Abstract

Fuel cells generate electricity with high energy efficiency and zero emissions. Among various types of fuel cells, the proton exchange membrane (PEM) fuel cell is more suitable for the automotive sector due to its better transient operation. The power density improves with an increase in current density; however, its energy efficiency decreases. Simultaneous improvement of both energy efficiency and power density in a PEM fuel cell is a technical challenge in fuel cells.

This research work is mainly focused on the characterization of materials for electrodes, and the enhancement of energy efficiency and power density using graphite-graphene electrode combinations and oxygen-enriched air from 23% oxygen (base) to 100%. It is observed from the Raman Spectra result indicates the sp^2 hybridised lattice, showing that the graphene material has a higher electrical conductivity (10^4 S/cm) compared to graphite (100 S/cm). The higher contact angle for graphene (154.3°) compared to graphite (107.8°) shows the superior hydrophobicity, facilitating the efficient water removal for avoiding water flooding and pore blocking.

In the next phase, the experimental tests were conducted on a hydrogen PEM fuel cell with different graphite-graphene electrode (anode and cathode) combinations, and the final phase with oxygen-enriched air (23% to 100% by mass). The experimental results indicate that the performance of the fuel cell is the highest with graphene (anode) - graphite (cathode) electrode combinations compared to other material combinations (graphite-graphite, graphite-graphene, graphene-graphene). The voltage efficiency at power output of 1 W improved from 47.96 % with graphite-graphite to 52.84 % with graphene-graphite due to a decrease in losses, as it is observed from the Nyquist plot that ohmic resistance and capacitance decreased from 0.113 Ω to 0.065 Ω and 3.8 F to 1.57 F. The Tafel slope of 81.09 mV/dec for graphene-graphite is lower than 119.25 mV/dec for graphite, resulting in lower activation energy loss. The Bode plot shows the phase angle that is -26.5° for the graphite-graphite electrode and -18.5° for graphene-graphite, indicating a shift toward more resistive behavior. The maximum power density is 79.2 mW/cm^2 compared to base graphite-graphite electrodes (53 mW/cm^2).

In the final phase, the performance of the fuel cell with all electrode combinations with oxygen-enriched air and 100% oxygen is analysed. The performance with graphene-graphite electrodes with 100% oxygen is the highest due to a reduction in losses (ohmic losses and activation losses). The voltage efficiency at power output of 1 W improved from 52.84% with 23%

oxygen in air to 66.87% with 100% oxygen with graphene-graphite due to a decrease in losses such as ohmic resistance (0.101 Ω to 0.096 Ω) and charge transfer resistance (0.326 Ω to 0.203 Ω). The maximum power density increased to 132.92 mW/cm^2, which is the highest. A notable conclusion emerged from this study is that voltage efficiency and power density with graphene (anode) -graphite (cathode) and 100% oxygen could be improved significantly.