Tubular positive plate batteries for motive power and electric vehicle applications

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Abstract

In flooded lead/acid batteries for electric vans and buses, watering intervals can be extended substantially by reducing the overcharge factor to a minimal value of about 4%. In order to avoid rapid loss of discharge capacity, due to electrolyte stratification, use of reduced overcharge factor must be done in conjunction with electrolyte agitation; most readily achieved through the use of high-current/voltage pulses at the end of the recharge period. This can extend watering intervals to in excess of three months in some cases.

CMP Batteries is continuing its development of lead/acid batteries for electric vehicles (principally vans and buses) by combining its established technologies of flooded, close-pitched tubular motive-power batteries and the more recent techniques of reduced-maintenance charging.

Over the past decade, CMP's principal requirement in the development of its electric vehicle battery has been to improve energy density and cycle life. High power density has been achieved for tubular products by reducing tube diameter, plate thickness and pitch and the use of separators with low electrical resistance and minimum acid displacement.

Table 1 shows the transition to thinner positive plates with smaller tube and spine diameters and its effects on both energy density and cycle life, which are now well appreciated.

TABLE 1

Development of high energy density electric vehicle batteries

Battery designation	Standard performance	High performance	Advanced electric vehicle
Working electrolyte (sp. gr)	1.280	1.300	1.320
Plate pitch (mm)	18	13.5	11.4
Number of tubes	19	21	30
Tube diameter (mm)	8.0	6.1	4.9
Spine diameter (mm)	3.2	2.3	1.85
Energy density (W h/kg)	28	36	38
Cycle life	1500	1000	800

0378-7753/92/$5.00

This table appertains to large-voltage batteries. Performance improvements like these have been achievable due to the greater design freedom in that plate couple pitches do not, unlike materials handling products, have to be compatible with standard container sizes.

The other aspect of electric vehicle battery systems is the need to provide either sealed or flooded batteries. It is at this stage that vehicle programmes split into application niches. For domestic car applications, the use of batteries which do not require watering maintenance (i.e., sealed) justify reductions in energy density and cycle life. It is the view, however, that for the applications of buses and delivery vans, the demand for range (i.e., A h capacity) and cycle life dictates the use of flooded technology. Cycle life expectancies can be shown in Table 2 for both normal materials handling and electric vehicles. Note, again, the typical high-voltage battery systems for electric vehicles in payload carriers.

An overall comparison of the two technologies in the latter application can be seen in Table 3. Freedom from watering maintenance is the most apparent advantage for the sealed product. In some major applications (i.e., electric cars), this feature is very important.

As stated, CMP have chosen to focus on the flooded battery approach for vans and buses. Flooded batteries consume water and so require watering maintenance. With this in mind, CMP have been developing ways of reducing this. Where individual cell watering is employed, the large number of cells (in many cases up to 108) and often inaccessibility present a problem; water addition is difficult and time consuming.

TABLE 2

Comparison of cycle life expectancy of flooded and sealed lead/acid batteries

Application	Battery voltage (V)	Depth-of-discharge (%)	Cycle life	
			Flooded	Maintenance-free
Materials handling	24	50	1500+	1200
	24	80	1500	700
High-performance	216	50	800+	700
Electric vehicles	216	80	800	500

TABLE 3

Flooded and sealed traction batteries in electric vehicles

Flooded batteries	Maximum battery energy density and depth-of discharge Longer cycle life Lower cost High-voltage systems applications Shorter recharge times
Sealed valve-regulated batteries	No watering interval Reduced battery energy density and depth-of discharge Shorter cycle life Higher cost Longer recharge times

This is clearly evident in Fig. 1, which shows the underbody location of the battery in a G Van as manufactured by Conceptor Industries Inc., Canada.

To help lessen this task, single-point watering systems have been incorporated into electric vehicle batteries. Provision of a conveniently-placed watering point eliminates the access problem, making the operation easy, convenient and more precise. This is shown in Fig. 2. However, water maintenance is still required at relatively short intervals of one or two weeks, depending on duty cycle and the cell electrolyte head space. In some designs, head space has been reduced in order to give maximum volumetric energy density and, therefore, watering is frequent and becomes even more inconvenient.

A major objective is to extend watering intervals so as to be consistent with routine vehicle maintenance, making it appropriate to vehicle fleet contract maintenance. This is very important in providing a commercially-acceptable package.

Low-charge factor or extended maintenance charging techniques are being developed for the standard traction product. Electrolyte stratification is controlled when charging

Fig. 1. G Van.

Fig. 2. Battery design.

with low-charge factor by mixing the electrolyte either by air agitation or by application of high-current pulses of gassing charge, which are optimized for effective mixing. Using these techniques, capacity can be maintained with substantial reductions in charge factor. This extends the watering period and the improved charge efficiency reduces the operating cost. The mechanical handling market now appears to appreciate the benefits of economy and reduced charge time above the extended watering interval. Table 4 shows the general advantages and disadvantages of using low-charge factor charging.

CMP is developing low-charge factor charging techniques for electric vehicle applications, as well as for the standard motive-power products. The following short review of our current programme in this area can be given.

Let us take first conventional charging, the regime of which is profiled in Fig. 3. During discharge, open circuit and the early part of charge, electrolysis of water is slow. Towards the end-of-charge cell voltage increases with the falling efficiency of

TABLE 4

Low-charge factor charging

+	−
Shorter recharge times	Potential for capacity 'walkdown' Higher system cost in air pump or charger power
Reduced energy usage cost	Available capacity reduced for low-temperature application
Lower working temperature — an advantage for arduous service	Precise charger termination is critical Risk of earlier antimony accumulation in negative plates
Extended watering interval and reduced maintenance cost	Risk of system failure due to active material blockage if air agitation systems used in conjunction

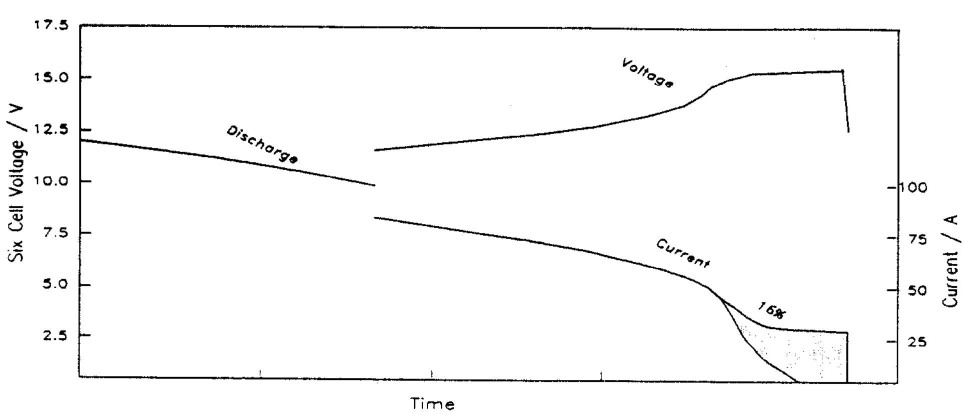

Fig. 3. Conventional charging.

the charge reactions, and the gassing reaction rates increase until (at the end of charge) they predominate.

Towards the end of conventional charging, following an 80% discharge, typical overcharge equivalent to 16% of discharge capacity would be associated with gas evolution, water consumption and heating.

If the heating aspect is considered, then because the charging current is driving electrochemical reactions, heating is equivalent to the difference between the charging electrical energy and the chemical energy. For each of the reactions heating is equal to the product of reaction current and reaction overvoltage. Each reaction should be treated separately but in general terms the equilibrium voltage for the charge reactions is about 2 V and that for the electrolysis reactions about 1.1 V.

Since most of the charging reactions takes place at voltages below 2.4 V and most gassing reactions occur with voltage increasing from 2.4 to 2.8 V, heating associated with gas evolution is 1.5 multiplied by the current, compared with 0.2 multiplied by the current for the charging process.

A substantial proportion of the electrical heating during recharge is a consequence of the gassing overcharge.

In the case of maintenance-free, valve-regulated batteries, oxygen recombines at the negative plate and hydrogen evolution are substantially suppressed. Since there is no (net) chemical product of the overcharge, heating due to overcharge increases to the full current/voltage product.

These products use a recharge characteristic which is constrained to avoid any risk of thermal runaway. This is shown in Figure 4. The voltage and current are limited so that there is only a modest heating effect during the bulk recharge into a discharged battery; charging is completed at a rate which is consistent with recombination capacity and battery heating.

The density of pure sulfuric acid is almost double than that of water and so the local concentration of the electrolyte is strongly influenced by gravity as cells are discharged and charged. Figure 5 illustrates the variation of electrolyte specific gravity, measured at the top of the cell, during discharge and charge.

During discharge, acid is consumed and water is produced within the plates. As the concentration falls, convective mixing occurs with the relatively dense electrolyte above the electrodes and so the measured specific gravity falls, following the discharge process.

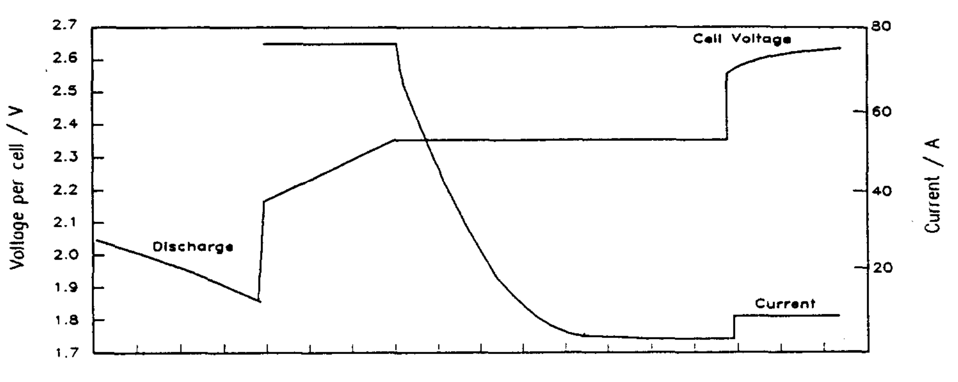

Fig. 4. Maintenance-free charging.

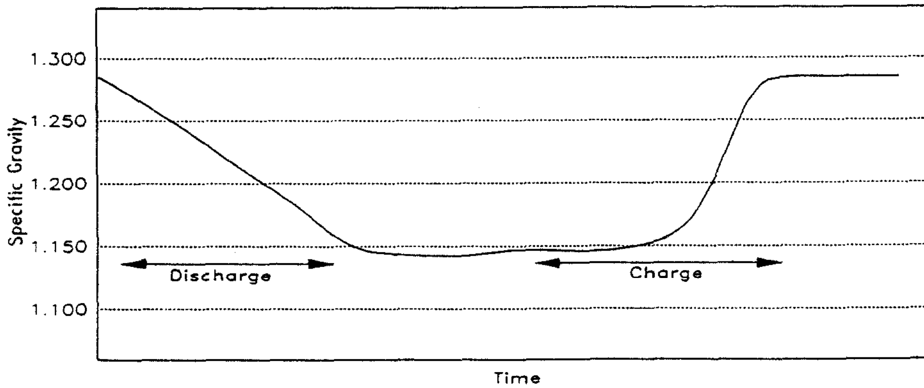

Fig. 5. Electrolyte stratification and mixing.

During recharge, water is consumed and acid is produced within the electrodes. Because the electrolyte above the electrodes has a lower density, there is no convective mixing and the measured specific gravity of the electrolyte does not increase as the bulk recharge progresses. Convection can, however, cause an increase in the concentration of electrolyte at the bottom of the cell.

Towards the end of charge, gassing mixes the electrolyte, resulting in a rapid increase in the measured specific gravity. The specific gravity continues to increase until charging is complete.

If the electrolyte of a conventional, flooded cell is not mixed, the electrolyte becomes stratified with concentrated acid at the bottom of the cell and weaker acid at the top. In these circumstances, there would be insufficient sulfuric acid to discharge the upper plate portions and the lower plate sections would suffer the effects of strong acid including reduced charge acceptance.

In valve-regulated, maintenance-free cells, the development of electrolyte stratification is substantially reduced by immobilizing the electrolyte as a gel or by absorption in glass microfibre (GMF) separators.

With conventional flooded cells and a low-charge factor, stratification is avoided by using air agitation of the electrolyte or by using a charge regime which controls the gassing charge to give efficient electrolyte mixing. For the latter, pulses of high current are more effective than continuous gassing at a lower current.

Refer again to Fig. 3, which shows voltage and current for discharge and conventional recharge with a charge factor of 1.16. The upper current curve reflects the actual charge current and the lower curve represents the charge accepted; overcharge, amounting to 16% of discharge capacity, is illustrated by the area between these curves. Figure 6 depicts a recharge with charge factor reduced to 1.04. The reduced overcharge is illustrated by the smaller area between the current curves. Cycle tests have been made with conventional cell designs having an increased maximum electrolyte level to maximise the watering interval. Equally important as watering intervals is the degree of capacity 'walkdown' with a reduced charge factor and the reduced working temperature. Cells were discharged to 80% of nominal capacity and recharged with the reduced charge factor.

Figure 7 shows how capacity was sustained using a charge factor of 1.04 in combination with agitation of the electrolyte. End-of-discharge voltage, for six cells, is plotted against cycle number in the top curve. The bottom curve shows the response

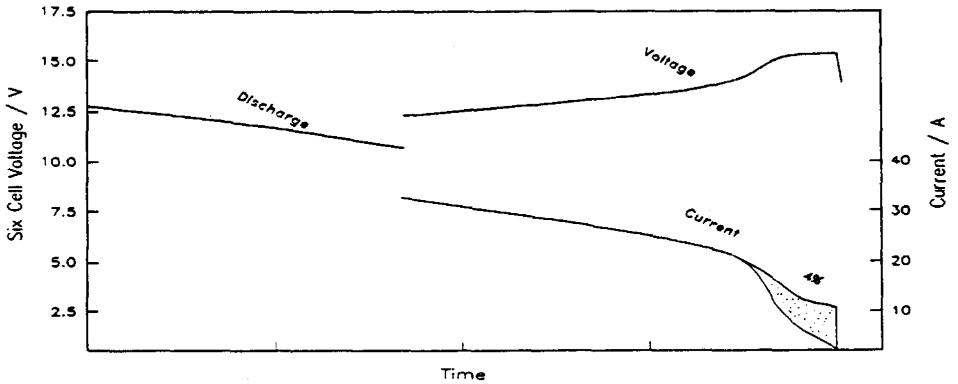

Fig. 6. Low-maintenance charging with air mixing.

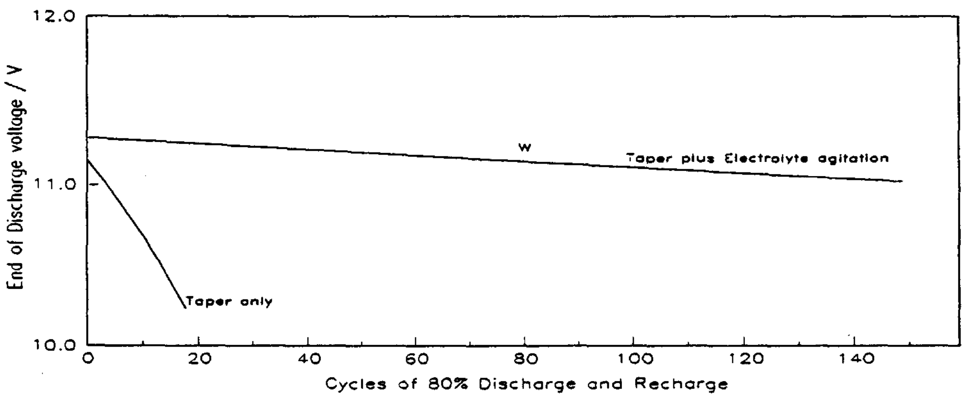

Fig. 7. Low-maintenance charging — charge factor = 1.04.

of similar cells to the same charge characteristic and charge factor, but without electrolyte mixing. Capacity had fallen to 80% of nominal in 18 cycles.

Whilst this result appears to be poor in comparison with the charging with electrolyte mixing, if we consider a decline in capacity at a rate of 1% per cycle in the context of the reduction in overcharge of 12% per cycle, compared with conventional charging, the charging efficiency is not poor. With a charge factor of 1.04, electrolyte mixing improves the rate of loss of available capacity from 1% per cycle to less than 0.1% per cycle. This very low rate of capacity loss may be corrected by extra charge at the watering interval, at shorter intervals or by slightly increasing the charge factor.

The pulse charge mixing characteristic used in these tests is illustrated in Fig. 8. They were applied at the end of charge and are included in the charge factor of 1.04. They constitute the final 2% of charge. With this regime there is no extra mixing during the bulk charge so there can be no influence on the efficiency of the charge reactions other than those related to long-term development of electrolyte stratification.

Useful increases in watering maintenance intervals are achieved together with improved energy efficiency. The test demonstrates that the important influence of electrolyte mixing is to control stratification of the electrolyte.

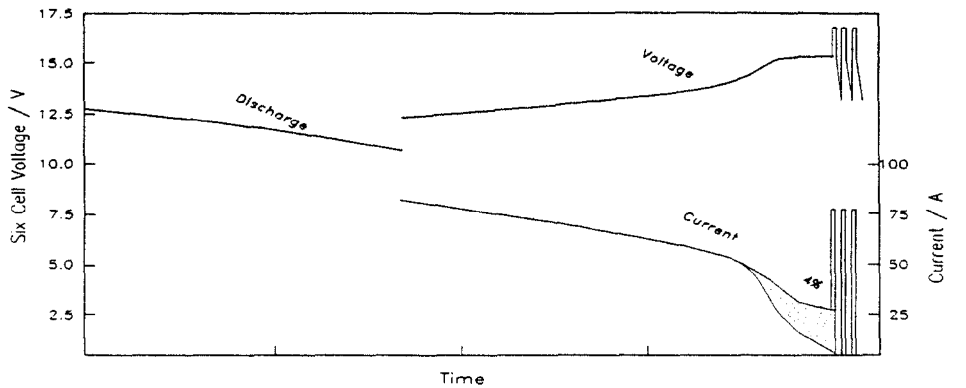

Fig. 8. Low-maintenance charging with pulse-charge mixing.

TABLE 5

Maintenance of conventional flooded cells in electric vehicles

1.	Individual cell watering	difficult access and time consuming
2.	Single-point watering	convenient, more precise
3.	Single-point watering with low-maintenance pulse technology	as 2, but extended watering interval up to three months
4.	Advanced low-maintenance systems, e.g., air agitation/improved pulse	as 2, but extended watering interval greater than three months
5.	Sealed maintenance-free system	no watering intervals

It has been shown that there are a number of different options with varying improvements open to us in the maintenance of conventional flooded cells in electric vehicles. Table 5 summarizes the full range from individual cell watering to sealed maintenance-free systems. With this low-charge factor charging development work continuing, we are in good position to offer a full electric vehicle battery and charger package that meets the following objectives of:

- maximum battery capacity (vehicle range) and optimised power density (vehicle drive system)
- maximum battery life
- minimum system cost
- extended watering intervals (ease of maintenance)
- reduced recharge time

In conclusion, this package can be seen as high energy density and long cycle life being achieved with lowest cost and commercially-acceptable battery maintenance using thin tubular plate flooded technology and low-maintenance charging systems. The major applications in electric vehicles for this package are the payload carrier and people shuttles/buses.