




An empirical investigation of lead-acid battery desulfation using a high-frequency pulse desulfator

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ABSTRACT

The major cause of deterioration in lead-acid batteries is sulfation. There are patents on the use of high-frequency pulse desulfators to desulfate lead-acid batteries. Also, many products available in the market worldwide claim to use this technique to effectively desulfate lead-acid batteries that deteriorate due to sulfation. But there are little or no systematic studies to evaluate the performance of these products to know whether they do what their manufacturers claim. This research, therefore, aims at empirically evaluating one of such products. Four fully charged 100 Ampere-hour Valve Regulated Lead-Acid Gel batteries were discharged with an electronic-load battery discharger to ascertain their capacities. Thereafter, a high-frequency pulse desulfator was connected to desulfate the battery bank consisting of the four batteries. The battery bank was connected to be charged at the same time by a photovoltaic system. The desulfation experiment lasted for ten weeks but the batteries were tested to know their capacities after two, six, and ten weeks. The results show that the desulfation device works in desulfating lead-acid batteries as there are different degrees of improvement on the capacity of all the batteries. The percentage improvement in the capacity of the batteries is 89.5%, 75.9%, 1.6% and 1.4%, for batteries 1, 2, 3 and 4, respectively.

1. Introduction

The lead-acid battery was invented in 1859 by a French Physicist, Gaston Plante [1]. It was commercialized in 1895 in Kyoto, Japan by Genzo Shimadzu [2] and has continued to remain popular despite the invention of better performing batteries like lithium-ion, nickel-cadmium, and nickel-metal hydride batteries in terms of energy capacity per kilogram weight, energy to volume ratio and depth of discharge tolerance. Its continued popularity is largely due to its cost-per-watt advantage

and the ability to supply large surge currents [3]. From the type first patented, called the traditional flat-plate batteries, it has undergone several developmental changes in a bid to improve on its capacity and durability.

The other developed types include low-maintenance flat-plate batteries, tubular-plate batteries and valve-regulated batteries. These lead-acid battery types and their accompanying improvements can be seen in [1],[4]–[10]. Despite the developmental changes in the design and structure of the battery, the system and chemical reactions

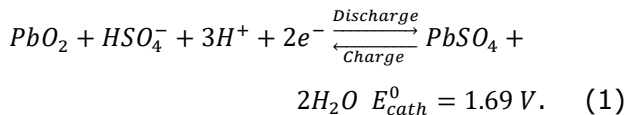
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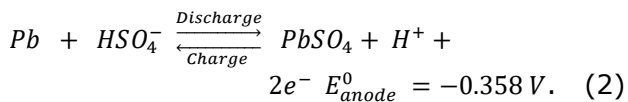
basically remain the same. The system comprises lead dioxide (PbO₂) positive electrodes, lead negative electrodes and sulfuric acid (H₂SO₄) electrolyte. It is a rechargeable (secondary) battery and the electrolyte comprises about 33-38% solution of sulfuric acid in water [11], [12].

The charge and discharge chemical reactions at the electrodes of the battery are as follows [4]:

At the positive electrode (PbO₂);

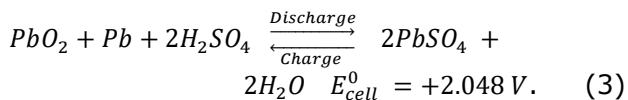


At the negative electrode (Pb);



Where, E_{cath}^0 and E_{anode}^0 are the standard electrode potential for the positive electrode (cathode) and negative electrode (anode) reactions, respectively.

The overall reaction is:



Where, E_{cell}^0 is the standard cell voltage.

From the charge and discharge equations, it is can be seen that during discharge, sulfuric acid (H₂SO₄) is consumed and water (H₂O) and lead sulfate (PbSO₄) are produced while during charge, the reverse is the case.

One of the problems that have remained with all the lead-acid battery types is sulfation [5], [10], [12] – [17]. Another problem is the inability to accept a fast charge. In the normal operation of lead-acid batteries, as portrayed in the reaction equations (1) and (2), lead sulfate (PbSO₄) is produced at both the positive and negative electrodes during discharge. The lead sulfate reacts during charge and the constituents return to where they belong, but not all the lead sulfate deposit on the negative plates is removed. The amount that dissolves-off the negative plates and returns to the cell as active material depends on how often the battery is fully recharged. If the battery is left uncharged or undercharged for some time, the lead sulfate recrystallizes from soft and soluble material to a hard and insoluble crystalline material. As the thickness of this hard, insoluble and resistive lead sulfate film on the negative plate increases, the plates are further insulated from the electrolyte, and the internal

resistance of the battery increases. This reduces the amount of current or charge the battery can accept and further deteriorates the battery's condition. Sulfation can cause premature failure of lead-acid batteries when they are not properly charged as and when due.

A school of thought believes that the main reason for the deterioration of lead-acid batteries while in use is the softening of the positive electrodes. It has been confirmed that sulfation plays a greater role in the failure of lead-acid batteries as about 70 % of "dead" batteries due to deterioration in use, recovered their performance to an almost similar state to that of new ones by the use of additives, which act on the negative electrodes [2], [18]. It has been reported [14], [19]–[28] that the addition of some form of carbon to the negative electrode helps to reduce the negative effects of sulfation and also boosts the charge acceptance rates of lead-acid batteries.

Apart from the use of additives that act on the negative electrodes to desulfate lead-acid batteries, it has been reported that the use of specially designed chargers can also help to desulfate batteries that deteriorate due to sulfation. Some of the charger operation techniques reported [3], [15] for this purpose include pulse width modulation, pressure feedback, and resonant frequency or high-frequency pulse desulfation techniques.

The high-frequency pulse desulfator operates by sending pulses at about 3.26 MHz frequency to the battery to make the lead sulfate crystal vibrate at the resonant frequency of sulfur crystal, which is 3.26 MHz and therefore impacts energy that will cause the sulfate molecules to dissolve back into the electrolyte [29]–[31]. The high-frequency pulse desulfators are of two types: the stand-alone charger and desulfator type; and the non-charger type that uses energy from the same battery to desulfate it and therefore needs to be supported with a charger.

There are many products in the market worldwide claiming to use the high-frequency pulse technique to effectively desulfate sulfated lead-acid batteries. But there is little or no comprehensive research to test and analyze the performance of these products to know whether they do what they are claimed to do by their manufacturers. This research is therefore aimed at testing and analyzing one of such products to ascertain whether it can revive sulfated lead-acid batteries. The high-frequency pulse desulfator to be tested here is the non-charger type because it is the one

that can be used for a photovoltaic (PV) system's battery bank as the charging here will come from the PV modules via the charge controller.

2. Materials and Methods

The battery-bank to be desulfated comprises four 12 V/100 Ah Valve Regulated Lead-Acid (VRLA) Gel batteries, B1 to B4 connected in series. This battery bank has deteriorated in capacity after being in use for 3 years as the 48 V/100 Ah battery bank of a standalone photovoltaic power plant. The battery-bank was charged for six weeks using a photovoltaic system consisting of 8 roof-top mounted PV modules with each module having a capacity to supply 8 A maximum current and 18 V open-circuit voltage. The PV modules were connected in a 4 (series) by 2 (parallel) arrays. The system also comprises an MPPT solar charge controller. The 8 PV modules array was used to supply 16 A current for proper charging of the batteries because the battery manufacturer recommended a bulk charging current of between 10 to 30 % of the battery capacity. The long charging period was to ensure that the batteries were fully charged and any lead sulfate deposits that charging could dissolve must have been dissolved.

A discharge test was carried out on each of the batteries to ascertain its capacity before the desulfation experiment. A standard electronic load battery discharger and analyzer, SkyRC BD200 interfaced with a computer, was used. The batteries were discharged at constant current C10-rate (10 A) and to a discharge-end voltage of 1.96 V/Cell. The discharge results comprising voltage, current, power and capacity against time plotted by the discharger software were saved.

The battery-bank was then connected back and a non-charger type High-frequency pulse desulfator (BR 12-72 600) sourced from an online store (aliexpress.com) was connected to desulfate the battery-bank. The PV system was also connected to charge the battery bank. The battery desulfation setup diagram is shown in Fig. 1. This particular desulfator was chosen because it was the most popular among the desulfators in terms of the number of orders made from the online store. The desulfation setup was allowed to run for two weeks after which a second discharge test was carried out on each of the batteries to ascertain the capacity after two weeks of desulfation. The discharge setup diagram is shown in Fig. 2.

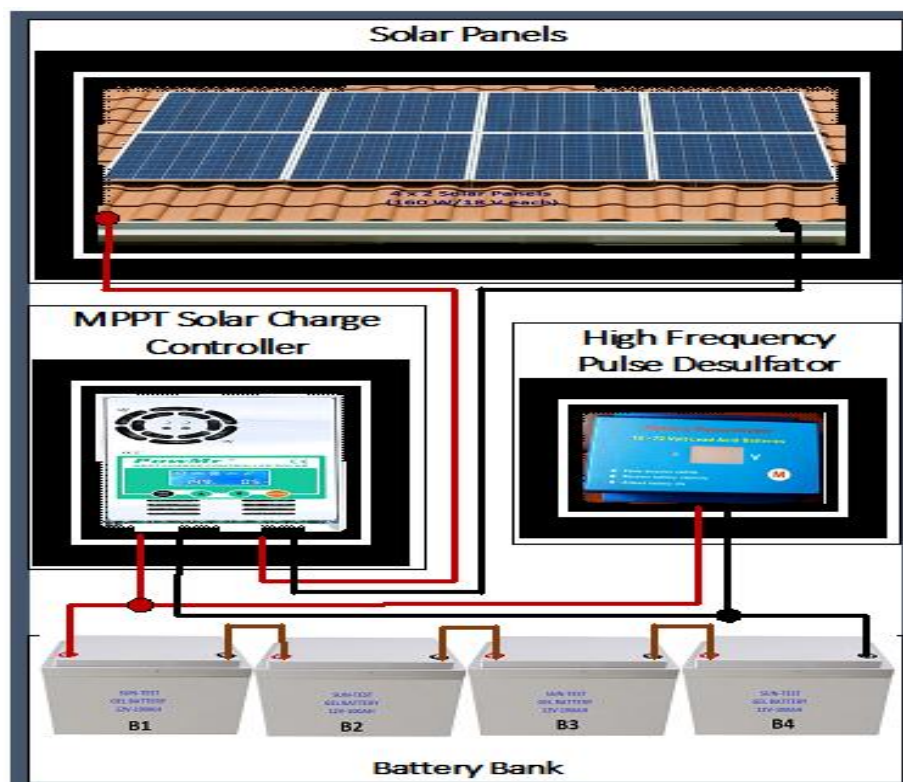


Fig. 1 Battery bank desulfation setup diagram.

The desulfation setup was reconnected and allowed to run again for four weeks after which a third discharge test was carried out. To further carry out the desulfation experiment, the desulfation process was repeated for another four weeks and the

fourth discharge test was done on the batteries. The discharge test results were saved. Fig. 3 shows the battery discharger software screenshot depicting the discharge settings and plots.

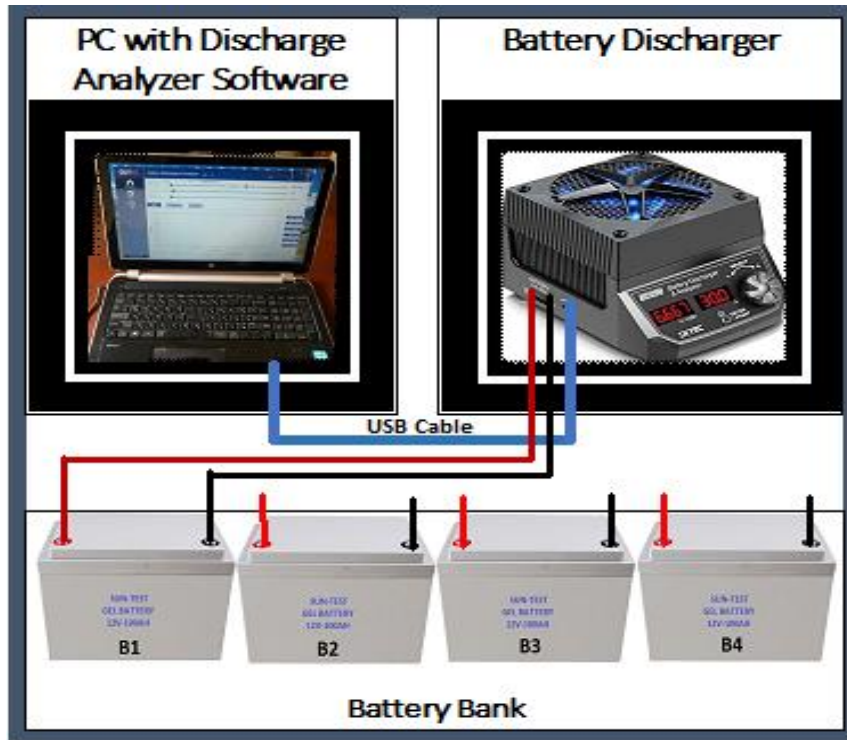


Fig. 2 Battery discharge setup diagram.



Fig. 3 Battery discharger software screenshot showing the discharge settings.

3. Results and Discussion

The battery discharge voltage was plotted against time for the four discharge tests on each of the four batteries in the battery bank. That is the first discharge tests before the desulfation experiment and the three

discharge tests after desulfating the battery-bank for two, six, and ten weeks. The plots are given in Figs. 4 to 7. The graphs showed that the desulfation process produced some changes in the batteries' capacity as the discharge curves from the same battery for tests 1 to 4 mostly followed different paths.

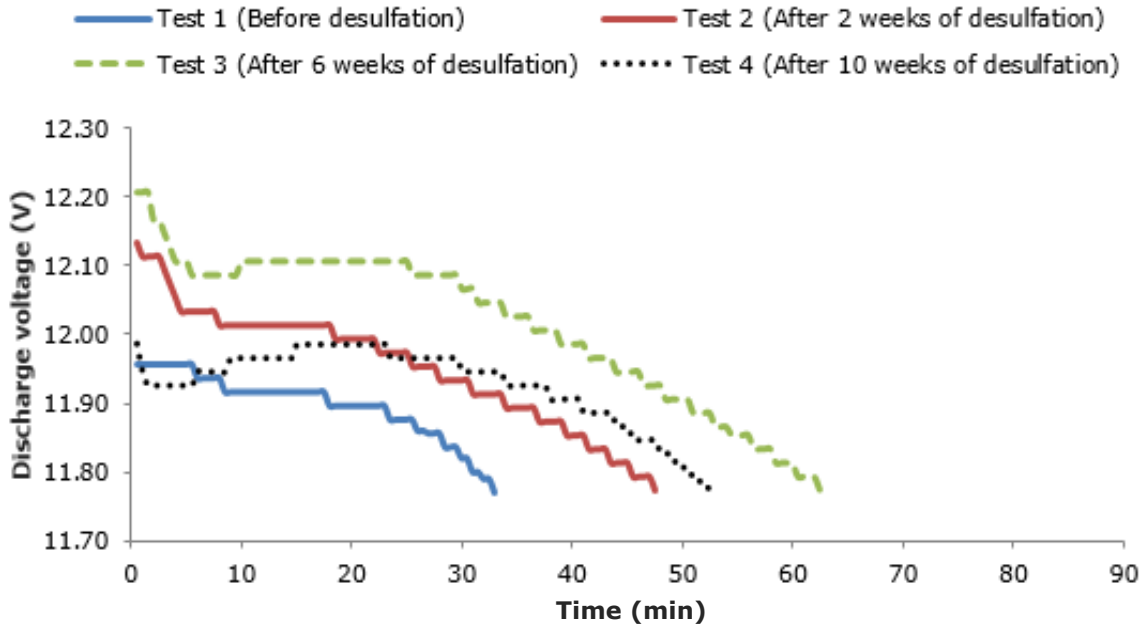


Fig. 4 Battery 1 discharge voltage against time for tests 1 to 4.

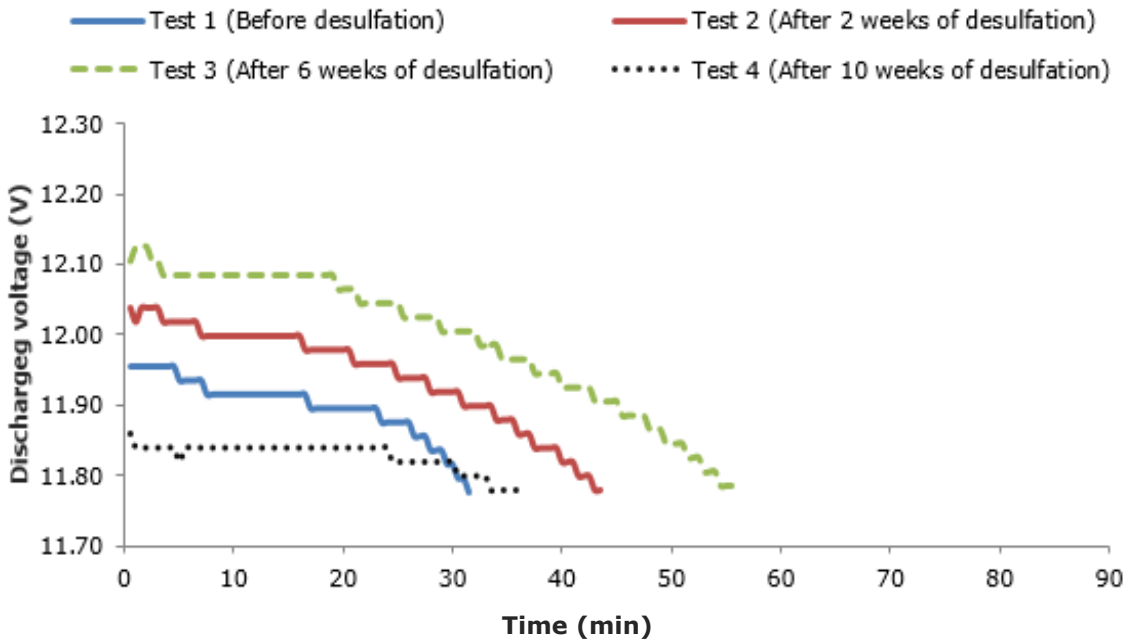


Fig. 5 Battery 2 discharge voltage against time for tests 1 to 4.

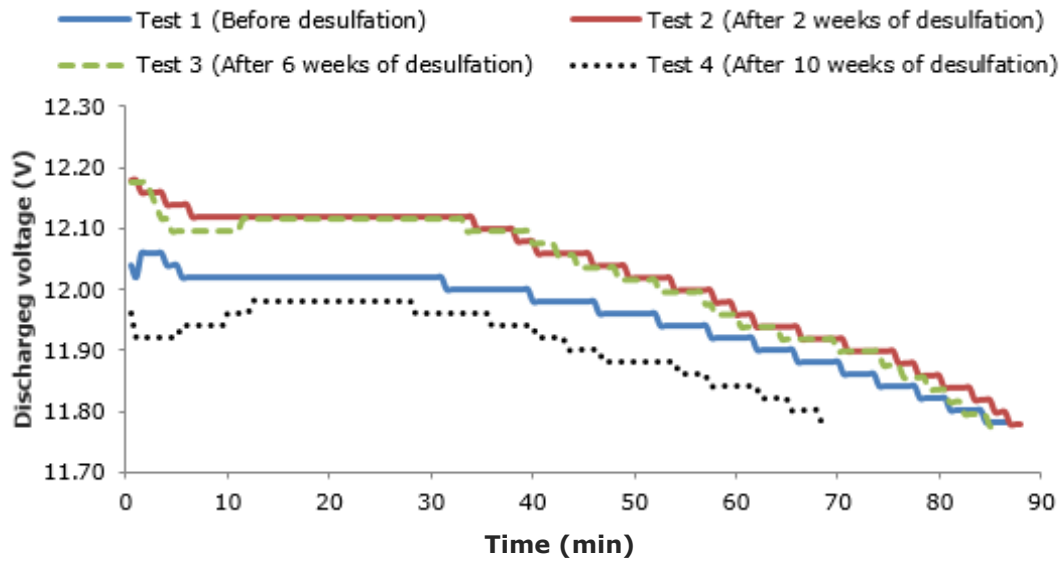


Fig. 6 Battery 3 discharge voltage against time for tests 1 to 4.

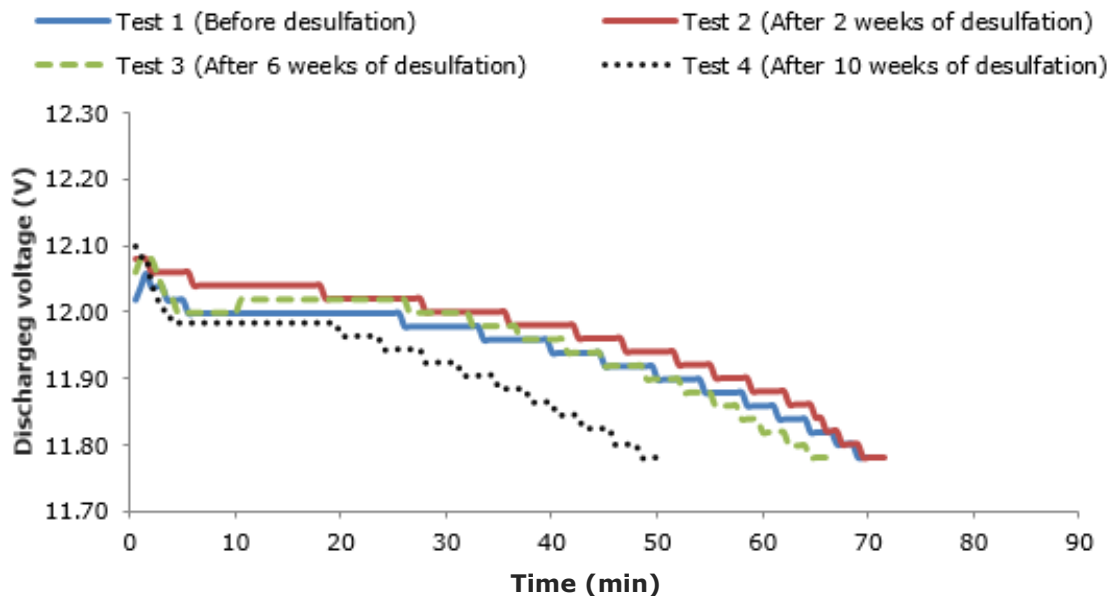


Fig. 7 Battery 4 discharge voltage against time for tests 1 to 4.

A chart showing the delivered capacity by each of the batteries before the desulfation and after the two, six, and ten weeks of desulfation was also prepared as shown in Fig. 8. This chart shows that there were different degrees of improvement in the capacity of the batteries after two weeks of desulfation. Batteries 1 and 2 that had lower capacities (and therefore more deterioration) than batteries 3 and 4, which showed higher improvements as their capacities increased by 44.4 % and 38.0 %, respectively. The capacity of batteries 3 and 4 increased by 1.6 % and 1.4 %, respectively when compared to their capacities measured before the desulfation

experiment. After six weeks of desulfation, the capacity of batteries 1 and 2 as against the initial capacity before the desulfation experiment further increased by 89.5 % and 75.9 % respectively, while batteries 3 and 4 decreased in capacity by 0.5 % and 6.4 %, respectively. But after ten weeks of desulfation, the capacity of the four batteries (B1 to B4) decreased from their highest attained levels. The capacity increment for batteries 1 and 2 after ten weeks of desulfation became 59.1 % and 14.1 %, respectively while those of batteries 3 and 4 reduced by 20.1% and 27.7%, respectively.

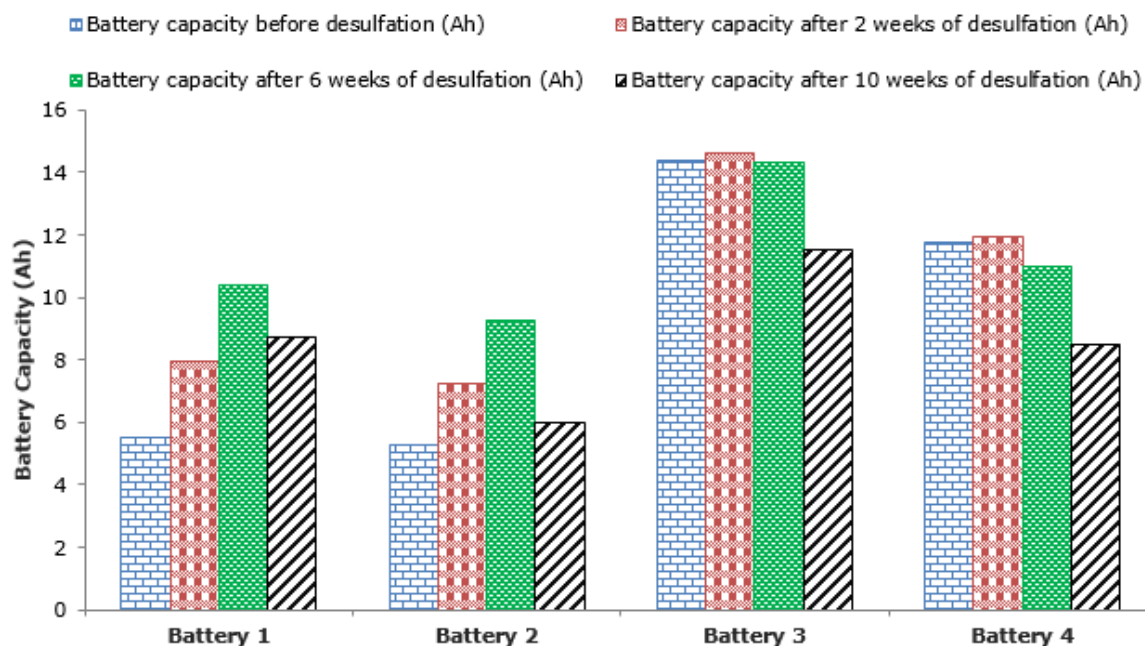


Fig. 8 Battery capacity before and after 2, 6, and 10 weeks of desulfation.

The results of this research, therefore, support the claims of the United States Patents US6184650 [29], US5677612 [30], and others that developed high-frequency pulse desulfators and projected them to be effective in desulfating and reviving lead-acid batteries that deteriorate as a result of sulfation.

The maximum increase in capacity for batteries 1 and 2 was attained after six weeks of desulfation and further desulfation for another four weeks brought about a decrease in capacity, while the maximum increase in capacity for batteries 3 and 4 happened after two weeks of desulfation and further desulfation caused a decrease in the capacity of the batteries. This could be as a result of the drying out of the batteries' electrolyte due to overcharging of the batteries after the desulfator might have completely dissolved the crystalline lead sulfate deposits. If this is the case, it means that desulfators that are also chargers and incorporate mechanisms to prevent the batteries from overcharging are better than those that are not chargers and have to work with separate chargers like the one used in this desulfation experiment, as claimed by Gelbman in his patent [29]. The deterioration could also be as a result of the 10 A discharge current or the depth of discharge being too high for the batteries due to age-induced weakness. Therefore, further works need to be done to find out exactly what caused the loss of capacity as the batteries were desulfated further.

4. Conclusion

The high-frequency pulse desulfator can actually desulfate lead-acid batteries that deteriorate as a result of sulfation. This is because all the four batteries in the battery bank desulfated using a high-frequency pulse desulfator showed different levels of improvement at different periods of desulfation. The increase in the capacity of the batteries includes: battery 1 – from 5.5 Ah to 10.42 Ah (89.5 %) after six weeks of desulfation; battery 2 – from 5.26 Ah to 9.25 Ah (75.9 %) after six weeks of desulfation; battery 3 – from 14.4 Ah to 14.63 Ah (1.6 %) after two weeks of desulfation; and battery 4 – from 11.75 Ah to 11.92 Ah (1.4 %) after two weeks of desulfation. The difference in the capacity change of the batteries is a result of their position in the battery bank as there is a trend of more improvement towards the positive terminal of the desulfator. That is, battery 1 was the most improved followed by batteries 2, 3 and 4, in that order.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

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