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# Positive-plate gauntlets—the non-woven fabric solution

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## Abstract

The tubular positive plate has undergone a gradual change in design that has progressed from single tube assembly to the gauntlet concept. The latest step in gauntlet development is the introduction of non-woven fabrics. These latest fabrics offer many advantages to the tubular battery. The advantages are both of a technical as well as of an economic nature. On the technical side, these non-woven fabrics offer structures which are very porous and yet have relatively small pore sizes. This combination of characteristics results in excellent positive active-material retention and low electrical resistance. The surface finish and physical characteristics of the non-woven fabrics also have an impact on the different plate-manufacturing techniques. But the one of the greatest benefits of this type of positive-plate gauntlet is its contribution to an improvement of the electrical output of the cycling battery both in terms of higher capacity (due to the lower electrical resistance) and to longer cycle life (due to the finer pore structure). © 1998 Elsevier Science S.A. All rights reserved.

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## 1. Evolution of the positive tubular plate: from single tubes to gauntlets

The positive tubular plate is widely employed in lead/acid batteries for industrial applications. Most regions of the world use this technology successfully. The major reasons for the preference for tubular plates are:

- improved specific energy (W h $kg^{-1}$);
- improved energy density (W h $l^{-1}$);
- more positive active-material;
- more acid;
- higher active material/grid ratios.

The evolution of the lead/acid battery covers four periods [1,2], each typified by key technological improvements. A schematic overview of these four evolutionary stages is shown in Fig. 1.

The *first* and *second* periods cover nearly one century that saw the lead/acid battery proceed from infancy to maturity. By 1950, the tubular plate had evolved from the early empirically derived designs to the single-tube version that is still used by some manufacturers.

The *third* evolutionary period occurred between 1950 and 1980 and was dominated by the rapid automation on the battery factory floor. It was at the start of this period, in the early 1950s, that woven or braided tubes of C-glass fibres protected by perforated plastic armour made their appearance. Afterwards, the armour was replaced by impregnation with phenolic resins to stiffen the tubes.

Towards the mid 1960s, positive tubular plates started to be made of multi-tube panels composed of woven fabrics impregnated with, at first, phenolic resins and later with thermo-plastic acrylic resins. These panels were named ‘gauntlets’ and represented a significant improvement in both the economics and the performance of the positive tubular plate.

From 1980 to the present, the industry is living through a period of intense restructuring that is dominated by the drive for even lower production costs and increasing standardization. It was during this *fourth* period that the non-woven gauntlet was introduced. This innovation has permitted simultaneously a cost reduction and significant improvements to the electrical performance of the positive tubular plate.

The fourth period is being characterized by the rise of the valve-regulated lead/acid (VRLA) battery. Even though techniques of immobilizing the electrolyte and using the internal oxygen cycle as a means of reducing water consumption were generally well known before the present period, it has only been in the last 10 years that the

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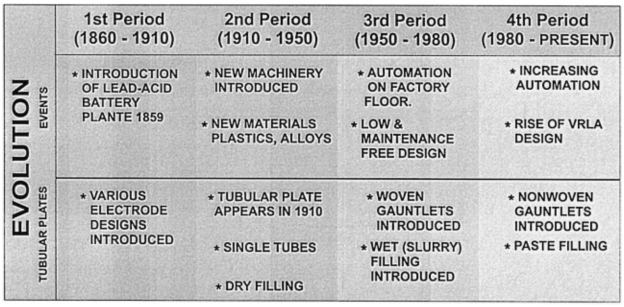

| EVOLUTION | 1st Period (1860 - 1910) | 2nd Period (1910 - 1950) | 3rd Period (1950 - 1980) | 4th Period (1980 - PRESENT) |
|---|---|---|---|---|
| EVENTS | * INTRODUCTION OF LEAD-ACID BATTERY PLANTE 1859 | * NEW MACHINERY INTRODUCED<br>* NEW MATERIALS PLASTICS, ALLOYS | * AUTOMATION ON FACTORY FLOOR.<br>* LOW & MAINTENANCE FREE DESIGN | * INCREASING AUTOMATION<br>* RISE OF VRLA DESIGN |
| TUBULAR PLATES | * VARIOUS ELECTRODE DESIGNS INTRODUCED | * TUBULAR PLATE APPEARS IN 1910<br>* SINGLE TUBES<br>* DRY FILLING | * WOVEN GAUNTLETS INTRODUCED<br>* WET (SLURRY) FILLING INTRODUCED | * NONWOVEN GAUNTLETS INTRODUCED<br>* PASTE FILLING |

Fig. 1. Evolution of the lead/acid battery and the positive tubular plate.

VRLA battery has taken center stage and started to dominate entire applications. Now, in the fourth period, the tubular gauntlet has evolved to include modern non-woven fabrics which can further reduce production costs and expand its performance in the latest battery designs, including valve-regulated technology.

## 2. Impact of gauntlet fabric and design: tubular-plate filling

The first step in manufacturing modern tubular plates starts with the casting of the spine grid, followed by the insertion of the individual tubes or the gauntlet. Then, the tubes are filled. There are two basic methods of tube filling, each characterized by the state of the active material used for filling. (i) *Dry filling*: powdered lead oxide compounds are vibrated into the tubes until the desired density is achieved. (ii) *Wet filling*: the lead oxides are added moist to the tubes. The wet active material can be a mixture of lead oxides and water only, this is referred to as ‘slurry’. The active material can also be a pre-mixed ‘paste’ containing lead oxides, and tribasic and tetrabasic lead sulfates in various ratios. Paste densities can vary depending on the process.

Each filling method has its relative advantages and disadvantages. In terms of evolution, the dry-filling method is the oldest and dates from the very first tubular-plate process. The change to wet filling occurred during the third period of battery evolution whereas the paste filling is a relatively late arrival that is enjoying good success. An extensive description of each method is beyond the scope of this paper, but good insights into the merits of each process have been published [3–5].

From the point of view of the gauntlet, wet filling requires that the gauntlet act as a filter; it must retain all the solid particles and allow the excess liquid to flow through. Since the finest particles in the filling slurry can measure only a few microns across, it is easy to understand why fine and uniform fabric structure is so important in this type of filling. In dry filling, the gauntlet fabric must allow the air that is being displaced by the incoming oxide powder to be quickly evacuated through its pore structure. Thus, in this filling method, a very closed and impervious fabric would slow down the process. Finally, paste filling seems to be a compromise of both methods. Here, paste with a given optimized consistency fills the tubes in a uniform manner. The fabric must allow for the evacuation of displaced air and retain all the active-material particles in the paste, even the smallest ones that measure barely a few microns across.

## 3. Impact of gauntlet fabric and design: electrical performance

The main beneficiary of the high porosity, fine pore structure of non-woven gauntlets is the electrical performance of cells assembled with positive tubular plates made with such gauntlets. The improved performance is due to the lower electrical resistance of non-woven, materials and to the greater retention of the finest crystals [4,6,7]. This greater ability to retain even the finest particulates is very important. On one hand, fine particles are entrapped during filling and, on the other hand, are prevented from leaving the positive tubular plate during the cycle life of the cell. The role of fine crystals in acting as binders to the positive active material, and hence giving higher performance and longer life, has been demonstrated in recent studies [6,7].

The impact of having better active-material retention in flooded traction cells is clearly seen from the test results shown in Fig. 2. In general, the results of these accelerated life-cycle tests indicate that more cycles are obtained with non-woven gauntlets. On weighing the shed active material that has accumulated at the bottom of the cells after the cycling test, it is found that the deposit is less with non-woven gauntlets cells than with woven counterparts. It is also important to note that slight increases of capacity are observed with cells containing non-woven gauntlets throughout most of the cycle life of the cells being tested. Thus, experimental evidence bears out the logical expectation that a more porous, finer pore structure offering less resistance to the passage of ionic flows leads to a longer cycle life, less active material loss, and higher capacities.

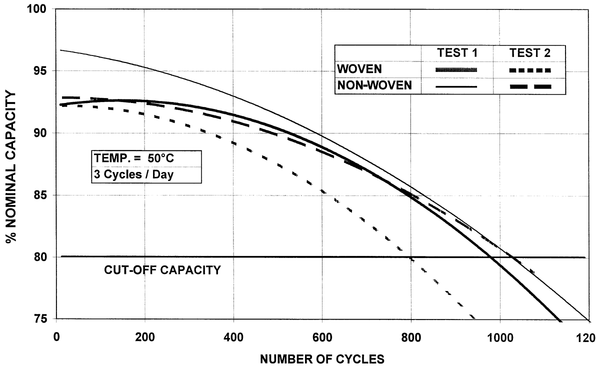

Fig. 2. Accelerated life cycle test results of traction cells.

Since more and more industrial batteries are being made with valve-regulated technology, the abovementioned characteristics of non-woven materials are very critical. There is a growing interest in making deep-discharge cycling VRLA batteries in which the electrolyte is immobilized in a gel. These batteries must have low electrical resistance and highly porous materials to be able to function properly. Non-woven gauntlets offer characteristics well suited for these gel designs.

## 4. Conclusions

Non-woven gauntlets are the latest evolutionary step in the development of the positive tubular plate. Due to the nature of non-woven fabrics, non-woven gauntlets offer an excellent combination of optimal active-material retention, low electrical resistance and good physical strength and resistance to the highly oxidizing environment of the positive plates in lead/acid batteries.

As a direct consequence of the characteristics of non-woven fabrics, the gauntlet can be employed successfully with each of the two main filling methods, i.e., the dry-and wet-filling techniques, the latter includes filling with low density slurry all the way to higher density, paste filling.

The fine pore size and low electrical resistance of non-woven gauntlets lead to superior electrical performance. Life-cycle tests of traction cells show longer cycle life and higher capacities with cells containing non-woven gauntlets, when compared with equivalent cells assembled with woven gauntlets.

The requirements of new VRLA battery designs impose the need for internal components which are very porous and have low electrical resistance. The non-woven gauntlet is the material of choice for positive tubular plates to be used in these modern battery types. Of special interest is the valve-regulated battery with gelled electrolyte that is designed for deep-cycling applications.

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