Chapter V

Redox Ion Exchanger Fuel Cell
Our conventional sources of energy, such as fossil fuels, hydroelectricity and nuclear energy, each has its own limitations and associated hazards. This necessitates the development of sources of energy other than the conventional ones. The possibility of finding new sources of energy has been highlighted recently in our country.\textsuperscript{1} Much emphasis has been given to research needs for advanced fuel cells.\textsuperscript{2} Its technology and applications have also been studied.\textsuperscript{3}

In general a hydrogen/oxygen fuel cell is used in which electrodes are made of titanium coated with platinum and the electrolyte is a cation exchange resin.\textsuperscript{4} Oxygen is normally the oxidant and hydrogen is most widely used fuel. The energy producing reaction is the oxidation of hydrogen by oxygen.

Ion exchangers have been widely used as an electrolyte in fuel cells. Fugita et al.\textsuperscript{5} have made a fuel cell in which a combined body of cation exchange membrane electrolyte between two electrodes had porous collector of sintered Ti fibers pressed on electrodes. A sulfonated perfluorocarbon cation exchange membrane
was coated with Pt to form a cathode on one side and with Rh on the other side to form anode. Mucoyama and Hirai\textsuperscript{6} made fuel cells using electrolytes which were prepared from particles of strongly acid cation exchange resin. The resin particles were made into paste with the addition of water and SiC powder and filled into the cavity between the fuel (MeOH) anode and an ion exchange membrane covering the oxidant (air) cathode. A fibrous ion exchanger sheet has been used as an electrolyte in a fuel cell prepared by Mitsubishi Rayon Co. Ltd. Japan.\textsuperscript{7} The fibrous cation exchanger bonded on a Ni mesh core to prepare an electrolyte was sandwiched between an anode and a cathode. Kummer and Oei\textsuperscript{8} prepared a chemically regenerative redox fuel cell in which a suitable cation exchange memberane was housed in a housing provided with opennings on opposite sides of the membrane for the catholyte and anolyte respectively so that necessary exchange may take place to form a redox cell.

The present work was undertaken to study the usefulness of a redox reaction between Fe\textsuperscript{3+} and Zn on an ion exchanger bed for the preparation of a fuel cell. A comprehensive review of the literature reveals that Zn\textsuperscript{2+}/Zn and Fe\textsuperscript{2+}/Fe\textsuperscript{3+} system has not been used for the
preparation of redox ion exchanger fuel cells so far. The system in question has been chosen because of a significant difference between the electrode potentials of $\text{Zn}^{2+}/\text{Zn}$ and $\text{Fe}^{2+}/\text{Fe}^{3+}$ couples. Moreover, the system becomes further important owing to its low cost, easy availability and the ease with which the redox ion exchanger can be prepared i.e. simply by incorporating $\text{Fe}^{3+}$ ion in an easily available cation exchange resin (e.g. Dowex 50 W X 8). The redox ion exchanger so formed can be regenerated after use. Most of the ion exchanger fuel cells reported in literature$^{5-8}$ suffer from several shortcomings. Their assemblies are either too complicated hence need sophisticated operators, or the procedures for making them are cumbersome. Our redox ion exchanger fuel cell (REFC) requires a very simple assembly and the operation is very easy yet it furnishes a voltage of $0.69 \pm 0.05$ V which is comparable with the magnitude of voltage obtained from other fuel cells using ion exchangers.
V.2 EXPERIMENTAL

V.2.1 Electrode Material for REFC: In the present investigation a redox ion exchanger has been used for the construction of the electrode. Redox ion exchanger was prepared from Dowex 50 W X 8 cation exchange resin by replacing the counter ion by $\text{Fe}^{3+}$ ion. Standard electrode potential of the couple $\text{Fe}^{2+}/\text{Fe}^{3+}$ is little affected by incorporation of the couple into the ion exchanger. Dowex 50 W X 8 was kept in one molar solution of ferric nitrate for 24 hours then it was washed thoroughly with distilled water and was dried at 30±1°C. The resulting redox ion exchanger was packed in a glass tube narrow at one end fitted with glass wool.

V.2.2 Design and Working of REFC: Redox ion exchanger (5 g) packed in a glass tube worked as cathode while zinc metal was used as anode. Both the electrodes were dipped in a beaker containing one molar solution of zinc nitrate (50 ml). Connections were made through a copper wire. Although platinum wire gives better results, the use of copper wire is recommended to keep the cost low. A multimeter was used for voltage and current measurements. A schematic diagram of the REFC is given in Figure V.1.
Figure V.1 A redox ion exchanger fuel cell
The concentration of zinc nitrate solution was kept constant at one molar and that of \( \text{Fe}^{3+} \) ion in the redox exchanger at one molal, to maintain standard conditions. Electrode potentials were calculated using Nernst equation. Electrode potentials of the couples \( \text{Fe}^{2+}/\text{Fe}^{3+} \) and \( \text{Zn}^{2+}/\text{Zn} \) were found to be +0.771 volts and -0.763 volts respectively. Since electrode potential of the couple \( \text{Zn}^{2+}/\text{Zn} \) is lower than that of the couple \( \text{Fe}^{3+}/\text{Fe}^{2+} \), the former is oxidised and furnishes electrons to the latter. The energy producing reaction is oxidation of the substrate by the redox ion exchanger.

\[
\text{Zn} \rightleftharpoons \text{Zn}^{2+} + 2e^- \quad \text{at anode} \quad \ldots \quad (1)
\]
\[
2\text{Fe}^{3+} + 2e^- \rightleftharpoons 2\text{Fe}^{2+} \quad \text{at cathode} \quad \ldots \quad (2)
\]
so that net reaction is

\[
\text{Zn} + 2\text{Fe}^{3+} \rightleftharpoons \text{Zn}^{2+} + 2\text{Fe}^{2+} \quad \ldots \quad (3)
\]
V.3 RESULTS

From a single cell, a voltage of $0.69 \pm 0.05$ V and $370 \pm 70$ $\mu$A current was obtained. Voltage and current data for six similar redox ion exchanger fuel cells are summarized in Table V.1.

**TABLE - V.1**

Voltage and current data for six similar redox ion exchanger fuel cells

<table>
<thead>
<tr>
<th>Cell No.</th>
<th>Voltage V</th>
<th>Current mA</th>
<th>Standard deviation</th>
<th>Relative standard deviation</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>For voltage V</td>
<td>For current mA %</td>
</tr>
<tr>
<td>1</td>
<td>0.64</td>
<td>0.42</td>
<td>0.027 absolute value</td>
<td>0.037 absolute value</td>
</tr>
<tr>
<td>2</td>
<td>0.72</td>
<td>0.34</td>
<td>0.027 absolute value</td>
<td>0.037 absolute value</td>
</tr>
<tr>
<td>3</td>
<td>0.70</td>
<td>0.34</td>
<td>3.92</td>
<td>10.00</td>
</tr>
<tr>
<td>4</td>
<td>0.68</td>
<td>0.34</td>
<td>0.027 absolute value</td>
<td>0.037 absolute value</td>
</tr>
<tr>
<td>5</td>
<td>0.70</td>
<td>0.41</td>
<td>0.027 absolute value</td>
<td>0.037 absolute value</td>
</tr>
<tr>
<td>6</td>
<td>0.69</td>
<td>0.38</td>
<td>0.027 absolute value</td>
<td>0.037 absolute value</td>
</tr>
</tbody>
</table>

The magnitude of the current and voltage of the redox ion exchanger fuel cell was increased by connecting the cells in series and parallel. The results are summarized in Table V.2.
TABLE - V.2

Increase in voltage and current on connecting the redox ion exchanger
fuel cells in series and parallel

<table>
<thead>
<tr>
<th>Type of connection</th>
<th>Number of cells</th>
<th>Theoretical value</th>
<th>Experimental value</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Voltage V</td>
<td>Current mA</td>
</tr>
<tr>
<td>(a) Series</td>
<td>2</td>
<td>1.38</td>
<td>0.37</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>2.76</td>
<td>0.37</td>
</tr>
<tr>
<td>(b) Parallel</td>
<td>2</td>
<td>0.69</td>
<td>0.74</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>0.69</td>
<td>1.48</td>
</tr>
</tbody>
</table>
V.4 DISCUSSION

For six redox ion exchanger fuel cells voltage and current measurements were made individually. It is clear from Table V.1 that the value of voltage varies from 0.64 to 0.72 V whereas the value of current lies within 340 to 420 μA range. The voltage was taken as a steady state voltage. Standard and relative standard deviations for voltage and current measurements were also computed (Table V.1). These results show the reproducibility of the redox ion exchanger fuel cell.

The magnitude of the voltage was increased additively by connecting more cells in series. For example when four cells were connected in series a voltage of 2.43 V was obtained which is in good agreement with a theoretically expected value of 2.76 V (Table V.2). The theoretical value of voltage for four cells in series is simply four times the voltage due to a single cell. A little discrepancy seen between the observed and theoretically predicted value may be attributed to experimental errors. The same arrangement of four cells in series furnishes a current of 370 μA which is sufficient enough to display on electronic calculator. When the cells are connected in parallel
the current increases additively. Table V.2 shows that
on connecting four cells in parallel 1.30 mA current
is obtained which is approximately four times the current
due to a single cell. The experimental value is in
agreement with the theoretical value (1.48 mA). A fuel
cell system consists of fuel cell stacks connected in
parallel.\[^{11}\]

One difficulty was observed with this redox
ion exchanger fuel cell that an internal resistance
is produced on loading the cell (Figure V.2). As a result
there was a voltage drop in the cell and somewhat lesser
voltage was available to the load. However, internal
resistance can be minimized by connecting more cells
in parallel.

The number of fuel cells required to obtain
10 mA current were calculated. The voltage obtained
from four cells connected in series, without loading
was 2.43 V. On connecting a 1.5 V bulb (load) there
was a voltage drop and only 1.515 V were available to
the load.

\[
\text{Therefore voltage drop} = 2.43 \text{ V} - 1.515 \text{ V} \\
= 0.915 \text{ V}
\]

\[
\text{Current measured} = 370 \text{ mA} = 370 \times 10^{-6} \text{ A}
\]
Figure V.2 Circuit diagram of REFC showing internal resistance
\[ \text{Internal resistance} = \frac{0.915 \text{ V}}{370 \times 10^{-6} \text{A}} \]
\[ = 2472.97 \text{ Ohm} \]

Since current required is 10 mA, the resistance should be minimized to a value

\[ = \frac{0.915 \text{ V}}{10 \times 10^{-3} \text{A}} \]
\[ = 91.5 \text{ Ohm} \]

Now number of fuel cell stacks connected in parallel

\[ = \frac{2472.97 \text{ Ohm}}{91.5 \text{ Ohm}} \]
\[ = 28 \]

Where each fuel cell stack consists of four cells connected in series.

The theoretical calculations suggest that 112 cells are required to obtain 10 mA current. There are 28 such fuel cell stacks and all these 28 fuel cell stacks should be connected in parallel. The resulting fuel cell system can furnish a voltage equal to 2.43 volts and 10 mA current. Although, these calculations are purely theoretical and have not been put to any experimental test, they may give an idea about the number
of cells required to obtain 10 mA current.

Redox ion exchanger fuel cells have many advantages over others such as their low cost, pollution free operation, regenerative nature and easy reaction conditions. However, they require further improvements in current, voltage output and need to be more compact for their development.
REFERENCES


