle that has small but long term loads and still having enough reserve to crank the engine.

4.2 Cold cranking amperes (CCA)

The primary duty of battery is to start the engine to crank or rotate the crankshaft while also maintaining sufficient voltage to activate the ignition system until the engine starts. It is difficult for a battery to deliver power when it is furthermore; cold requires more power to turn over. Therefore CCA is an important measurement of battery capacity. This rating measures the discharge lead (in Amps) that a battery can supply for 30 sec at 0ºF, while maintaining a voltage of 1.2 volts per cell or 7.2 volts per battery or higher.

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