CHAPTER 6

CONCLUSIONS

The low-temperature hydrogen-based proton exchange membrane fuel cells are becoming more popular due to their ability to use a proton exchange membrane (PEM) without any harmful emission. The PEMFCs are both silent and portable also can be used as stationary source of energy in remote areas. However, the cost of energy production using PEMFC is high due to the high cost of Pt-based electrocatalyst used. Thus, a special emphasis was given to develop bimetallic cathode electrocatalyst to replace pure Pt metal electrocatalyst. In this thesis, the low cost laboratory synthesized Pd-Co/C_{AB}-EG and Pt-Ni/C_{AB}-EG cathode electrocatalyst synthesized in the present work were used in hydrogen-based proton exchange membrane fuel cell. The active component of cathode electrode i.e., electrocatalysts were synthesized in laboratory and further characterized by physicochemical characterization and electrochemical characterization techniques for the use PEMFC. The performance of synthesized anode electrocatalysts were promising in terms of power density.

6.1 Cathode electrocatalyst characterization

6.1.1 Physical characterization

The solvothermal process was used to synthesize the Pt-Co/C_{AB} and Pt-Ni/C_{AB} cathode electrocatalysts in laboratory of various atomic ratio of Pt to Co and Pt to Ni i.e., 3:1, 1:1 and 1:3 using different of solvents as like DMSO, DMF, EG and Water, respectively. In every synthesized electrocatalyst, the support material acetylene black was fixed at 80 wt. % and metal loading with 20 wt. % in both Pt-Co/C_{AB} and Pt-Ni/C_{AB} cathode electrocatalysts. The XRD, SEM, EDX, and TEM were used for physicochemical characterization. The XRD characterization indicates that

the face-centered cubic (FCC) for Pt at plane (220) diffraction peaks are prominent and that the Pt-Co(3:1)/C_{AB}-EG electrocatalysts were all synthesized were crystalline in structure. This considerable displacement of 2-theta indicates the incorporation of Co into Pt metal of the FCC structure, leading to the alloy production of Pt-Co/C_{AB}. The Pt-Ni(3:1)/C_{AB}-EG XRD patterns show that the synthesized electrocatalysts have a face-centered cubic (FCC) structure with a highly crystalline Pt-phase. All Pt-Ni/C_{AB} alloy electrocatalysts fall within a range of lattice parameters between pure Pt (0.3924 nm) and pure Ni (0.3523 nm). The SEM analysis was used to examine the surface morphology of all the synthesized Pt-Co/C_{AB} and Pt-Ni/C_{AB} electrocatalysts. The synthesized metal particles are mostly spherical nanoparticles in shape homogeneously distributed on support material. The EDX analysis make possible to determine the surface composition, metal concentration, and carbon support in all electrocatalysts. The EDX analysis shows the presence of all the elements, i.e., Pd, Pt, and C for Pd-Pt/C_{AB} and Pd, Ni, and C for Pd-Ni/C_{AB} electrocatalyst. The TEM analysis was used to determine the average particle size and distribution of every synthesized electrocatalyst. The TEM images show that every electrocatalyst is in the nano range in size and is uniformly distributed throughout the support material. The physical characterization show that the synthesized electrocatalysts and Pt-Co(3:1)/C_{AB}-EG and Pt-Ni(3:1)/C_{AB}-EG are better than other synthesized electrocatalyst using different solvents like DMSO, DMF and water.

6.1.2 Electrochemical characterization

The cyclic voltammetry (CV) and electrochemical impedance spectroscopy (EIS) studies were used to characterize the electrochemical properties of the synthesized electrocatalyst. The cathode electrocatalyst Pt-Co(3:1)/C_{AB}-EG and Pt-Ni(3:1)/C_{AB}-EG exhibited the higher positive peak potentials in the CV analysis. The oxygen peaks were observed at peak position of +1.25 V and

+0.43 V with corresponding current density of 0.45 mA/cm^2 and 1.80 mA/cm^2 for the cathode electrocatalyst Pt-Co(3:1)/C_{AB}-EG and Pt-Ni(3:1)/C_{AB}-EG, respectively. In ORR both cathode electrocatalyst follow the one step four electron transfer pathway to reduce oxygen in acidic medium.

However, according to the EIS analysis, the Pt-Co/C_{AB}-EG had the lowest charge transfer resistance, among all synthesized Pt-Co(3:1)/$C_{AB.}$ The physical and electrochemical characterization confirms that Pt-Co(3:1)/C_{AB}-EG and Pt-Ni(3:1)/C_{AB}-EG are better among all Pt-Co/C_{AB} and Pt-Ni/C_{AB}.

6.2 Single cell performance

The synthesized cathode electrocatalyst Pt-Ni/C_{AB}-EG displayed superior cell performance, over Pt-Co/C_{AB}-EG according to PEMFC study. In PEMFC, using Pt-Co (3:1)/C_{AB}-EG electrocatalyst at room temperature the maximum OCV of 0.896 V, and maximum power density of 19.46 mW/cm^2 were obtained whereas at higher temperature of 60 ºC, maximum OCV of 0.890 V and maximum power density of 26.11 mW/cm^2 were obtained. The Pt-Ni(3:1)/C_{AB}-EG in PEMFC at room temperature of 33ºC produced the maximum OCV of 0.909 V and maximum power density of 25.56 mW/cm^2. At higher temperature of 60 ºC, Pt-Ni(3:1)/C_{AB}-EG produced maximum of OCV 0.908 V and maximum power density of 42.29 mW/cm^2. The maximum power density was 61.67% higher for Pt-Ni(3:1)/C_{AB}-EG electrocatalyst at the cell temperature of 60ºC when compared with Pt-Co (3:1)/C_{AB}-EG electrocatalyst.

6.2.3 Optimization of cell parameters using RSM

The effect of process parameters in hydrogen based PEMFC, such as cathode electrocatalyst loading (A), cell temperature (B) and hydrogen flow rate (C), on the power density as a response

(Y), was investigated using the Box Benkhen design (BBD) tool in response surface methodology (RSM). This was followed by process parameter optimization to achieve the highest power density. The RSM study indicates that the operational parameters have an impact on power density (Y) in the following order: A > C > B. This implies that cathode electrocatalyst loading (A) has a greater impact on power density than cell operating temperature (B), which has the least effect on power density of PEMFC. The quadratic model was developed to optimize operating conditions as it perfectly fitted the experimental data. The predicted optimum parameters for the following variables were identified: 0.99 mg/cm^2 for cathode electrocatalyst loading (A), 60.84 ^{o}C for cell temperature (B) and 49.97 ml/min for hydrogen flow rate (C). The maximum power density produced from the single cell experiment under the predicted optimum conditions was 42.19 mW/cm^2, which was 0.31% less than the predicted power density value of 42.32 mW/cm^2. Thus, it can be concluded from the current study that RSM operational parameter optimization is important to achieve higher cell performance at their optimum process parameter conditions.

6.3 Future scope

Form the present research work it was found that Pt-based synthesized cathode electrocatalyst Pt-Ni/C_{AB}-EG provides the significant performance in PEMFC. So, it shows a promising future for the application in the portable devices as well as automobile industries. The other noticeable benefits are its compactness, easy handling, cost, low operating temperature, renewable and high efficiency. Operating PEMFC under optimized condition using Pt-Ni/C_{AB}-EG as cathode electrocatalyst could provide an idea for the development of low temperature hydrogen based cost effective proton exchange membrane fuel cell (PEMFC) to fulfill the future energy demand.

However, the present study has also identified several crucial areas for future research. One significant avenue is the optimization of PEMFC stacks to achieve higher power densities, focusing on improving the efficiency and performance of the overall system. Another promising direction is the development of metallic (stainless steel) bipolar plates tailored specifically for PEMFC workstations, along with modifications in flow channel geometry aimed at reducing electrode area and cell size. Additionally, exploring tri-metallic cathode electrocatalysts holds promise for enhancing the oxygen reduction reaction, thereby boosting cell performance in terms of power density through improved reaction kinetics and reduced activation losses at the cathode electrode. Furthermore, extending the operational period of cells to ensure stability over longer durations is a critical objective for advancing the practical application of PEMFC technology.