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Preparation and Evaluation of Nanomembranes for Proton Exchange Membrane Fuel Cells

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Abstract

By utilizing a chemical method, carbon nanotubes (CNTs) were mixed with polyvinylpyrrolidone (PVP) to prepare a nanomembrane intended for use as a proton exchange membrane in PEM fuel cells. Various tests were conducted to characterize the nanomembrane, including the examination of its morphology using a scanning electron microscope (SEM) and the analysis of its physical properties using XRD. An electrolyzer unit was developed to supply hydrogen gas to the PEM fuel cell, and electrochemical parameters such as the relationship between hydrogen volume and current, as well as the correlation between voltage and current, were investigated. Through electrochemical modeling and optimization of the nanomembrane, impressive results were achieved with a cell voltage of 1.24V and a current of 2.5A.

Keywords: Fuel Cells, Nanomembrane, Nanocomposite'sMaterials, Synthetic Approaches, Carbon Nanotubes, Conductivity Enhancement.

Abbreviations

CNTs	Carbon Nanotubes
PVP	Polyvinylpyrrolidone
PEM	Proton Exchange Membrane
SEM	Scanning Electron Microscope
XRD	X-Ray Diffraction
LLC	Limited Liability Companies
FWHM	Full Width at Half Maximum
Dhkl	Miller Indices
Pt	Platinum
ORR	Oxygen Reduction Reaction
HOR	Hydrogen Oxidation Reaction
KOH	Potassium Hydroxide

1. Introduction

Nanocomposites can contain a phase with a nanoscale structure, it can be nanoparticles, nanotubes, or have lamellar nanostructure. They are multiphase materials; at least one of the phases should be in the size range of 10–100 nm [1]. This has led to a growth of this field to an extent that it is now possible to synthesize many new materials with unique characteristics using unconventional synthesis techniques [2, 3]. Hence, the idea behind nanocomposite is to use building blocks with dimensions in the nanometer range to design and create new materials with unprecedented flexibility and improvements in their physical properties. Carbon nanotubes (CNTs), their properties and applications, have created tremendous interest in technologies and scientific research [4,5]. Single-walled carbon nanotubes (CNTs) have gained popularity in scientific research with the development of composite membranes. Recent studies have considered the properties and advantages of polymerization with CNT [6]. To encapsulate carbon nanotubes, the PVP polymer strongly distributes on their surface [7]. Polyvinylpyrrolidone (PVP) has excellent bonding properties and high stability [8]. Nanotechnology is a significant option in the power sector due to its corrosion resistance and good power characteristics [9]. The catalyst for a standard PEM consists of platinum, carbon, and Nafion [10]. The first two are sometimes mixed in the form of powder and often blended with Nafion ionomer. On one side, the Pt contributes to and improves the catalytic activity of ORR and HOR, while the carbon enhances the electrical conductivity to and from the required sites [11, 12]. Furthermore, the catalyst on the cathode represents a real test since it should withstand environmental conditions such as corrosion and be active from a chemical perspective, generating oxygen gas [13].The paper aims to prepare conductive membranes for

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the fuel cell from simple and cheap materials that available in the local market instead of high-cost membrane.

2. EXPERMETAL DETAIL

2.1. (PVP: CNTs) membrane preparation method

The prepared CNTs were blended with PVP powder in a ratio of 2 parts CNTs to 1 part PVP by total weight. The mixture was then introduced to ethanol alcohol in a proportion of 5:1 (mixture: ethanol alcohol). The mixture was slowly stirred using a Sonicators Qsonica device, as illustrated in Figure 1. For digestion, the liquid was heated to boiling temperature for 30 minutes and then allowed to cool and solidify under a cover for 48 hours. This process resulted in a slightly viscous solution, which was poured into a mold to form a membrane. The membrane was then withdrawn from the bonding solution and left to rest for a few hours. Finally, the membrane was equilibrated with KOH at 50 °C for 3 hours, after which it was removed and made ready for use, as depicted in Figure 2.

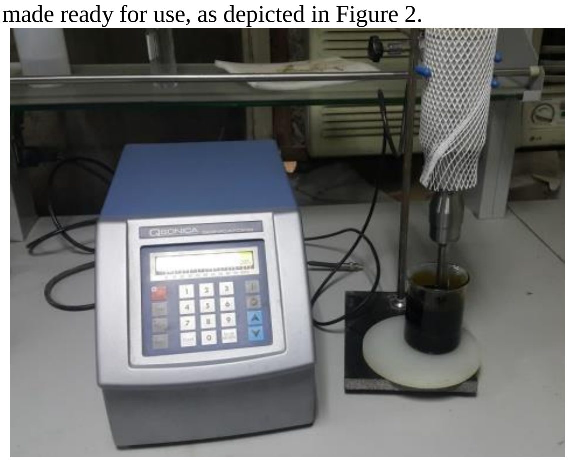

Figure 1. Nano Mixture Stirrer (SonicatorsQsonica. LLC) device

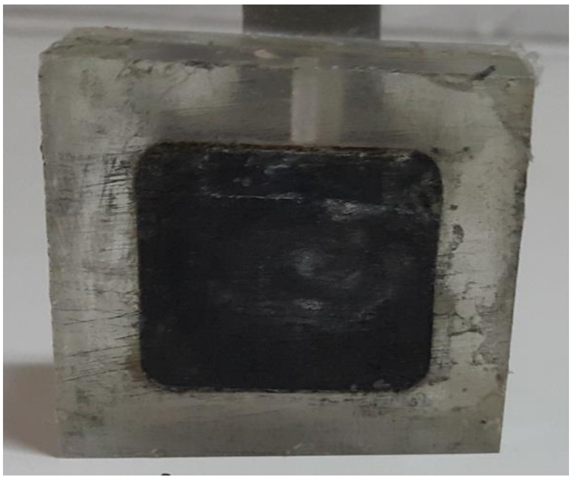

Figure 2. (PVP: CNTs) membrane in KOH solution

The membrane electrode assembly, which determines the PEM fuel cell's lifetime and performance, must be considered for effective use. Since the electrochemical reactions take place within this particular area, membrane electrode assemblies consist of four main parts: a catalyst layer, a polymeric membrane, a gas diffusion layer, and a bipolar plate.

The bipolar plates handle the spreading of fuel gas (H_2) as well as air (O_2) uniformly, as well as conducting current to the cell. In addition, it acts as a support and a thin protective film to provide a mechanical foundation. For the fuel cell to operate efficiently, it should have excellent chemical and mechanical properties. A few options are available to choose from. Bipolar plate materials deteriorate due to metal resistance, necessitating coating to prevent corrosion. In this paper, it is coated with a polymeric layer of PVP-CNTs.

2.2. Gas diffusion layers

It has a porous medium and is a critical part of the work of a polymeric fuel cell. The function of gas diffusion layers is to transport electrons, reactants, and products to the catalyst layer and to support water management across both sides of the membrane by ensuring the right amount of water is left in the membrane so it can be hydrated, while at the same time preventing water molecules from clogging the pores of the flue gases by water.

2.3. Electrolyser unit

The PEM fuel cell requires hydrogen gas to feed its anode, necessitating the construction of an electrolyser unit. The unit consists of several parts depicted. The electrolyser is used to decompose and split water into its initial molecules by applying a voltage difference to two steel plates immersed in water mixed with KOH. The hydrogen molecules gathered on the cathode side (the negative side), while the oxygen molecules gathered on the anode side (the positive side). The fuel cell then transports the hydrogen to the oxidation side. The electrolyser unit assembly

3. RESULTS and DISCUSSION

3.1. X-Ray diffraction Results

The XRD spectra of nanocomposites (PVP:CNTs) have been examined and recorded using X-ray spectroscopy. The prepared samples are semi-crystalline, with an average crystalline size of a few nanometers,as listed in Supplementary Table 1. (Figure 3) represents the XRD of the PVP:CNTs mixture. It has been observed that a clear interaction occurred between the polymer mixture and the carbon nanotube nanoparticles. This polymer encapsulates the carbon nanotube nanoparticles, which contributes to making the membrane amorphous and thus enhances the membrane's proton conduction while at the same time reducing the energy barrier.

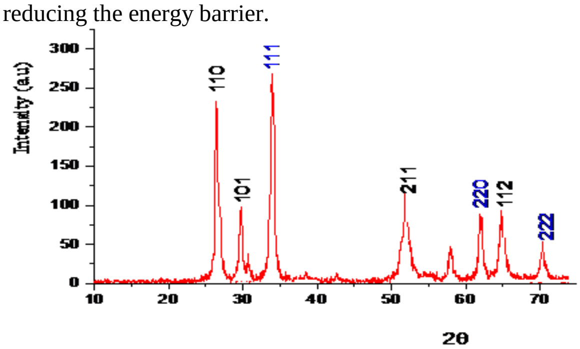

Figure 3.XRD pattern of Nanocomposite (PVP:CNTs) mixture

Table Error! No text of specified style in document.**.** Structuralpropertiesof theXRD spectra of Nanocomposite (PVP:CNTs)

2θ (Deg.)	FWHM (Deg.)	dhkl Std.(Å)	dhkl Exp.(Å)	Crystallite size (nm)	Average Crystallite size (nm)
26.641	0.551	3.4	3.34	14.80	13.5
33.935	0.606	2.53	2.64	13.69	
51.87	0.63	1.72	1.76	14.02	
58.82	0.67	1.53	1.67	13.44	
61.99	0.70	1.50	1.50	13.24	
65.40	0.80	1.52	1.44	11.77	
70.22	0.72	1.53	1.32	13.57	

3.2. SEM

Both polymers contribute to increasing the diameters of the carbon nanotube particles, forming a homogeneous nanocomposite film. (Figure 4) shows the surface morphology of the carbon nanotube membrane at the nanoscale after mixing it with polymers (PVP).

3.3. The effect of parameters on the efficiency of electrolyser cell

A 30 cm^2 electrolyser cell was constructed to study some parameters. (Figure 5). Researchers looked at how voltage and the concentration of the KOH solution affected the amount of hydrogen that was made to find the best amount to feed the fuel cell, as shown. The relationship between the gas volume (formed in the electrolyser) and the amount of current was studied. It was observed that the amount of hydrogen increases with an increase in current for a given amount of time. The relation between the amount of KOH, voltage, current, and H_2 volume is provided in Supplementary Table 2. It was found that the volume of H_2 increases with higher KOH concentration, as the salt enhances electrical conductivity, as demonstrated in Figures 6, 7, and 8.

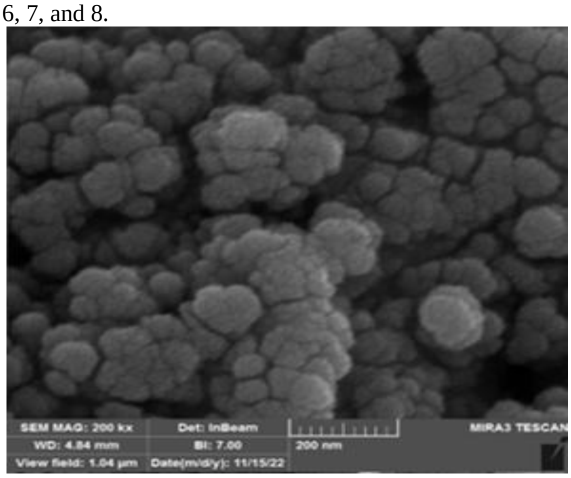

Figure 4. anocomosite(PVP:CNTs)ScanningElectronMicroscopy (FE-SEM) Analysis

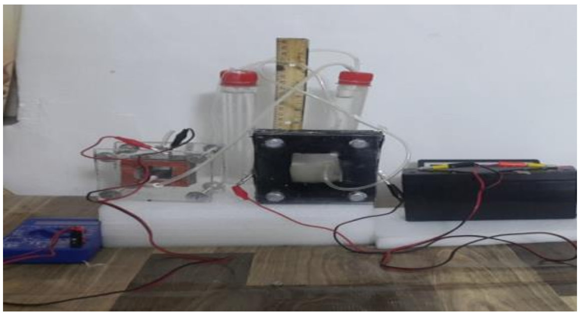

Figure 5. Show electrolyser cell and fuel cell system

Table 2. Shows the relationship between the volume of gas with time

Volume H_2 (ml)	Concentration KOH (M)	Voltage (Volt)	current (A)	Time (min)
0	0.14	2	0.5	2
4.4	0.18	4.5	1	4
10.5	0.22	6.4	2.7	6
16	0.25	7.8	3.6	8
20	0.28	9.7	4.4	10
25.8	0.32	10.8	5.3	12

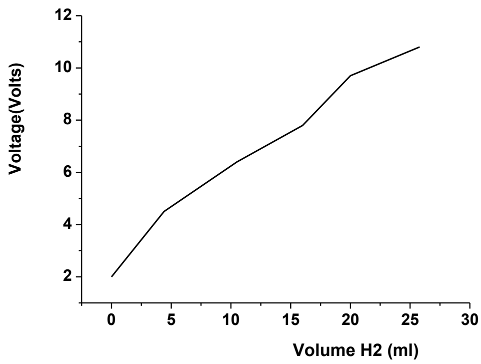

Figure 6. Graph shows the relationshipbetween Volume–Voltage

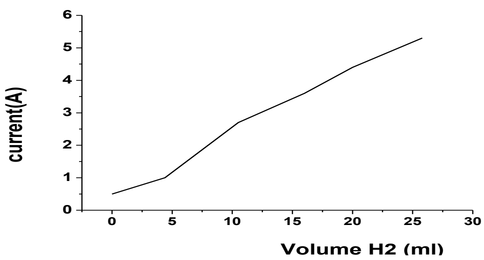

Figure 7. Graph shows the relationshipbetween Volume – Current

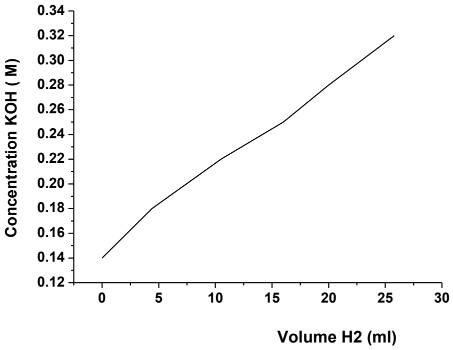

Figure 8. Graph shows the relationship between Volume – Concentration

The disintegration of water molecules in the electrolyser cell releases hydrogen gas into the cell through the anode electrode, touching the nano membrane (PVP: Closely related are carbon nanotubes (CNTs). This in turn dissociates the hydrogen molecules into hydrogen atoms, protons and electrons and is fed through the outer load circuit –OH-1 in the reverse direction to the cathode electrode. The reactions at the cathode electrode where oxygen molecules are dissociated with electrons passing through the external load circuit to form water molecule at the anode electrode is presented in supplementary material table 3 and figures 9. This process is accompanied by an increase in the fuel cell temperature to between 50 and 90 °C and generates up to 1. 24 volts and a current of 250 milli amperes.

The performance of the fuel cell depends on the quantity and thickness of the nanocatalyst, which splits the hydrogen molecules and works as a proton conductor in the membrane [14,15] . The electrodes of a PEM fuel cell consist of a gas diffusion layer, a microporous layer, and a catalyst layer [16]. A triple-phase boundary layer was created, combining the ionomer, gas phase, and catalyst material, to ensure sufficient production of oxygen reduction reaction (ORR) and hydrogen oxidation reaction (HOR). This approach addresses the challenge of increasing the surface area of the electrochemical reaction interface[17,18]. In catalyst surface reactions, the ionomer facilitates the transport of protons and contributes to oxygen dissolution [19].Membrane-based processes also provide a sustainable solution to the ever-increasing demand for energy [20]. The use of these membranes is due to their water absorption capacity, barrier property, film formation ability, bonding ability, and low cost. [21].

Table 3. Shows the relationship between the current with voltage

Current (A)	Voltage (V)
0.5	0.98
0.8	1.03
1	1.09
1.5	1.17
2	1.2
2,5	1,24

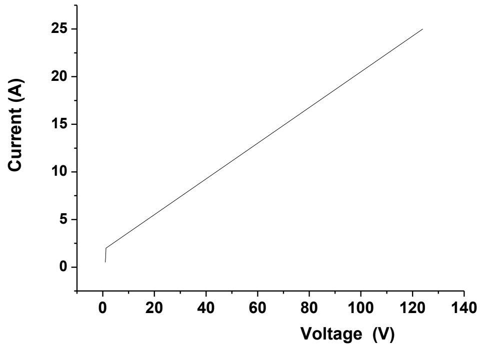

Figure 9. Graph shows the relationship between Voltage – Current.

4. CONCLUSIONS

This study examines the preparation and performance of a PVP: CNTs membrane for fuel cell systems, a topic of great relevance in the field of clean energy technologies. Fuel cell technology is essential for producing clean and efficient energy, positioning it as a major focus for researchers and engineers working in sustainable energy and environmental domains. The key findings of this study are summarized as follows:

- The PVP: CNTs membrane was produced in a cost-effective and efficient manner due to the accessibility of raw materials in the local market.
- Increasing the concentration of KOH in the electrolyzer was found to enhance the volume of hydrogen gas generated proportionally.
- A direct correlation was observed between the fuel cell's voltage and the current flow rate, with performance improving as the current increased.
- The membrane's electrical conductivity was enhanced with higher current levels, demonstrating the beneficial effects of PVP: CNTs on conductivity.

In conclusion, the PVP: CNTs membrane markedly improved protonic conductivity, leading to enhanced efficiency of the fuel cell system

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