CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

This thesis study was aimed at various aspects of hydrogen generation by electrolysis of water. Based on the experimental results and analysis, the following conclusions are summarized below:

1. Electrodes prepared, by various types of electrodeposition like direct current method, pulse method, sonoassisted direct current method, sono assisted pulse electrodeposition method, from Nickel intercalated with zinc and sulphur embedded in a nickel matrix were investigated as anode materials in alkaline electrolysis. When compared to direct current electrodeposition, pulse electrodeposition enabled higher cathodic current density to be applied at the electrode interface due to the higher concentration of metal ions at the surface of the electrode. The ultrasonic agitation of the plating bath increased surface smoothness and decreased the residual stresses. The findings proved that the plating current density of 40 mA/cm$^2$ and pulse 40 % duty cycle in presence of ultrasonic agitation was the best suited one to produce high surface area electrodes for alkaline electrolysis. A high current density of 0.42 A/cm$^2$ and exchange current density
of $8.25 \times 10^{-3}$ A/cm$^2$ was achieved in pulse-sono electrodeposited electrodes.

2. Nickel is known to form nickel citrate complexes with citric acid preventing precipitation of nickel hydroxide when dipped into alkaline solution. Citric acid was added as an electrolyte additive during electrolysis of water to stabilise the active form of the catalyst and improve efficiency. A study was carried out to optimise the amount of electrolyte required to achieve optimum performance. An increase in the current density of about 25% resulted at the temperature of 30°C in the presence of 0.2 wt. % of CA at 1.0V vs Hg/HgO, as the CA distributed throughout the Nickel matrix created more organized transfer channels to produce high surface area electrodes for alkaline water electrolysis. SEM and XRD figures obtained after electrolysis confirm the deposition of the metal on the surface of the electrode from the complex. This form of deposit was very active and improved the catalytic activity of the electrode. Complex formation improved wettability and the bridging ability between the electrolyte and metal surfaces and helped in to transfer ions between the two phases. Thus, through simple processing, high current density and good efficiency was obtained.

3. A non-noble metal based alkaline anion exchange membrane water electrolyzer was fabricated with hybrid electrode. The cathode was a pulse electrodeposited ternary alloy of Ni and the anode was a hybrid graphene oxide coated oxidized Ni electrode. The surface groups of graphene oxide adhered to the Ni electrode through electrostatic attraction of the groups
forming a continuous film. The hybrid electrode had lower resistance and provided higher surface area for contact with the membrane improving the electrochemical properties. The resistance of the electrodes was found to decrease with increasing temperature. The anion exchange membrane water electrolyzer with the hybrid electrode gave a current density of 90 mA/cm² at 30°C and with deionised water compared to 60 mA/cm² for the conventional electrode at 2V. Performance was found to increase with increase in temperature and with the use of alkaline solutions. A maximum performance of 590 mA/cm² was obtained at 2V with 30% KOH solution as electrolyte at 80°C with hybrid electrodes when compared to 326 mA/cm² with the uncoated electrodes. Stable performance was obtained when the electrodes were operated for long duration at high current densities.

4. The nanocomposite membranes were prepared using CNT and GO as fillers with a sulfonated polysulfone as the polymer matrix. The nanocomposite membranes consisting of SPSF-GO offered improved conductivity and higher performance in terms of current density than those of SPSF-CNT membranes. A high current density of 1.39 A/cm² was
performance low cost membranes with high performance could be obtained using GO as fillers for many electrochemical applications.

5. The composite membranes were prepared by Sol-gel method. The electrochemical properties, tensile strength, swelling, and dimensional stability were improved with the addition of fillers and blended with CsSiWA to avoid excessive swelling was reduced in the presence of water. The fillers also improved the mechanical properties of the membranes. SPEEK- CsSiWA-ZrO$_2$ composite membrane showed near comparable performance to Nafion® 117 due to high proton conductivity as well as high IEC values. The addition of CsSiWA and zirconium oxide in the SPEEK polymer organic matrix enabled the preparation of composite membranes with a wide range of properties concerning proton conductivity, water uptake and IEC values. The results of SEM and AFM showed that the chain length of the ionic channels increases with increase in ionic conductivity. Further, our experimental results suggest that conventional brush coating method has superior performance than the impregnation reduction method.

5.2 RECOMMENDATION FOR FUTURE RESEARCH
recommendations were identified as to further improve the further research directions:

1. We believe the role of stabilizers deserves further investigation and is a good candidate for use in various energy applications.

2. Molecular modelling investigation on the possible role of fillers in polymers will shine light on proton transport mechanism for electrolysers systems.

3. Study the effect of ionomer impregnation on the electrodes in alkaline anion exchange membrane based water electrolysis technique.

4. Studies on the durability of alkaline anion exchange membranes for hydroxyl ion transport in water and other alkaline solutions.

5. Scale up of the cells developed to demonstrate large-scale water electrolyzers based on the materials developed.