

Electrochemical Performance Of Graphite Felt/Epr Modified Carbon-Polymer Composite Electrodes (III) Effect Of Overcharge On Electrode Deterioration

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ABSTRACT

Conducting plastic electrodes have been developed and investigated for the vanadium redox flow battery. The results have revealed that, due to damage to electrical contact at interface between the felt/composite polymer substrate, the deactivation of graphite felt/composite electrode after severe anodization is irreversible mainly. It was also found that neither electrochemical oxidation of felt nor physical detachments of the felt layer from its substrate is the main reasons for conductive polymer electrodes deterioration. Actually, the polymer destruction under highly oxidizing overcharge V(V) solution is the real mechanism for conductive polymer electrode deterioration.

However, the composite electrodes fabricated in this project have proved to be about 10 and 3 times more stable than Toray and graphite fiber filled SEBS composite electrodes respectively under overcharge condition. These electrodes are thus superior to the commercial electrodes for application in the vanadium redox battery.

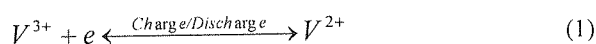
KEYWORDS

Conductive plastics, vanadium battery, composite electrode.

INTRODUCTION

As was reported before [1,2] the following reactions occur during charging and discharging in vanadium redox system:

At the negative electrode:



At the positive electrode:



Hydrogen and oxygen can also evolve at the negative and positive electrodes respectively during charging at high state of charge's, or if the battery is overcharged. The composite electrode which was employed in vanadium redox battery consisted of a graphite felt layer bonded onto the conductive composite substrate, each performing different tasks. Functioning as a catalyst and/or catalyst support, the felt electroactive layer is the surface where the vanadium redox reactions to take place whereas the conductive polymer substrate acts as a current collector as well as being a support for the felt layer.

On the positive electrode of the vanadium redox flow battery, the felt active layer works as an anode and contacts an oxidizing electrolyte during electrolyte during cell charging. Furthermore, at high states-of-charge, oxygen evolution takes place. Therefore, if the cell is overcharged, oxygen evolution becomes the predominant reaction in the positive half of the vanadium redox flow battery. The change in the surface chemical characteristics of the graphite felt under these operation conditions is important, since it will directly affect the electroactivity and cycle life of the electrode in the vanadium redox flow cell.

Under overcharge conditions a dramatic increase in cell resistance and charge potential as well as low voltage efficiencies were reported for the cell employing conductive plastic electrodes, leading to total failure in cell performance. Tests with graphite positive electrodes in the vanadium redox cell have shown that if oxygen evolution takes place in the positive half cell during charging, mechanical degradation of the carbon can occur due to CO₂ formation. Furthermore, it has been observed that the commercial Toray electrode is damaged when the electrodes are operated under overcharging conditions for more than 10, minutes [3].

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Two mechanisms have been suggested as contributing to electrode failure under overcharge conditions in the vanadium redox battery [4].

1) Electrochemical oxidation of the felt layer by formation of high oxygen containing functional groups, especially $-\text{CO}_3^-$ on the surface of the graphite fibers of the felt layer leading to a low of its electroactivity toward the V(IV)/V(V) redox reactions.

2) Physical detachment of the felt layer from its substrate; i.e. formation of a gap between the felt layer and the conductive composite substrate leading to loss of electrical contact within the composite electrode in the positive half cell.

The physical detachment was observed for the commercial Toray composite electrode while for the Styrene-Ethylene-Butadiene-Styrene composite electrode the emphasis has been of the formation of high oxygen containing functional groups e.g. $-\text{CO}_3^-$ on the surface of the graphite fibers of the felt.[3] Moreover, anodic oxidation of FMI and GFD2 composite electrodes in 3M H_2SO_4 at +1.5 V(Hg_2/SO_4) for 15 minutes resulted in considerable electrode deterioration which again was attributed to serious oxidation of the felt layer rather than its physical detachment [3].

In addition, there have been a number of reports on the reduction of various functional groups on the surface of carbon/graphite electrodes [5]. In the majority of the electrochemical approaches for activation of carbon/graphite electrodes, application of a cathodic potential after oxidation under anodic potential has been suggested for activation of carbon/graphite electrodes, application of carbon/graphite electrodes [6]. The application of a cathodic potential has been considered necessary for fast electron transfer of metal containing redox couples. In addition, in other work this step has been revealed to partial removal of the high oxygen containing surface, leaving an active graphite/carbon electrode surface [3]. However in most studies, cathodic reduction has simply been performed without any further explanation.

Thus, an electrochemical study was undertaken in this part of the present work to investigate the effect of cell overcharging on electrode active layer and substrate.

EXPERIMENTAL

To evaluate the life of the ethylene-polypropylene rubber-blended-polypropylene composite electrodes (SEBS electrodes) with heat treated Sigri felt under overcharging conditions, two heat-treated Sigri GFD5 felt were bonded onto the carbon-polymer composite sheet to form the composite electrodes for the laboratory scale test cell which was explained in a pervious paper [1]. The electrodes were subjected to normal charge/discharge and overcharging conditions. A constant charging current was

applied to a fully charged vanadium redox single cell for 10 minutes, followed by a series of measurements in cell resistance, cell efficiencies and cell charge-up potential in several consecutive cycles. This performance was repeated 20 times, i.e. the total overcharge time was around 8.5 hrs.

For oxidation behavior and protection of carbon particles in the conductive carbon-polymer composite study a carbon rod was drilled on the top and conducting silver-glued with a copper wire. The wire become detached after sever oxidation at high anodic potential. In order to prevent such damage to these electrodes, they were encased in epoxy resin as shown in Figure1.

The electrochemical cell for the weight loss studies was a 50ml beaker, containing 0.25M V(V) in 0.2M H_2SO_4 as electrolyte. Covering of the top of the cell was a 3 opening Perspex lid for accommodation of the reference, counter and working electrodes. A standard calomel electrode (SCE) and an ultra-high purity graphite rod were used as reference and counter electrodes respectively. The three-electrode system was connected to a potentiostat with built in scan generator (RDE3; Pine Instrument Ca).

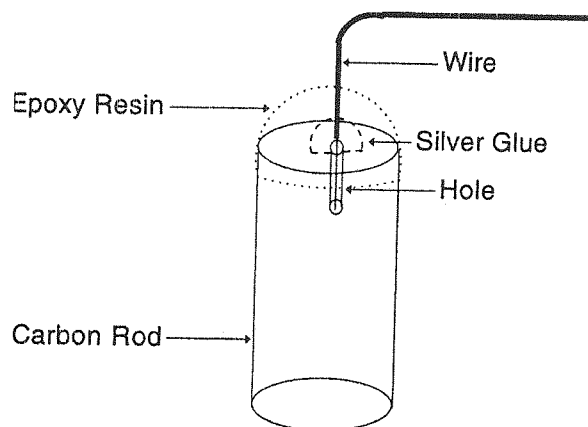


Figure 1: Construction of the carbon rod working electrode

Other experimental conditions are also as follows:
 Current Density = 10 (mA/cm²)
 Epoxy Resin = 2.00 (V)
 Time = 24 (hrs)
 Temperature = Room Temperature

RESULTS AND DISCUSSION

Figure 2 shows the trend in cell resistance versus overcharge time for a cell that been subjected to an current density of 20 mA.cm⁻². It seen that the cell resistance nearly increases up to 9 times and then after a small jump it increases slowly up to 15 times and then increases dramatically, indicating that the electrode had been seriously damaged. At this stage, the battery can not operate due to poor voltage efficiency.

According to following equation:

$$V_{CELL} = \Delta E_{eq} - \eta_a + \eta_e - IR \quad (3)$$

Cell voltage is determined by the equilibrium potential difference of the redox couples, the polarization losses and ohmic losses. Combining the last two components into one gives the total polarization losses which is written as $V_{pol} (= IR_{CELL})$. The cell voltage during charging and discharging can be explained as:

During charging:

$$V_{Cell\ Charging} = V_{eq} + V_{Pol.Charging} \quad (4)$$

During discharging:

$$V_{Cell\ Discharging} = V_{eq} - V_{Pol.Discharging} \quad (5)$$

The cell charging voltage at 100% state of charge (SOC) will be a function of cell resistance. For example at 5th time, when the cell resistance increased to $5 \Omega \cdot \text{cm}^2$, the cell charge-up voltage jumped to 1.9V indicating only 0.35V cell polarization ($V_{eq-at100\%SOC} = 1.60$), whereas at 20th time, when the cell resistance increased to $65 \Omega \cdot \text{cm}^2$, the cell charge-up voltage increased to 3.0V indicating the cell has polarization losses of 1.4V. Assuming $V_{Pol.Charging} = V_{Pol.Discharging}$ the cell voltage efficiency at the beginning of the discharge process can be readily determined from above equations, and is found to be very low and reduces further with decreasing SOC during discharging.

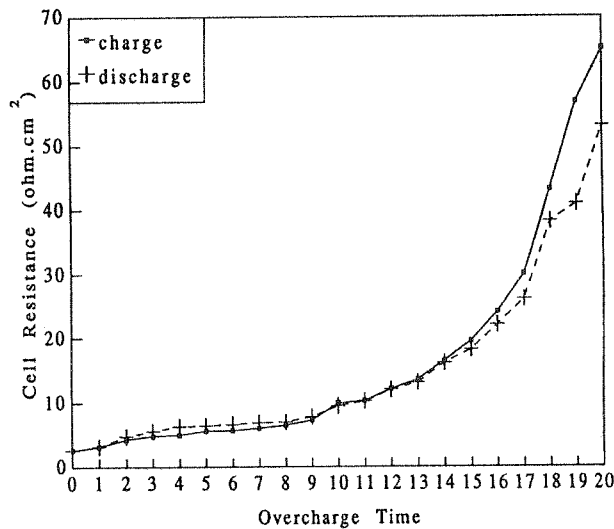


Figure 2: Effect of overcharge on cell resistance of vanadium redox flow cell with the EPR modified carbon-polypropylene composite/heat treated Sigr GFD5 felt electrode ($i=20 \text{ (mA} \cdot \text{cm}^{-2}$), 10 (min))

However, Figure 3 shows in overcharge conditions, the composite electrode is several times more stable than commercial Toray and SEBS electrodes. The reason for increased cell resistance with cell overcharge for Toray electrode is related to the formation of a gap between the felt and composite sheet when the electrode is operated under serious overcharging conditions. It is said that, this

is due to the decomposition of the graphite felt at the interface with the composite sheet which destroy the electrical contact between the felt and substrate. In addition, in the case of other electrode, oxidation of the graphite felt is said to be the main reason for electrode deterioration.

To evaluate the area resistivity of the damaged electrodes, at the end of 20th time, the electrodes were removed from the cell and then soaked slowly in V(III) solution for two days followed by washing with distilled water and then samples were dried. As can be seen from Table 1 the area resistivity of the positive side increased of the positive side increased dramatically while only a small increase was recorded in negative side which confirms the effect of oxygen evolution in positive side on electrode deterioration.

Table1: Effect of Overcharging on the Area Resistance of Electrode.

Electrodes	Area resistance (R) ($\Omega \cdot \text{cm}^2$)		ΔR ($\Omega \cdot \text{cm}^2$)
	Before overcharging	After overcharging	
Positive side	0.56	101.7	101.14
Negative side	0.56	0.9	0.34

$$\Delta R = R \text{ after overcharging} - R \text{ before overcharging}$$

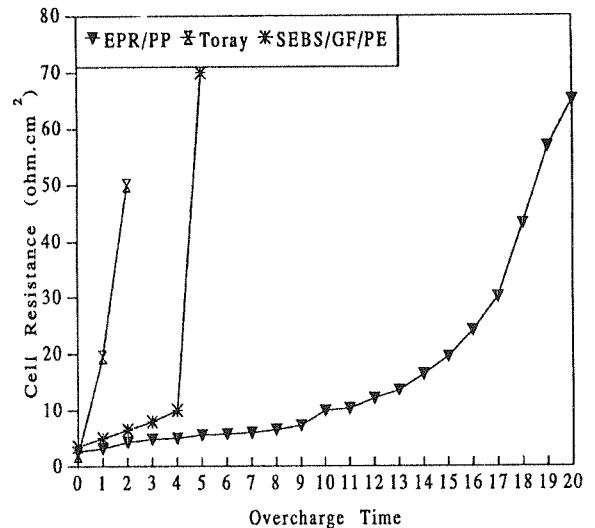


Figure 3: Comparison of the overcharge stability of EPR modified carbon-PP electrode with other commercial electrodes ($t=10$ (min)).

To evaluate the effect of overcharging time on the behavior of electrode, after 4th- 10 min. overcharge cycle, the overcharge period increased from 10 minutes to 20 minutes. As can be seen from Figure 4, the cell resistance was increased dramatically to around $20 (\Omega \cdot \text{cm}^2)$ and 50

($\Omega \cdot \text{cm}^2$) for first and second 20 minutes respectively. In addition, it can be seen from the comparison of Figures 2 and 5 that, although after 15 times 10 minutes-overcharging cell resistance increases to around 20 ($\Omega \cdot \text{cm}^2$) only a two-time continuous 30 minutes resulted in a same cell resistance. Therefore it can be concluded that the one long-term overcharging is more effective than several short-time overcharging cycle to deteriorate electrode.

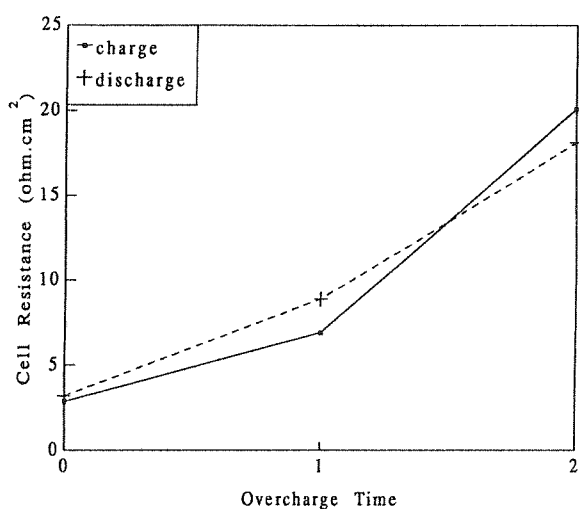


Figure 4: Effect of overcharging time on cell resistance ($i = 20$ ($\text{mA} \cdot \text{cm}^{-2}$))

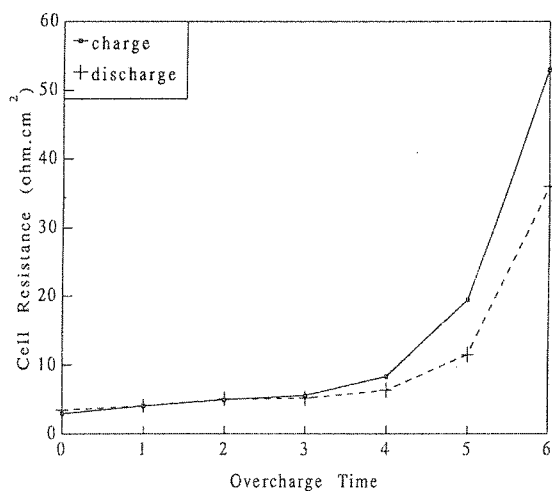


Figure 5: Effect of overcharging time on cell resistance ($i = 20$ ($\text{mA} \cdot \text{cm}^{-2}$), $t = 30$ (min))

It was also observed that during overcharging, higher current density results in higher cell resistance. Figure 6 shows that increasing the current density to 60 ($\text{mA} \cdot \text{cm}^{-2}$) resulted in a cell resistance about 6 times greater than that of 20 ($\text{mA} \cdot \text{cm}^{-2}$).

To find out the real mechanism of electrode deterioration, an experimental approach in which the physical detachment of the felt layer from its substrate

does not interfere in the oxidation study of the graphite felt electrode is thus necessary. Therefore, by eliminating the possible effect of polymeric substrate deterioration or physical detachment of the felt layer from its substrate, the electrochemical oxidation of the graphite felt electrodes which results in loss of electroactivity or increase in the activation over potential component of the cell resistance could be evaluated.

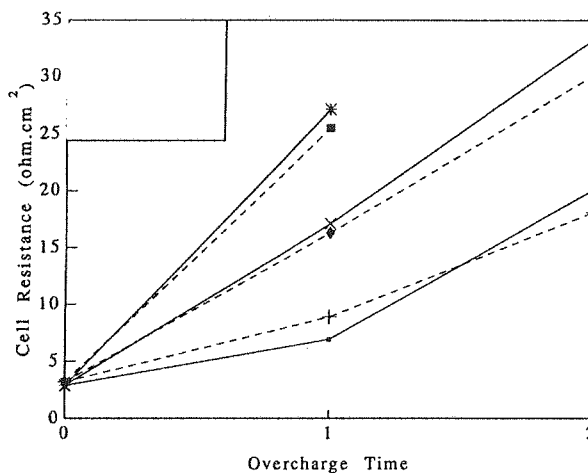


Figure 6: Effect of overcharging current density on cell resistance ($t = 30$ (min)). ■ Discharge ($60 \text{ mA} \cdot \text{cm}^{-2}$) * Charge ($60 \text{ mA} \cdot \text{cm}^{-2}$) ♦ Discharge ($40 \text{ mA} \cdot \text{cm}^{-2}$) X Charge ($40 \text{ mA} \cdot \text{cm}^{-2}$) + Discharge ($20 \text{ mA} \cdot \text{cm}^{-2}$) ● Charge ($20 \text{ mA} \cdot \text{cm}^{-2}$)

The peaks which corresponded to oxidation/reduction of hydroquinone/quinone-like groups on the surface of graphite felt could be removed from the surface of the electrode by application of a negative potential. Therefore, after each 10-minute overcharging, same time over-discharging (as negative potential) was applied to the cell to reverse problem graphite felt functional groups reactions. Figure 7 shows that after each over-discharging time, cell resistance drops, which confirms this theory that electrochemical oxidation of the felt layer by formation of high oxygen containing functional groups, especially $-\text{CO}_3$ on the surface of the graphite fibers of the felt layer leads to a loss of its electro activity toward the V(IV)/V(V) redox reactions. The dark surface of positive side electrode also confirmed the existence of these functional groups which were not observed on the negative side electrode.

On the other hand, although discharging of overcharged cell reduced slightly cell resistance, this drop was not significant which indicated the deactivation of graphite felt/composite electrode is just slightly reversible and there should be another reason for electrode deterioration.

For further investigation of the effect of overcharge on the felt layer of the composite electrode and on cell performance and also to eliminate the possible problem of physical detachment of graphite felt, a cavity fill-in flow cell was employed as a test flow cell. The design of the cell is such that the graphite felt electrode is compressed

between a membrane and a graphite plate current collector in either side of the cell. Therefore the relation between surface functional groups and electrical resistance of the felt layer during overcharge or anodic oxidation should be achieved.

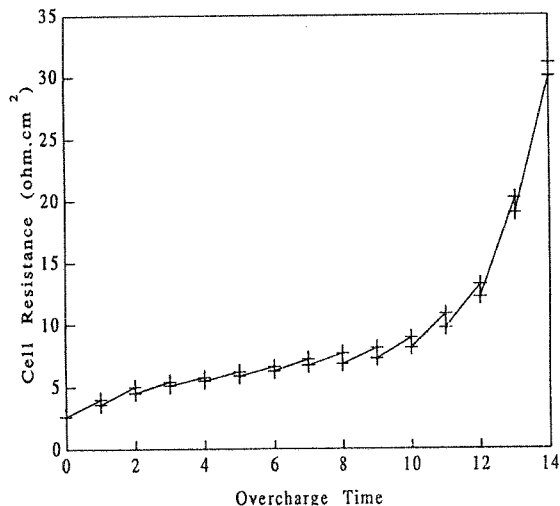


Figure 7: Effect of negative potential on cell resistance of overcharged cell ($i = 30 \text{ (mA.cm}^{-2}\text{)}$, $t = 10 \text{ (min)}$).

The cell resistance was used as a criterion for evaluation of the entire system resistance before and after overcharge. Due to expected oxidation of positive graphite current collector which can interfere with overall cell performance, after each overcharge experiment, cell resistance measurement was repeated after polishing and through washing of the positive current collector until an even, clean and conductive surface was obtained. Therefore, the cell resistance should reflect the effect of overcharge on the oxidation of the graphite felt rather than oxidation of the current collector by removing any interference because of the current collector.

In addition, the electrical resistivity of the graphite felt was also measured before and after overcharge. Any changes in electrical resistivity of the graphite felt electrodes which might be caused by damaged graphite fiber or formation of very low conductive graphite oxide were investigated.

To compare the results of this study with those obtained with others, the same graphite felt materials and also same overcharge conditions such as current density and oxidizing solution were employed.

Tables 2 and 3 show the effect of overcharge on the electrical resistivity of Sigrig graphite felt material in $2\text{M VO}_2^+/3\text{M H}_2\text{SO}_4$ solution at $20 \text{ (mA.cm}^{-2}\text{)}$ for 1 hr. As can be seen, even after 1 hour overcharging, volume and area resistivities of the positive side felt only increased to $0.15 \text{ } \Omega\text{.cm}^2$ respectively. In addition, very small increase in both volume and area resistivities of negative electrodes were observed.

Table 2: Effect of Overcharge on Volume Resistivity of Graphite Felt (Sigrig GFD5) Material, Overcharged with $2\text{M VO}_2^+/3\text{M H}_2\text{SO}_4$ for 1 (hr) at $20 \text{ (mA.cm}^{-2}\text{)}$.

Electrodes	Area resistance (ρ) ($\Omega\text{.cm}$)		$\Delta\rho$ ($\Omega\text{.cm}^2$)
	Before overcharging	After overcharging	
Positive	0.1040	0.2557	0.1517
Negative	0.1113	0.1203	0.009

$$\Delta\rho = \rho_{\text{after overcharge}} - \rho_{\text{before overcharge}}$$

From the comparison of Tables 3 and 4 it can be realized that although area resistivity of the positive side felt increased $1.57 \text{ } \Omega\text{.cm}^2$, comparing to the increase in area resistivity of graphite felt/conductive polymer electrode ($101.14 \text{ } \Omega\text{.cm}^2$), it is negligible. It was also observed that overall cell resistance after 1 hr overcharge was increased to $4.5 \text{ } \Omega\text{.cm}^2$ whereas for graphite felt/conductive polymer electrode, at same time, cell resistance was more than $65 \text{ } \Omega\text{.cm}^2$. Therefore, it can be concluded that the formation of functional groups on the surface of felt electrode should not be a major contributor to any serious changes in the electrical properties of the graphite felt/conductive composite electrodes. In other word, anodic oxidation or overcharge conditions are more effective for graphite/conductive polymer electrode than graphite felt alone.

Table 3: Effect of Overcharge on Area Resistivity of Graphite Felt (Sigrig GFD5) Material, overcharged with $2\text{M VO}_2^+/3\text{M H}_2\text{SO}_4$ for 1hr at $20 \text{ (mA.cm}^{-2}\text{)}$

Electrode	Area Resistivity (R) ($\Omega\text{.cm}^2$)		ΔR ($\Omega\text{.cm}^2$)
	Before overcharge	After overcharge	
Positive	0.35	1.92	1.57
Negative	0.36	0.35	0.17

$$\Delta R = R_{\text{after overcharging}} - R_{\text{before overcharging}}$$

Table 4: Voltage Efficiency Comparison of EPR Modified Carbon-Polypropylene Electrode with Two Commercially Available Electrodes.

Electrode	Voltage Efficiency
Toray Electrode (with Toray felt)	90.0
Graphite fiber-SEBS/heat treated Sigrig GFD5 felt electrode	89.0
EPR modified carbon-PP/heat treated Sigrig GFD5 felt electrode	95.0

However, in the case of graphite felt, the slight increase in resistivity under overcharge conditions is related to formation of electrochemically non-conductive "graphite oxide".

Effect of Overcharge on the Physical Properties of Carbon-Polymer Composite

To find out the main contributor to the graphite felt/composite polymer electrode deterioration, the overcharging time was increased to two hour. Physical detachment of the felt layer from is substrate; i.e. formation of a gap between the felt layer and the conductive composite substrate was observed.

Oxidation Behavior and Protection of Carbon Particles in the Conductive Carbon-Polymer Composite

There were two assumptions made about this phenomenon. Firstly, was oxidation degradation of the polymeric matrix and the secondly was the oxidation of black materials. More investigations revealed that the latter phenomenon is the main reason for the destruction of the composite substrate. Two anodic processes occur, namely formation of a surface oxide and evolution of CO₂. As the coverage of the of the surface by oxide increases, CO₂ evolution becomes the major reaction, the two processes, being independent of each other, since the surface oxidation does not inhibit CO₂ formation. The rate of oxidation is dependent on the surface microstructure for each specific carbon sample, with graphitized carbon showing lower specific oxidation rates than ungraphitized carbon.

Therefore, to find the solution for this drawback, a complete investigation and study was needed about carbon and graphite materials, their oxidation behavior, and oxidation protection of these conductive particles.

It is well known that in many aqueous solutions, backed carbon and electrographite may be electrooxidized to give a variety of anode gases, such as CO₂, CO and O₂ together with a proportion of carbon dust produced by undercutting. The relative proportions of the products vary with the type of carbon, solution composition (including pH), temperature, and current density.

Carbon protection of carbon composites is one of the most important unresolved issues in the quest for a new generation of material with high-specific-conductive properties. Although in the past decade, a large number of publication and a brief review have appeared on this topic, simulated by the increasing interest in using these materials in structural as well as ablative applications, a recent review of the state of knowledge in this area, a consensus emerged that a fundamental understanding of oxidation kinetics, inhibition and protection of carbon oxidation still does not exist.

In general, there are two different ideas about inhibitor utilization. The first one is addition of the inhibitors into the V(V) solution and then applying the current and the second one is impregnation of the carbon rod with inhibitors before using in the solution. Table 5 (a, b) summarizes the results of the first procedure. As can be seen from Table 5 (a, b), not only these famous in not prevent the CO₂ generation and consequently carbon

consumption, but also they precipitate in the V(V) solution. In addition, silicon carbide resulted in a retardation of V(V) reaction. As a result, it was found that the first procedure is not useful for the prevention of the carbon consumption. Therefore to find more about the effect of these materials in the vanadium solution, more studies are focused on the cyclic voltametry.

Table 5 a: Weight Loss Percentage of Carbon Rod Electrode in V(V) Solution.

Additive	Sample No.	Time		
		24 hrs.		
		Concentration (M)		
		Blank	0.02	0.2
Borax	1	2.3%	1.5%	2.4%
	2	3.5%	2.1%	2.2%
Boron carbide	1	2.3%	2.3%	2.0%
	2	3.5%	3.1%	2.5%
Silicon carbide	1	2.3%	3.3%	3.6%
	2	3.5%	3.1%	2.8%

Table 5 b: Weight Loss Percentage of Carbon Rod Electrode in V(V) Solution.

Additive	Sample No.	Time		
		48 hrs.		
		Concentration (M)		
		Blank	0.02	0.2
Borax	1	4.0%	-	-
	2	5.5%	-	-
Boron carbide	1	4.0%	-	-
	2	5.5%	-	-
Silicon carbide	1	4.0%	-	-
	2	5.5%	-	-

Furthermore, more tests were carried out to find some solvents for these additives. Table 6 summarizes the results of this trial. As can be seen only Borax is slightly soluble in the vanadium acidic media. However, it was observed that this procedure was not successful to inhibit the degradation of the carbon rod. More investigation revealed that sodium hydroxide may accelerate the degradation reaction. Up to 0.05M, Borax was soluble in water, sulphuric acid, V^{3.5+} and glycerin. However, addition of these solutions (with the additives) to the V(V) solution could not prevent the carbon degradation. In the case of glycerol, although up to 0.5M Borax is soluble in the boiling glycerol; the resultant solution was not able to prevent the degradation either.

Table 6: Solvent used for the Additives.

Additive	Solvent			
	Water	Sulphuric acid	K(OH)	Glycerin
Borax	Slightly soluble	Slightly soluble	Insoluble	Soluble
Boron carbide	Insoluble	Insoluble	Insoluble	Insoluble

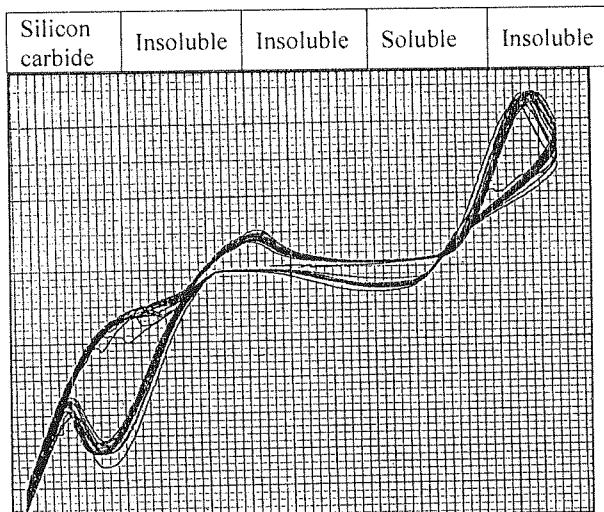


Figure 8: Cyclic voltammogram of waxed carbon rod (Scan rate: $4 \text{ (V.min}^{-1}\text{)}$, current converter: 20 (mA/V) , $X=5 \text{ (V/inch)}$, $Y=10 \text{ (V/inch)}$)

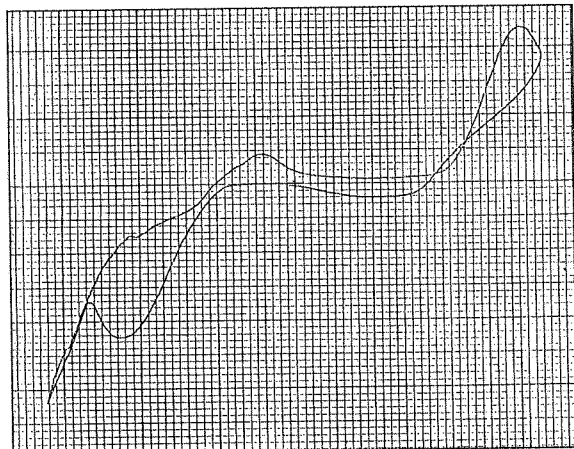


Figure 9: Cyclic voltammogram of waxed carbon rod.

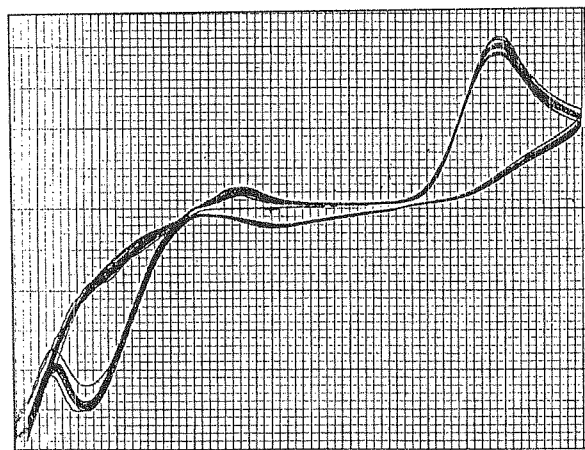


Figure 10: Cyclic voltammogram of carbon rod. (Additive = Borax in water, scan rate = 4 (V/inch) , $Y=10 \text{ (V/inch)}$, Current= 20 (mA/V))

As was mentioned before, the second procedure was impregnating of the carbon rod with inhibitors before using in the V(V) solution. The following tests were therefore carried out:

- a) Carbon rod was impregnated in boiling wax material. The experiment was continued until bubbling of the carbon rod stopped which showed that the soaking of the solution into the rod was completed. Then the carbon rod was tested for 24 hrs in the cell under the same conditions which were mentioned in the experimental section.
- b) Carbon rod was impregnated in 0.5M Borax in boiling glycerol. Then the carbon rod was tested under the same conditions as above.
- c) Since no strong solvent could be found which can dissolve the boron carbide completely, it was mixed and stirred boiling wax. Then carbon rod was impregnated with this solution. The carbon rod was tested under the same conditions as above.
- d) The same experiment was carried out for silicon carbide.

As a result, it was observed that impregnation of the carbon rod with boron or silicon carbide may reduce the carbon degradation. It was found that the carbon consumption was half of the normal rod.

Therefore, to study the effect of these materials and particles in the carbon-polymer composite electrodes, they were mixed with carbon black particles and then some end-electrodes were made.

Figures 11-12 show the results of these materials on the overcharge degradation of the polypropylene electrodes. It was observed that up to 2 wt% the additives could not prevent the degradation, although the electrical resistivity of the electrode was slightly increased.

Increasing the amount of the additives to 5wt% dramatically increased the electrical resistivity of the electrode and subsequently the cell resistance. As an important result, it can be observed from Figures 12 and 13 that the trend of the degradation was to slow down in both cases of boron and silicon carbides, which shows that although adding of these materials increases the electrical resistivity of the electrode, they could however, prevent the degradation to some degree. In addition it was observed that in the case of these materials, instead of 1 hr, delamination of the felt was happened after 3 hrs.

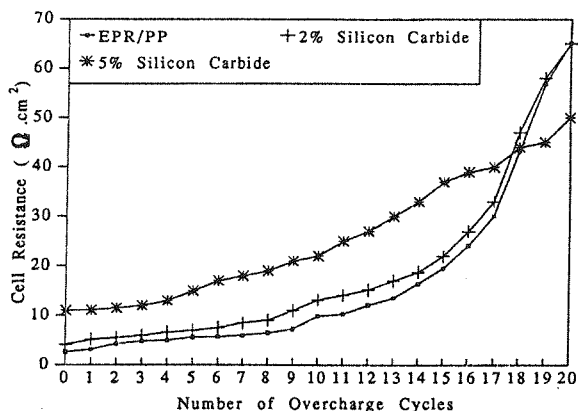


Figure 11: effect of silicon carbide on overcharge degradation of carbon-polymer composite electrode.

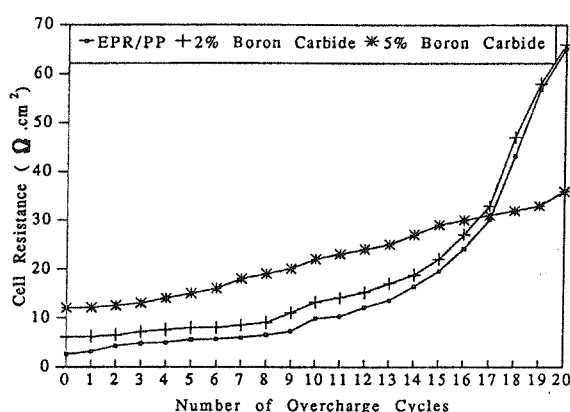


Figure 12: Effect of boron carbide on the overcharge degradation of carbon-polymer composite electrode.

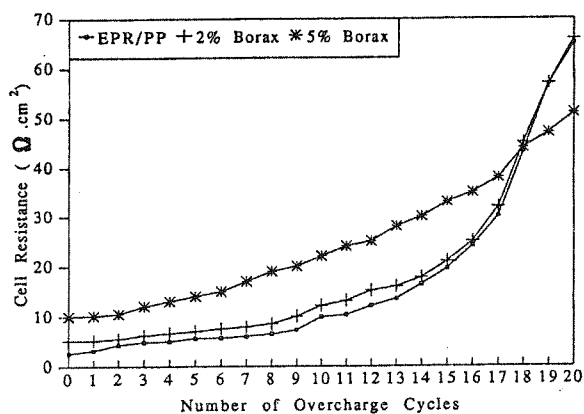


Figure 13: Effect of Borax on the overcharge degradation of carbon-polymer composite electrode.

applications, but the results have revealed that the deactivation of graphite felt/composite electrode after severe anodization is irreversible mainly due to damage to electrical contact at interface between the felt/composite polymer substrate.

It was also found that neither electrochemical oxidation of felt nor physical detachments of the felt layer from its substrate is the main reasons for conductive polymer electrodes deterioration. The polymer destruction under highly oxidizing overcharge V(V) solution is the real mechanism for conductive polymer electrode deterioration.

However, the composite electrodes fabricated in this project have been shown, under overcharge condition, to be about 10 and 3 times more stable than Toray and graphite fiber filled SEBS composite electrodes respectively. These electrodes are thus superior to the commercial electrodes for application in the vanadium redox battery.

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CONCLUSION

Although cell performance tests with graphite felt/EPR modified carbon-polypropylene composites electrode in the vanadium redox battery have shown that these electrodes are promising for vanadium battery