Charging the Lives of Farmers in Rural India

In the 21st century electricity is no longer just a want, but a need. The high prices of electricity have negatively impacted those who fall in the lower socio-economic strand of developing countries because this means they have less disposable income left for other important needs such as education, sanitation, and food. For example, Indian farmers use lead-acid batteries to power their households which can account for 32% of their monthly spending as cited by the Indian National Defence Report of 2017. To tackle this issue, experiments were done involving three solutions: Magnesium Sulphate, Sodium Sulphate and Ethylenediaminetetraacetic acid (EDTA). To measure the success of these solutions, the study accounted for three variables using a two-sample independent t-test: Voltage, Internal Resistance, and Cold Cranking Amps. After the experiments, the main solution which showed the most promising results in increasing the lifespan of the lead acid batteries was EDTA. This solution would be helpful in decreasing the long-term burden of these lead-acid batteries on the rural farmers in India.

1. Introduction

The Indian society is mainly divided between the rich and the poor and while there has been staggering economic development averaging a GDP growth of 6.12% since 1990[1], these gains haven't been reflected in the country's living standards as most of the money ends up in the pockets of the wealthy. Currently, India's top 1% take home 58% of the annual income.[2] This is why the poor in India have to live through rough financial conditions. In a survey by the India's National Sample Survey Organization, it is reported that 1.5% of the citizens live in houses made from grass, bamboo or thatch.[3] While this percentage seems small, in India it accounts for 18 million people. The impoverished don't have enough income to fulfill the basic need of providing a good shelter for their family.[3]

A majority of the population in the lowest socio-economic strand are farmers.[4] While being the backbone of the country's economy, they transpire with the smallest share of the national revenue. As recorded by the Indian Department of Agriculture and Welfare, a farmer in India makes 150 rupees, or USD 2.30, in a day.[5] This amount is above the world poverty line of USD 1.90 a day, but still not enough to fulfill all their family's needs. Out of all their expenses, a major portion is spent on electricity for things such as standing fans, light bulbs, and other home appliances. As stated in the Indian National Defense Resource report of 2017, farmers in India spend 32% of their income to provide electricity for their households, compared to the average 7.2% for Indians in urban areas.[6] This percentage of burden seems high because the amount of money these farmers earn is almost trivial compared to the price of electricity. Even when compared internationally, in countries such as the US, citizens spend about 17% of their income on electricity, which is still half the burden faced by the farmers.

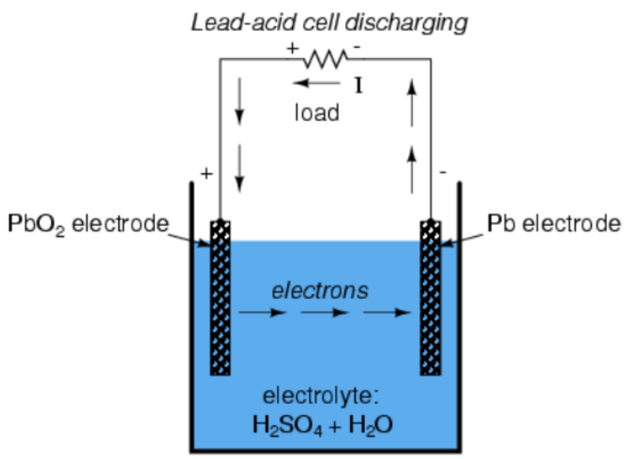
These high costs have impacted 240 million farmers in India as they have less disposable income left for sanitation and food.[4] Furthermore, large power companies find "supplying rural homes an unattractive business proposition because of thin usage and below-cost tariffs", according to Dinesh Arora, Chief Executive Officer at REC Power Distribution Co.[4] A paper by the World Bank about the consumption of electricity in India shows that in the rural parts of the country only about 37% of the population use any form of electricity to comply with their daily needs.[7] Additionally, while comparing the daily usage, we can see that the urban part of India can lead to revenues almost 7x the amount companies can make in rural parts.[4] Due to these low economic incentives, large companies stay away from the rural areas. Moreover, according to the Indian Centre for Policy Research, 90% of the rural households in India consume less than 100 kWh per month. Compared to that, an average urban household in India consumes more than 450 kWh per month. Rather than using the grid, the farmers can think of using renewable sources such as solar power to power their households. A popular alternative is solar energy. Solar is the key to the future of renewable energy as it outputs the most amount of power compared to wind and hydro energy. However, the issue is that solar energy needs an excessive upfront investment. As cited by the Energy Informative Organization, the initial cost can be as high as $20,000 and will take up to 7-9 years for reimbursement. This is high for the farmers considering their low daily income. Thus, these clean alternatives are not an option for them. They need a cheap and quick solution to lower their electricity burden.

Thus, the lead-acid battery packs are the only option the 195 million farmers have, but they are nowhere near an optimal solution. Lead-acid batteries still cost around 10,000 rupees or 150 USD[8]. Additionally, as cited by Mr. Singh in a Bloomberg article, batteries age faster in higher temperatures and thus leaving them outside in temperate is not the best option. [4] The usage by the farmers is also more exhaustive for the battery than being used in a car because in a car the battery is mostly only required for the startup and air conditioning, whereas home appliances require the battery for the whole cycle. This is why rather than lasting 4-5 years, these batteries last for only 9-10 months. Farmers are looking for a way to bring down the prices of these batteries, so they can have more income available to themselves. Moreover, in the last 30 years, prices of battery packs have stayed quite stable. The industry has reached a peak for profitability and thus manufactures aren't looking to make changes to the design. They have made the lead-acid battery as simple, cheap, and mobile as possible.

1.1 Background

A conventional lead acid battery has three main components: anode, cathode, and a chemical electrolyte solution. As shown in Figure 1, an anode can be interpreted as the negative component of the battery and the cathode can be seen as the positive one. For electricity to be created, there must be electrons flowing through the system as they provide the power. When a complete circuit is made, the connection starts at an anode, flows through the circuit, and goes to the cathode.[10] The energy inside the battery is stored in the form of chemical energy on the anodes as they are the ones that release the electrons.

In the case of the farmers in India, the preferred type of battery is the lead-acid batteries. A 'cell' in the battery outputs 2.3 v thus a car battery usually requires 6 cells to give the needed output of 13.8v. A cell has one plate made of the lead and one plate made of the lead dioxide. The cell is immersed in a sulphuric acid electrolyte to help with the electron flow. As shown in the equations above, the lead plate combines with the sulphate to create lead sulphate plus one electron. The



At (-) electrode: $Pb + HSO_4^- \rightarrow Pb(II)SO_4 + H^+ + 2e^-$ E° -0.356V

At (+) electrode: $Pb(IV)O_2 + 3H^+ + HSO_4^- + 2e^- \rightarrow Pb(II)SO_4 + 2H_2O$ E° 1.685V

Overall cell: $PbO_2 + Pb + 2H_2SO_4 \rightarrow 2PbSO_4 + 2H_2O$

Figure 1: Exhibiting the reactions and the flow of electrons in a lead-acid battery

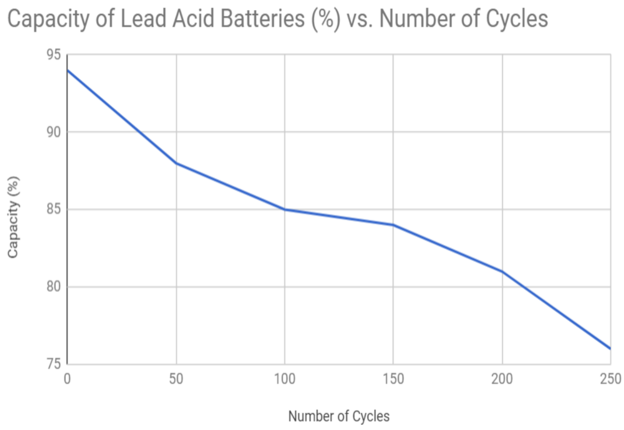


Figure 2: Correlation between charge cycles and the capacity of lead-acid batteries

lead dioxide plate combines with the hydrogen ions and sulphate ions and the extra electron from the lead plate to create lead sulphate and water. As the battery discharges, there is a build-up of lead sulphate crystals on the anode.[11] These classical lead-acid batteries have two main issues. The first problem is based on the durability factor of the battery. All batteries have limited lives due to their charge cycles. As the number of charge cycles increases, the level of output decreases over time as shown in the Figure 2.[12] The main reason behind this aging process in lead-acid batteries are sulfation and grid-corrosion.[9]

Sulfation occurs all the time in batteries. When a battery is powering something its active materials in the lead react with the sulphate in the electrolyte. When this reaction occurs, it results in small amounts of lead sulphate to be deposited on the inside of the battery as shown in Figure 3. When batteries are recharged, these lead sulphate particles are turned back into the compounds they started off with. However, the problem arises when the batteries are left unattended after a complete discharge. If a battery is completely discharged, the lead sulphate particles start forming crystals inside the battery membrane and act like barriers in the process.[11] Thus if not discharged properly, there is a higher chance of the crystals forming and making the battery

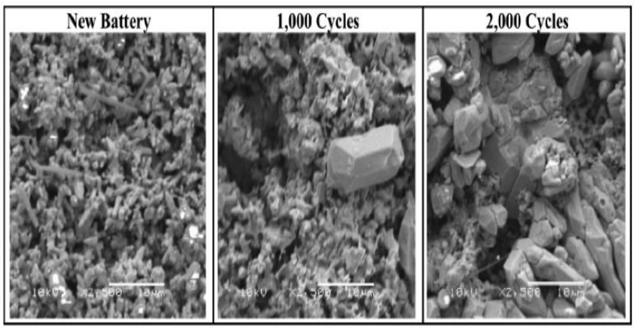


Figure 3: Displays the sulphation causing the formation of crystals and grid-corrosion causing the plates to disintegrate

ineffective. The second issue that contributes to the problem of battery aging is grid-corrosion. Grid-corrosion, just like sulfation, is a problem that can't be stopped completely as it is an inherent part of the battery technology we have. As the battery goes through cycles, the lead is softened, and it sheds in the electrolyte membrane. This reaction cannot be eliminated completely as the lead acid is always in a reactive environment. Some ways to slow down the shedding would be through reducing the charge cycles and using the batteries in moderate temperatures.[12]

1.2 Opportunities in the Field

The main problems with lead-acid battery are the durability and cost issues. Thus, if a solution is developed that helps revive dead batteries temporarily, we can make the batteries have an extended lifespan and solve both problems at the same time. The main reason companies haven't approached this method is because batteries are a dangerous piece of equipment which need safety precautions. High level of lead exposure can lead to impaired learning, and fatigue. Moreover, contact with sulphuric acid can lead to skin burns and irritation in the respiratory system. The challenge is to overcome the safety concern when opening battery packs. In the past when these methods were carried out by trained mechanics they reported an increased lifespan of at least 6 months, which would translate to a 70% increase in lifespan for the farmers and a $120 saving every time they buy a new battery.[6] Rather than going down the revival pathway, most companies are trying to make improvements through the use of R&D. This can be seen in the fact that they are investing huge amounts of capital in funding start-ups that are trying to research this, for example, Gridtential received 11 million dollars from battery industry leaders to improve the technology. While these improvements will make the battery more efficient, they will also lead to an increase in the prices. However, those living in developing countries need a cheaper and more accessible product.

Theoretically the solution can be made to revive these batteries. Thus, while making the product that revives these batteries, the one thing we need to take care of is the safety barrier as that is the main problem we need to counter. As currently these methods can only be performed by trained mechanics. To commercialize this method, we need to make it as safe as possible for commoners to perform. The safety barrier for this project includes problems such as the fact that the process will involve opening battery packs with acids with a pH level of 2.75 and the fact that it involves electrical current flows which can be harmful if not handled with care.

1.3 Implications

In this study, there are many implications that will arise, both with the product and ethics. For this study, the biggest obstacle will be the battery companies. If the report is successful at the end and makes lead-acid batteries more durable in the long term, it would lead to a financial loss for the companies who manufacture these products as their sales would decrease. Thus, to counter this issue, the researcher plans to receive aid from the Indian government, as unlike the companies, the government is there to provide help for the people. Interestingly, the Prime Minister of India just started a 160-billion-rupee program to provide electricity to the farmers in India by 2040.[15] The scheme he is suggesting is a long-term solution and thus this study would be a perfect match as a short-term solution. Until these farmers get electricity to power there houses through a grid-line, they can use the methods developed to extend the lifespans of their batteries.

Ethically there are two main things the study needs to consider. The first one involves setting priorities between people's lives and the amount of money they will be saving. The study is based on reviving dead lead-acid batteries, and the final product can have a risk percentage that might not make it safe for the users. The risk will be there while conducting the desulfation process as it might involve contact with acidic compounds, charging of open batteries, or mixing chemicals to make new electrolytes which can lead to explosions in the worst case. Thus, for the success of this study, the researcher needs to make sure that the risk factor for these solutions is almost nonexistent. The goal of this study is to bring down the costs of storing power in batteries for these farmers, so they can use the money on more important needs such as sanitation and food.

The second ethical consideration involves the Indian farmer demographic the study is targeting. Farmers in India still follow a rigid class system where the elder makes decisions for the whole village. These elders act like liaisons with the outside world. They are very strict about their traditions and thus don't want their followers to know about the exterior innovation.[4] For this study, however, this shouldn't be an issue as the solution is aiming to help them bring the prices down of storing electricity. It is not going against any of their tradition or beliefs thus they should be accepting towards it.

2. Methods

In this study, the researcher used a pre-post experimental research to record the results of the experiments. This analysis method helped check not only if there was a difference between the experimental and controlled, but also to check the variability in the different solution sets. This method is an adaption from Dr. V. Markovoc's study into electrochemical kinetics of Indium as published in the Journal of The Electrochemical Society.

For this experiment, the set-up is mainly based on finding the right batteries. The lead-acid batteries for this procedure must have a high IR (Internal Resistance), and low CCA (Cold Cranking Amh) and Voltage. The researcher needs to measure the IR, Voltage, and CCA when the battery is found and record the data. Then the battery should be fast charged for 35 mins, and the three variables should be measured again. These preliminary measurements will help provide a benchmark for the batteries after they have gone through the trials. If the battery shows changes that are below 15% of the recommended amount, and the voltage is above 5.5V, the battery is eligible for the trails of this method.

To go about the process, there will be three stages to the procedure. The first stage will be based upon finding which chemical solution produces the best results in increasing the lifespan of the lead-acid battery. To test this, the researcher will empty out the battery, use baking soda to neutralize the acid left over, and add in the 3 possible solutions in each trial. The solutions will be $MgS0_4$ (Magnesium Sulphate), Na_2SO_4 (Sodium Sulphate), and $C_{10}H_{16}N_2O_8$ (Ethylenediaminetetraacetic acid, EDTA). Below is a description of the reactions that help break down the lead-sulphate bonds. In the case for Magnesium Sulphate, the sodium can just be substituted by Magnesium in section 1.

1.

- $H_2 + Na_2SO_4 \text{-->} H_2SO_4 + 2Na+$
- $2Na+ + 2H_2O \text{->} 2NaOH + H_2$
- $2NaOH + PbSO_4 \text{->} Na_2SO_4 + Pb(OH)_2$
- $Pb(OH)_2 + H_2 \text{->} Pb + 2H_2O$

2. $EDTA + PbSO_4 = Pb(EDTA)^{2-} + HSO_4^- + 3H^+$

Adding the baking soda is an essential part as the residual sulfuric acid could act as a lurking variable which could affect the measurements later thus it is important to neutralize the acid. For this first stage, the researcher will use half the required solution quantities as this part 1 will be a trial to figure out the best chemical solutions. The second stage of the experiment will be based on developing the actual method. In part 2, the researcher will be taking the acid out of the battery and treating the battery before adding the filtered acid back in. It is important to filter the acid because it can contain lead from the plates. Whereas, in part 3, the solution will be directly added to the battery. In all three stages, the batteries will be charged using a slow charge process because the slow charge helps facilitate the breaking of the lead-sulphate bonds with the plates.

As stated before, in this study, there will be three major variables. The first one will be the voltage output. The voltage output will be helpful to check if the cell gives out the same amount of electricity as it started off with. The second variable will be the CCA. CCA is the amount of amps the battery can output at 0°F for 30 seconds while holding 7.2V. An increase in this normally leads to an increase in the time the battery can be used for. This variable is important because it gives an understanding of how long the battery will work for. It is possible for the battery to give a good voltage output at the start and then die out days later. Thus, the measure of CCA will be crucial to check if the battery will work in the long term. The third variable is the internal resistance. The internal resistance is directly linked to the level of sulfation in the battery. High levels of sulfation mean larger amounts of lead-sulfate deposits on the plates, which in turn increases the resistance. Thus, the before and after measurement of the IR would help the researcher understand if the solution helped break down the crystals on the plates. After collecting the data for this study, the analysis of the three variables stated above will be done using an independent two-sample t-test to compare the averages and check for a change in the means before and after the experiment. This analysis model is adopted by the study conducted by Dr. Shultz in the Journal of Chemical Education.[16] This will be the best model as it would help compare the before and after effects of the solution. Success in this study would mean the voltage and CCA would show an increase and the IR would show a decrease after the solution has been added.

<u>*Part 1: Finding the most effective solutions*</u>

1. Make a solution of 150g of 1.25 M $MgS0_4$ (Magnesium Sulfate) with 1.5L of distilled water and a separate solution of 300g of 3.57M $NaHCO_3$ (Baking Soda) with 1.5L of distilled water.
2. Carefully open the caps of the lead-acid battery and empty the H_2SO_4 (Sulphuric Acid) inside a glass tub. Filter the acid using a 150mm filter paper and a funnel to separate the acid and the waste inside the battery.
3. Add the $NaHCO_3$ solution in the battery by pouring 300ml in each cell. Add the solution slowly as there will be effervescence caused by the neutralization reaction. Perform this step under a bypass fume hood.
4. Put the caps back on and shake the battery for 30 secs and then dump the solution out.

5. Repeat part 3 and 4 for until the solution being poured out is clean.
6. Add 300 ml of $MgS0_4$ solution to each cell and put the caps back on.
7. Slow charge until the voltage crosses 13.5V.
8. Let the battery rest for 30 mins after the charge is complete and measure the three variables (Voltage, CCA and IR)
9. Dump the solution out and add in the filtered $MgS0_4$ solution back into the acid.
10. Slow charge until the voltage crosses 13.5V.
11. Let the battery rest for 30 mins and measure the same variables as part 8.
12. Repeat part 1 to 11 for the other two solutions.

Using the data for part 1, a graph was created to find the best solution out of the three. Through the results, we could see that EDTA and $MgS0_4$ produced the most convincing results.

Part 2: Developing the method (Part A)

1. Make a solution of 300g of 2.5 M $MgS0_4$ with 1.5L of distilled water
2. Carefully open the caps of the lead-acid battery and empty the H_2SO_4 inside in a glass tub. Filter the acid using a 150mm filter paper and a funnel to separate the acid and the waste inside the battery.
3. Add in distilled water to the battery until the cells are full and put the caps back on.
4. Shake the battery for 30 secs and dump out the solution.
5. Repeat part 3 and 4 for until the solution being poured out is clean.
6. Add in the $MgS0_4$ solution into the battery and charge with the caps off at 1.5-2 Amps until the voltage hits 13.5V. Measure the three variables stated in Part 1.
7. Dump the solution out and add in the filtered $MgS0_4$ solution back into the acid.
8. Slow charge until the voltage crosses 13.5V.
9. Measure the same variables again and repeat parts 1-8 using $C_{10}H_{16}N_2O_8$.

Part 3: Developing the method (Part B)

1. Open the caps in the battery and add in 15g of 0.12 M of $MgS0_4$ in each cell.
2. Add in distilled water to each cell until the level inside reaches the top of the plates inside.
3. Slow charge until voltage hits 13.5.
4. Measure the Voltage, CCA and IR of the battery
5. Repeat parts 1 to 4 for $C_{10}H_{16}N_2O_8$.

3. Results

Each section of the methods helped derive a different part of the solution and with the combination of all three parts the researcher was able to find a solution that can be used for the farmers in rural India.

Figure 4 shows the effects of the solutions on the condition of the lead-acid batteries. The voltage difference in the section is not too big as during the set-up part the batteries were pre-charged. The two variables that are important to analyze are IR and CCA. In the case of $MgS0_4$, the positive change in both the variables can be interpreted as success. The IR decreased by 4.18 and the CCA increased by 111. This means that the sulphation did decrease, which lead to battery being returning closer to the original state as shown by the increase in CCA. A similar effect can be seen in the trials involving EDTA as the IR decreased by 4.48 and the CCA increased by 104. On the other hand, the effects of Na_2SO_4 were not too dire. The CCA only increased by 15 and the IR only decreased 2.15. While there was change, the goal of the study is to find the best solution thus in the next steps the researcher decided to exclude Na_2SO_4 from the trials and focused in on the two solutions that showed the most promising results: EDTA and $MgS0_4$

	$MgS0_4$	$C_{10}H_{16}N_2O_8$	Na_2SO_4
Voltage (Before)	12.74	11.13	12.7
Voltage (After)	12.98	12.85	12.91
CCA (Before)	187	245	172
CCA (After)	298	349	187
IR (Before)	14.89	15.58	16.23
IR (After)	10.71	11	14.08

Figure 4: Data collected through part 1 of the methods section

	$MgS0_4$	$C_{10}H_{16}N_2O_8$
Voltage (Before)	11.96	10.41
Voltage (After)	12.67	12.98
CCA (Before)	233	235
CCA (After)	262	364
IR (Before)	12.01	11.86
IR (After)	8.7	6.71

Figure 5: Data collected through part 2 of the methods section

In the second part, the goal was to develop a method where the user will take the acid out of the battery pack. These set of results (Figure 5) also showed high levels of success. In the case of EDTA, there was an improvement in all three variables. The test batteries had a low voltage to start off with and through the procedure, the researcher was able to increase the voltage. The trials also showed an increase in the average CCA from 235 to 364. The benchmark for batteries is normally 350 CCA thus these results are beneficial for the study. There was also a decrease in the IR from 11.86 to 6.72. This means that the method was successful in breaking down the lead-sulphate crystals on the plates to increase the flow of electricity. The trials with $MgS0_4$ showed similar results but the one thing to note from these trials was the fact that the CCA only increased by 43 in the case of $MgS0_4$, whereas in the case of EDTA it increased by 104 on average. This is an important difference because the CCA helps account for the lifespan thus an increase in that is important for the method to be successful. These results from part one show success, however, it is crucial to note that this procedure is more hazardous due to the sulphuric acid.

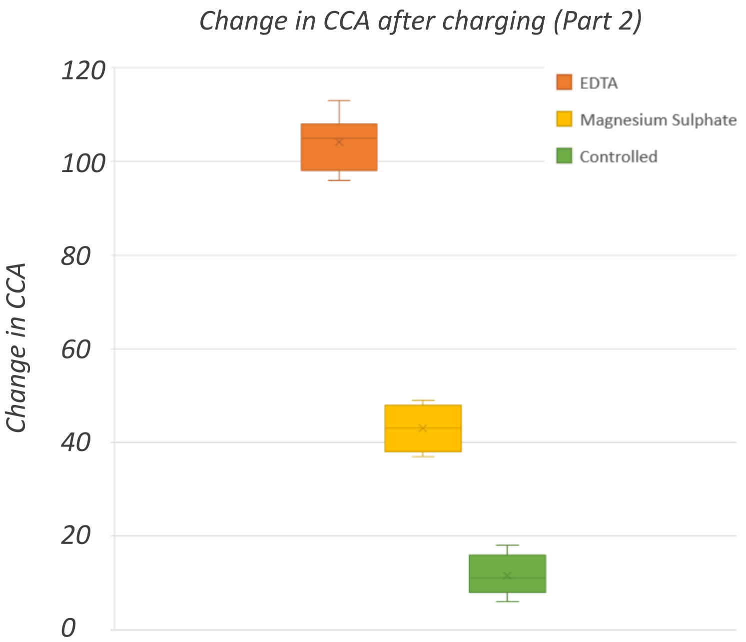


Figure 6: Data collected on change of the CCA through part 2 of methods development

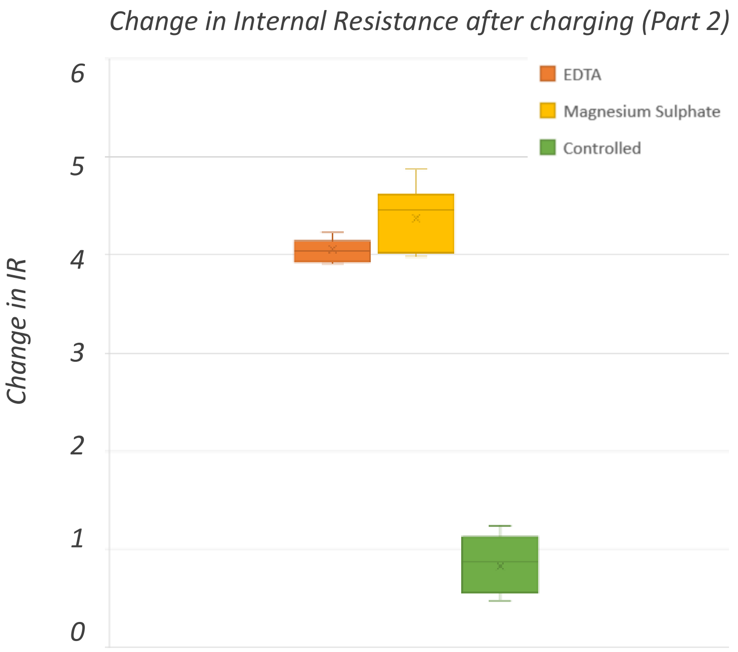


Figure 7: Data collected on change of the IR through part 2 of methods development

The figures on the left show the impact of the solution on the two main variables for this study in part 2 of the methods: CCA and IR. The analysis was done using an independent two-sample t-test where in each case the controlled (green) was compared to the treated ones. Figure 6 is based to show the change in the CCA before and after the experiments. The change in the CCA on the controlled batteries where the battery was not treated had a mean of 11.57 with a standard deviation of 4.35. In the study, the CCA change in the experiments treated with Magnesium Sulphate (Mean = 43, SD = 4.55) was hypothesized to be greater than the CCA change in batteries which were not treated (Mean = 11.57, SD = 4.35). After conducting an independent two-sample t-test, we can see that the change is significant as $p << 0.01$. Lastly, EDTA gave the best results as the change in CCA was huge. In the study, the CCA change in the experiments treated with EDTA (Mean = 104.14, SD = 5.92, Count = 7) was hypothesized to be greater than the CCA change in batteries which were not treated (Mean = 11.57, SD = 4.35, Count 7). After conducting an independent two-sample t-test, we can see that the change is significant as the $p << 0.01$.

Figure 7 is based to show the change in the Internal Resistance after treating and charging them in part 2 of the methods. The trials where the battery was not treated the IR has a mean of 0.83 with a standard deviation of 0.29. In this study, the IR change in the experiments treated with Magnesium Sulphate (Mean = 4.37, SD = 0.12, Count = 7) was hypothesized to be greater than the IR change in batteries which were not treated (Mean = 0.83, SD = 0.083, Count 7). After conducting an independent two-sample t-test, we can see the change is significant as $p << 0.01$. Similarly, the IR change in the experiments treated with EDTA (Mean = 4.06, SD = 0.014, Count = 7) was hypothesized to be greater than the IR change in batteries which were not treated (Mean = 0.83, SD = 0.083, Count 7). After conducting an independent two-sample t-test, we can see the change is significant as $p << 0.01$. In both cases the batteries treated showed higher changes which means they were successful to break down the lead-sulphate bonds. Overall, EDTA turned out to be

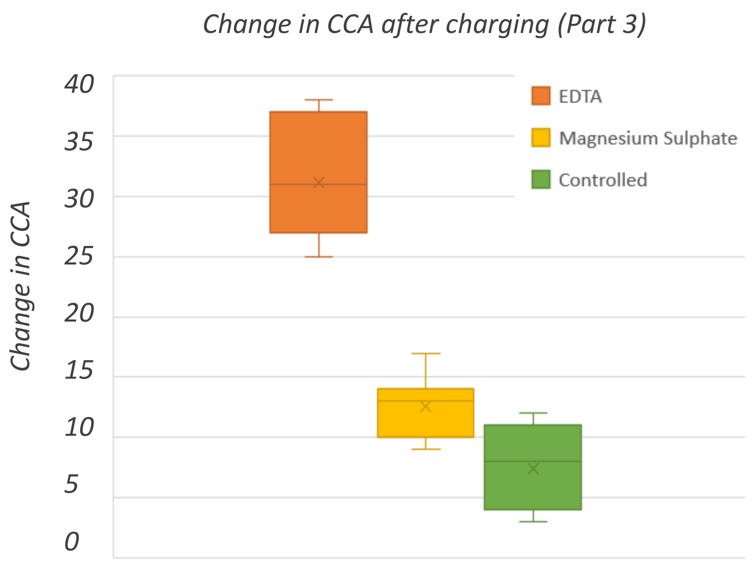


Figure 8: Data collected on change of the CCA through part 3 of methods development

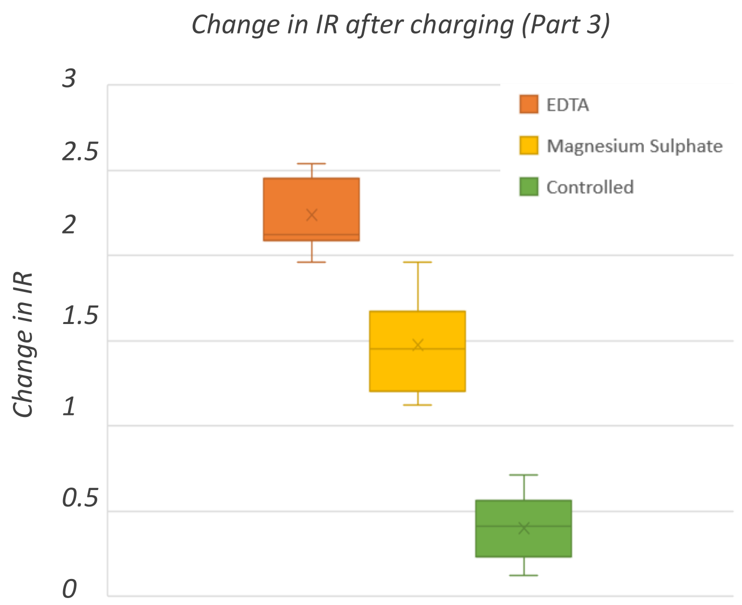


Figure 9: Data collected on change of the IR through part 3 of methods development

the total winner in terms of increasing the lifespan by increasing the CCA, and Magnesium Sulphate was the winner in breaking down the lead-sulphate crystals and decreasing the internal resistance. However, it is crucial to understand that in the IR results, EDTA was very close to Magnesium Sulphate whereas in the CCA trials EDTA was an easy winner. Thus, in part two of the experiments, EDTA could be presented as the best solution for the issue.

In step 3 of the Methods section, the goal was to develop a solution where the user needed minimal background experience. In this method, the goal was to just add the solution in the battery through the caps on the top and let the solutions break the lead-sulphate down by themselves. In this part too, the two main variables assessed are shown above. The analysis was done using an independent two-sample t-test where in each case the controlled (green) was compared to the treated ones.

The trials where the battery was not treated the change in CCA had a mean of 7.43 with a standard deviation of 3.5. In this study, the CCA change in the experiments treated with Magnesium Sulphate (Mean = 12.57, SD = 2.34, Count = 7) was hypothesized to be greater than the IR change in batteries which were not treated (Mean = 7.43, SD = 3.5, Count 7). After conducting an independent two-sample t-test, we can see the change is significant as $p \ll 0.01$. In the case of the EDTA (Mean = 31.14, SD = 4.95, Count = 7), the hypothesis was the same compared to the control. The p-value, in this case, was $p \ll 0.01$, which in turn means that the change is significant. Overall this means that both solutions were successful in increasing the lifespan but EDTA gave more promising results. As seen above in figure 6, the boxplot for EDTA is almost 3x times higher than for Magnesium Sulphate.

The next variable (IR) can be interpreted by looking at distributions in Figure 9. The trials where the battery was not treated the IR has a mean of 0.39 with a standard deviation of 0.2. In this study, the IR change in the experiments treated with Magnesium Sulphate (Mean = 1.48, SD = 0.28, Count = 7) was hypothesized to be greater than the IR change in batteries which were not treated. After conducting the data analysis, we can see the change is significant as $p \ll 0.01$. The same hypothesis was there for EDTA (Mean = 2.24, SD = 0.22, Count = 7) that it would lead to a higher change than for the controlled. The p-value for the comparison of the means leads to $p \ll 0.01$. Again, this means that both trials lead to success but just varying levels of success. As seen in figure 7, EDTA just lead to better results compared to Magnesium Sulphate which makes it a winner for this trail too.

Overall step 3 in the methods helped analyze which solution would be the main chemical to solve the energy crisis in India. EDTA proved to be a better candidate than Magnesium Sulphate in terms of breaking down the lead-sulphate bonds and in terms of increasing the lifespan of the battery.

4. Discussion

The results help analyse which solution is the most effective chemically in solving the issue. One extra variable that needs to be accounted for is the price levels of both products. In the case of EDTA, it can be bought at 30 Rupees/300g, or 0.46 USD/kg. Furthermore, in the case of $MgSO^4$, the solution can be bought at 7.5 Rupees/300g, or 0.12 USD/300g. This means that $MgSO4$ is a much cheaper option comparatively however it is important to realise that even EDTA is a feasible option. As stated before, the price of a new battery is 150 USD, which means that the EDTA solution would equal 0.3% for the price of a new battery, and in the case of MgSO4 it would cost 0.08%. Thus, the cost variable won't be an issue in the case of this study.

The results of this study help us understand which chemicals will play an important role in lowering the energy burden the farmers in India and many developing countries face. Results from parts 2 and 3 of the methods section lead to the same winner, EDTA, however, both parts lead to different results. In part 2, the change in CCA and IR was much higher than in the case of part 3. This is because part 2 involves removing acid from the battery and manually cleaning out the lead-sulphate crystals which makes the process more successful. This would mean that this method would be more worthwhile for users whose batteries are unserviceable and is not able to put out 6-7V charge for more than 30 mins. On the other hand, the second solution developed in part 3 can be used as a measure to improve the battery life for the users. It would not lead to high levels of change as the crystals and chemical solutions are still left in the battery. Thus, this solution would be better suited for users who have a battery that can still output around 11.5V for 30 mins. This distinction is important to keep in mind while applying the methods because it would make the process more efficient for the user and could possibly decrease the risk factor as the lower the contact with sulphuric acid, the better for the user. Each method would target a separate customer segment. The method developed in part 2 can be utilized by more skilled users such as mechanics who recycle these batteries. On the other hand, the method developed in part 3 would be better suited for the farmers to maintain the quality of the battery pack as long as it is possible.

While the data collected by the researcher shows positive results, further research is needed to check for long-term impacts on the lead-acid batteries. This future study would have long test periods where users use the battery for daily use to check for any negative consequences on these battery packs. The study should also include more types of batteries as currently the batteries being tested are the classic capped lead-acid batteries, which are the most prevalent among farmers in India, but it is important to check the impact of the solution on other types of batteries such as sealed lead-acid batteries.

The solution developed from part 3 would be a perfect solution for the current situation in India as the Indian government starts planning for a 300-day initiative for 2040 where they hope to provide solar energy for the 240 million farmers for 300 days of a year[15]. The method developed in the study would act as the perfect short-term solution. Until the initiative is rolled out, the EDTA solution could act like a battery life-extender which would bring the long-term prices for the batteries down. Furthermore, in the future when the initiative is rolled out with solar panels, the solution can still be used to extend the lives of the batteries being used to store the solar energy as normally they too use lead-acid batteries for the storage. Through the combination of these methods, perhaps one day Indian farmers will get their right for electricity.

(Word Count: 5429)

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