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Production of ion exchange membrane for hydrogen fuel cell

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ABSTRACT

Among of the components of the fuel cell, the polymer electrolyte membrane is critical to the performance and life time of the cell. Over the years the mechanical properties of the membrane, water management have tended to limit its wide spread commercialization as an alternative source of the renewable energy for portable power units. Fuel cell continues to attract extensive research interest as potential source of renewable energy. This work focuses on the production of ion-exchange membrane (IEM) for hydrogen fuel cell, using cheap and locally available starting materials. The polystyrene-butadiene rubber (SBR) of different styrene and butadiene compositions, have been explored for functionality in fuel cell application. The production process was conducted in three stages: the first stage involved hydrogenation process followed by sulfonation process. The second stage entailed the production of carbon nano-spheres for the blending in the hydrogenated sulfonated polystyrene-butadiene rubber. The blending was also done between hybrid nanoparticles and hydrogenated sulfonated polystyrene-butadiene rubber. The third stage was the casting in thin film of blended solutions employing the evaporative method and the use of casting tape machine technique. The thin film was later on characterized and tested in a single fuel cell stack.

Controlled hydrogenation of SBR employing catalytic method was achieved with maximum degree of hydrogenation in the range of:

- 90 – 92% for SBR with 23.5% styrene content and for SBR 25% styrene content
- 76 – 80% for SBR with 40% styrene content and
- 82 – 92% for SBR with 52% styrene content.

The optimum conditions of this process were obtained using the Design of Experiments.

SBR was also hydrogenated using a photocatalytic method and the percentage of hydrogenation for all SBR compositions used was found in the range between 60 and 74%. The hydrogenation results using the catalyst were higher compared to those obtained with the photocatalytic method. Therefore they were used to develop the kinetic model for prediction of hydrogenation process. Langmuir – Hinshelwood models were reviewed in this project as they explain these heterogeneous catalytic processes. Data from the kinetic tests were fitted to Langmuir – Hinshelwood models and reaction constants were found in the range between 0.445 h^{-1} and 0.610 h^{-1} for the reaction temperature between 20 and 30°C.

The hydrogenated SBR of different compositions were effectively sulfonated with chlorosulphonic acid employed as first sulfonating agent of concentrations 0.15, 0.175 and 0.25M for SBR 23.5 and 25% styrene content, for SBR 40% styrene content and for SBR 52% styrene content, respectively. The degree of sulfonation was found in the range between 56 and 72% depending on the rubber composition. Trimethylsilyl chlorosulfonate used as the second sulfonating agent was like wise attached to the same polymer back bone and the degree of sulfonation was between 59 and 74% depending on the rubber's styrene content.

Non-conductive carbon nanospheres (CNS) of uniform size of about 46 nm were produced employing the non-catalytic chemical vapour deposition method at 1000°C. Acetylene and argon were respectively used as carbon source and carrier gas, in a reactor of 16 mm in diameter. Successful blending of 4 wt% nanoparticles and hydrogenated sulfonated styrene butadiene solution was accomplished by magnetic stirring technique combined with ultrasonication at 60% amplitude. The blended solution was casted to produce a thin film membrane of 156 µm thickness. Further the tensile strength test of the membranes has shown an increase in Young's Modulus by 72-120% for all the rubbers. This test was done using TA.XT$^{\underline{plus}}$, Texture Analyser machine. The water uptake increment was in the range of 20-27% and thermal stability in the range of 2-20% depending on the rubber composition. Purchased electrodes from FuelCellsEtc (USA), were pasted on both sides of the membranes by the means of hot press at 125^{o}C for about 5 minutes at a pressure of 40 kPa. The Membrane Electrode Assembly (MEAs) fabricated were tested in the fuel cell stack. The highest power density of approximately 85mW/cm^2 was obtained for 52% styrene nanocomposite membrane with 4% hybrid nanoparticles at the current density of 212.41mA/cm^2 and the efficiency was between 41 and 43%. MEA fabricated with Nafion112 membrane was tested and yielded the open cell voltage of 0.79V, power density of about 77.34mW/cm^2 and efficiency of 45%. Results obtained disclose that the MEA with nanocomposites based SBR 52% styrene composition yielded higher power density and higher voltage than the one with Nafion 112 which is one of the fuel cell membranes available on the market. The results obtained revealed that the nanocomposite membranes with 4% hybrid nanoparticles (CNS + SiO_2) had higher voltage than the one with 4% CNS. These optimum conditions obtained in this work may be adopted for a typical continuous production of the membrane for hydrogen fuel cell.