6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusion

The aim of this research is to synthesize Proton Exchange Membrane (PEM) from polystyrene butadiene rubber locally available in South Africa. It also intends to fortify the synthesized membrane with carbon nanoballs synthesized by the Swirled Floating Chemical Catalytic Vapour Deposition (SFCCVD) method, with the intention of improving its properties. Such properties include: proton conductivity, methanol crossover, water uptake, thermal stability and the membrane performance in fuel cell.

The significant outcomes of this research are:

1. The non-catalytic synthesis of carbon nanoballs with diameters in the ranges 50 – 250 nm was undertaken in this research, using a continuous process swirled floating catalytic chemical vapour deposition reactor. The carbon nanoballs were produced using the direct pyrolysis of acetylene gas without the presence of a catalyst. A maximum production rate of about 0.35 g min\(^{-1}\) was obtained at an acetylene flow rate of 370 ml min\(^{-1}\) and a pyrolysis temperature of 1000\(^{\circ}\)C. This production rate gives an indication that this process allows for the large scale production of these materials. The carbon spheres produced were of uniform diameter and the size (nano or micro) was controlled by changing the pyrolysis temperature as well as the acetylene and argon flow rates. However, the effect of the gas flow rates displayed a larger impact on the size of the carbon spheres compared to the temperature effect. As the Ar flow rate increased, the amount of material increased and the size of the spheres became smaller.

2. The chemical modification of a locally available Polystyrene butadiene rubber (PSBR) to serve as an efficient and novel alternative to Nafion\(^{\circledast}\) for proton
exchange membrane fuel cell is possible. This involves carefully controlled
sulphonation with a well tailored degree of sulphonation in the ranges of 2.39-
39.38%. Results obtained showed that the concentration of sulphonating agent,
sulphonation time, stirring speed, weight of the polymer and sulphonation
temperature affect the qualities of the membranes synthesized. It was interesting
to discover that the membrane synthesized in this study overcomes the known
problems of methanol cross-over in spite of its good proton conductivity in the
ranges of $10^{-3}$ - $10^{-2}$ S/cm. The membrane also displayed good water uptake and
thermal stability up to 450°C depending on the degree of sulphonation, making it
fit for fuel cell application. However it was noted that the membrane requires
proper humidification in fuel cell operation.

3. The blending of the synthesized membrane with carbon nanoballs greatly
influenced its qualities’. Results obtained revealed that such a blending
significantly improved the thermal stability, water uptake, porosity, solvent
uptake, methanol crossover and proton conductivity of the membrane, with a
more than 50% increment compared to that of a non-blended membrane. The
results of various analyses conducted also confirm that the synthesized membrane
shows better qualities than Nafion 112, which is the commercially available
membrane.

4. The synthesized blended and non-blended membranes were sandwiched between
two electrodes to produce a membrane electrode assembly (MEA) using the hot
press method at a constant condition of temperature, pressure and time. The
performance of the fabricated MEA was tested in a single PEM fuel cell using
hydrogen as the fuel gas and oxygen as the oxidant at room temperature (about
25°C). Results obtained revealed that the utilization of sulphonated PSBR
resulted in higher performance compared to Nafion 112. Nafion 112 produced a maximum power density of $0.0669 \text{ W/cm}^2$ while the membrane synthesized from PSBR generated a maximum power density of $0.0737 \text{ W/cm}^2$. This difference corresponds to about a 10.16% increment. Also, the membrane blended with CNBs exhibits a superior performance to a non-blended membrane. The former gives a maximum power density in the range of $0.0737-0.0971 \text{ W/cm}^2$ depending on the mass of CNBs. These values are about 6.9-31.75% higher than those of the non-blended membrane. It can be inferred from the performance evaluation of the synthesized membranes that blended membrane is superior to non-blended membrane, which is in turn better than the Nafion 112 in terms of qualities and performance. The cell potential ($E$) against the current density ($i$) data at different masses of CNBs in the composite membranes is analyzed by fitting the data into the model equation: $E = E_0 - Aln i - Aln i_0 - iR - \gamma \exp (\omega i)$. Simulation of the model equation indicated that the calculated results conform to the experimental results with the standard error of 0.028-0.030.

6.2 Recommendations

1. The blending of the composites membrane with selected nanomaterials such as silicon oxide, phosphotungstic acid and a mixture of both can help to improve the qualities of the membrane. Further study should be conducted on the influence of atmospheric conditions and viscosity of the membrane on membrane casting techniques.

2. The effects of various parameters such as operating temperature, pressure, flow rate of gases and humidification on the performance of the membrane in the fuel cell stack should be investigated.

3. Long term performance of the membrane in the fuel cell should be investigated.