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EFFECT OF NANOPARTICLE DOPE ON ELECTRICAL AND THERMAL CONDUCTIVITY OF PVA NANOFIBERS

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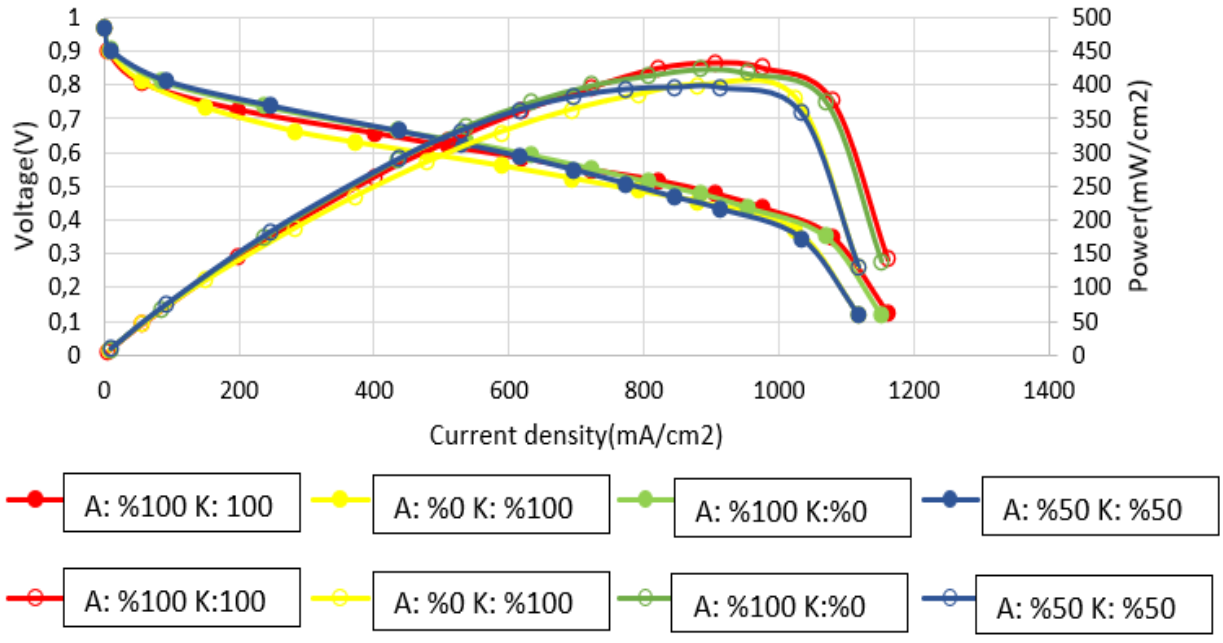
Highlights

- Ag and Pt doping significantly increased PVA nanofiber electrical conductivity.
- Ag doping improved thermal conductivity by 28%, while Pt caused a 43% decrease.
- Ag-doped fibers showed superior power and current densities compared to pure PVA.

Graphical Abstract



PEM fuel cell performance of 5 wt% Ag nanoparticle doped PVA nanofiber

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ABSTRACT: PVA nanofiber materials are widely utilized in energy applications, particularly in PEM fuel cells. In this study, Ag- and Pt-doped PVA nanofibers were fabricated via the electrospinning method at different weight ratios and compared with pure PVA nanofibers. The thermal and electrical conductivities, PEM fuel cell performances, and morphological structures of the nanofibers were investigated. The results demonstrated that the highest electrical conductivity (16.80 S/cm) was achieved with the addition of 5% Ag nanoparticles, while Pt nanoparticle doping also improved electrical conductivity but to a lesser extent (14.90 S/cm). In terms of thermal conductivity, Ag nanoparticle doping increased the Thermal Conductivity Coefficient by approximately 28%, whereas Pt nanoparticle doping had the opposite effect, reducing it by 43%. Additionally, the hydrophilicity of the nanofibers increased with increasing nanoparticle content. The PEM fuel cell tests indicated that Ag-doped PVA nanofibers exhibited superior performance compared to pure PVA nanofibers, making them a promising material for energy applications.

Keywords: *PEM Fuel Cell, PVA Nanofiber, Design of Experiment, Nanoparticle*

1. INTRODUCTION

Materials have different properties at the nanometer size compared to their other states. When the particles are small enough and can be characterized as nanoparticles, their mechanical properties change accordingly. Nanoscale materials may have better strength and thermal or electrical properties than bulk materials. PVA nanofibers are solid fibers with nano diameters developed for particular purposes. PVA nanofibers are fibers with submicron diameters developed for specific purposes. Although there are many ways to produce nanofibers, the electrospinning method is considered a very effective and widely used technique [1]. In this technique, PVA nanofibers are produced by applying a strong electric field and converting the polymeric material solution into continuous nano-sized fibers [2]. Ultra-high draw rates caused by extensional flow enable the development of a continuous nanofiber. In this way, fibers can be easily collected into non-woven fabrics [3]. Although PVA nanofibers are widely used in their pure form, they are also used in special applications by adding various properties. Wali et al. studied the effect of silver addition to PVA nanofibers on antibacterial activity using bacteria [4]. In a similar study, silver nanoparticle-doped nanofibers were investigated, and their positive effects were determined in terms of developing antimicrobial wound dressings that can solve the difficulties associated with chronic wounds and provide infection control and wound healing support [5]. Khaleel et al. investigated the antimicrobial effect of ZnO nanoparticle-reinforced PVA nanomaterial [6]. In another study, PVA samples prepared using the electrospinning technique of silver nanoparticles were examined, and it was determined that silver nanoparticles increased thermal stability and electrical conductivity [7]. Besides medical fields, the energy sector is another area of usage for nanoparticle-doped PVA nanofibers.

PEM fuel cells are electrochemical systems that convert hydrogen into electrical energy, whereas other fuel cell types, such as DMFC and SOFC, can utilize alternative fuels like methanol, biogas, or coal. In the fuel cell, electric current is obtained by combining hydrogen with oxygen through electrochemical processes [8]. Since there is no combustion, no exhaust gas is formed. As a result, fuel cells are a clean

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and environmentally friendly energy production source that does not pollute the environment [9, 10]. Although the electrochemical reaction in PEM fuel cells does not involve moving parts, auxiliary components such as compressors, cooling systems, and fans can impact system efficiency and may require maintenance over time [11]. They can reach maximum efficiency at low power levels, and efficiency decreases linearly with increasing power [12]. After discovering high-performance polymers, PEM fuel cells were developed for application in space studies [13, 14] and unique military systems [15]. Compared to efficiency, PEM fuel cells operate more efficiently than thermal energy systems. In addition, unlike thermal systems, fuel cells are unaffected by the Carnot cycle criteria. [16]. PVA nanofibers are critical materials for PEM fuel cells. Adding various nano-sized additives to this critical material can improve its essential properties. Yanılmaz et al. examined the electrical properties of PVA-based B, N, and F-doped carbon nanofiber material and found that the cycle numbers of batteries from this material increased [17]. The amount of power obtained from PEM fuel cells varies depending on the number of cells and the limitations of the fuel cell model. Model constraints rely on the design of the parts that make up the PEM fuel cell, the material properties of these parts, and the fuel and oxidizer used.

Surface contact angle and hydrophilicity significantly influence the efficiency of Proton Exchange Membrane (PEM) fuel cells by affecting gas diffusion, water management, and proton conductivity. A lower contact angle corresponds to higher hydrophilicity, which enhances water management and improves proton conductivity, ultimately increasing fuel cell efficiency. Conversely, a higher contact angle indicates a more hydrophobic surface, which can lead to water accumulation or inadequate hydration, negatively impacting overall performance. Hydrophilic surfaces facilitate effective water removal from the electrode surface while promoting proton transport, thus optimizing cell performance. However, excessive hydrophilicity may result in excessive water retention, potentially obstructing gas diffusion. In contrast, hydrophobic surfaces prevent water accumulation but may reduce proton conductivity if insufficient water is retained within the membrane. Nanofibers are produced using Ag and Pt nanoparticles with various materials other than PVA. For example, Wanwong et al. developed a multifunctional air filter made of Ag-doped nanofiber material [18]. In their studies, Sakthivel et al. used Ni-Pt nanoparticles and carbon nanofibers as catalysts [19]. In another study, Electrospun Ag/TiO2 heterostructured nanofibers were produced for photoelectrochemical applications. Photoelectrochemical performances of the samples were investigated under full spectrum light illumination. Study results showed that Ag nanoparticles enhanced photocatalytic activity compared to pure nanofibers [20]. Similar to this study, there are many studies examining carbon-based nanofibers produced using titanium dioxide [21], nitrogen [22-25], or some other additive materials [26-28]. Few studies in literature examine Ag or Pt nanoparticle-doped PVA nanofiber materials. This study examined the electrical and thermal effects of Ag and Pt nanoparticle-doped PVA nanofibers produced by the electrospinning method. Experimental studies were conducted to produce homogeneous PVA nanofiber by considering the concentration ratio, voltage, feeding amount, and distance. SEM analyses of the produced nanofibers were performed, and parameter optimization was performed by considering the average nanofiber diameter. After finding the ideal parameters, nanofiber production was carried out using Ag and Pt nanoparticles in various ratios.

This study aims to investigate the impact of Ag and Pt nanoparticle doping on the electrical and thermal properties of PVA nanofibers produced via the electrospinning method. By optimizing doping ratios and production parameters, the research seeks to enhance the performance of these nanofibers, particularly for applications in PEM fuel cells. The findings are expected to contribute to the development of advanced energy materials with improved conductivity and tailored thermal properties, offering potential benefits in clean energy technologies.

2. MATERIAL AND METHODS

2.1. Solution Preparation

PVA, sodium dodecyl sulfate (SDS), Ag nanoparticle, Pt nanoparticle, Dimethyl Formamide (DMF), Acetone, and Chloroform were used to produce Ag or Pt-doped PVA nanofibers. 98-99% Hydrolyzed, high molecular weight (average 88,000-97,000 g/mol) PVA polymer was used in the study, and Sodium Dodecyl Sulfate ($C_{12}H_{25}NaO_4S$) was used to lower the surface tension of the solution. Ag (silver) nanoparticles (99.995%, 18 nm) and Pt (platinum) used in the study were used as additives to PVA nanofibers with the best structure. Dimethylformamide (DMF), Chloroform ($CHCl_3$), and Acetone (C_3H_6O) were used to determine the solvent of PVA in the experiments.

2.2. Electrospinning And Characterization Setup

In this study, for the production of Ag and Pt doped PVA nanofibers, an electrospinning device, SEM device, Thermal Conductivity measurement device, static surface contact, angle measurement device, transmission electron microscope (TEM), four-point electrical conductivity measurement device were used. The nanofibers' diameters were analyzed with a Zeiss Evo LS10 microscope (SEM). Crystal structure examinations and XRD analysis of the samples were performed using a D8 Advance brand diffractometer. To determine the thermal conductivity coefficients of PVA nanofibers doped with Ag or Pt a P.A. Hilton H-940 brand thermal conductivity measuring device was used.

Temperature values measured from 6 different points were recorded depending on the 6, 8, and 10-watt power values supplied to the system. The probes on the device are connected to TC1, TC2, TC3, TC7, TC8, TC9. While the Th value was found by interpolating from T1-T3 values, the Tc value was found from T7-T9 values. The nanofibers whose thermal conductivity coefficient was desired to be measured were cut to 25 mm in diameter and placed between the cold and hot ends. The resulting temperature values were made and recorded separately for each sample. The hydrophobic and hydrophilic properties of the produced fibers were determined using the Dataphysics instruments GmbH O.C.A. 15EC device. The mixtures with PVA, Ag nanoparticles, Pt nanoparticles, and SDS were mixed in an ultrasonic mixer until they became homogeneous. A four-point electrical conductivity measuring device made resistance measurements of thin materials.

2.3. PVA Nanofiber Production to Determine Optimum Parameters

At the beginning of the experimental studies, PVA + pure water solution was mixed in an ultrasonic mixer until a homogeneous mixture was obtained. After this, as the mixed solution heated up, it was allowed to cool to room temperature. SDS solution with a concentration of 1% by weight was added to each gram of solution by syringe, and the solution was mixed in the magnetic stirrer for another 20 minutes. The solution was then cooled at low speed to room temperature. 2 mL of the solution was drawn into a syringe and placed in the teflon apparatus of the electrospin device. After the solution drawn into the syringe was connected to the device, the positive and negative polarization tips were attached to the needle at the end of the syringe and the collector. The distance between the syringe needle and the collector was adjusted according to the distance value determined in Table 1, and the needle tip was aligned in the middle of the collector.

In Proton Exchange Membrane (PEM) fuel cells, system efficiency is influenced by several factors, including electrical connections and conductivity, electrode and catalyst efficiency, hydrogen supply and purity, as well as auxiliary components such as compressors and cooling systems. In this study, the PEM fuel cell performance of the nanofiber with the highest electrical conductivity among the produced Ag- or Pt-doped PVA nanofibers was investigated. The performance measurements were conducted at the Fuel Cell Technologies Laboratory of TÜBİTAK Marmara Research Center (MAM) Energy Institute. For these experiments, Toray 120 was used as the gas diffusion layer (GDL), a widely utilized

component in PEM fuel cells. The primary role of the GDL is to ensure uniform gas distribution to the electrode surface while simultaneously contributing to electrical conductivity and water management. Toray 120's effectiveness in gas distribution, electrical conductivity, and water regulation significantly impacts overall fuel cell efficiency. By optimizing gas flow and water control, high-quality GDLs such as Toray 120 enhance PEM fuel cell performance.

SEM analysis confirmed the production of homogeneous PVA nanofibers, and optimized electrospinning parameters were determined accordingly. Using these parameters, Ag and Pt nanoparticle-doped PVA nanofibers were synthesized with weight ratios of 1%, 3%, and 5%. Initially, PVA nanofibers were prepared, and the solution was allowed to cool to room temperature. Then, Ag and Pt nanoparticles were added at the specified weight ratios and stirred magnetically for an extended period to ensure homogeneity. After cooling to room temperature, the mixture was processed. Although no additional analysis such as Dynamic Light Scattering (DLS) was conducted to verify aggregation, the extended stirring process aimed to promote uniform nanoparticle dispersion.

Table 1. Production parameters and average diameters of PVA nanofibers.

Number	Coding	Concentration Rate (%Weight)	Voltage (kV)	Feed Quantity (mL/h)	Distance (cm)	Average Nanofiber Diameter (nm)
1	FİBER-1	8	15	1	11	516.14 ± 35.4
2	FİBER-2	8	20	1.5	13	442.36 ± 41.6
3	FİBER-3	8	25	2	15	331.82 ± 35.7
4	FİBER-4	10	15	1.5	15	320.66 ± 55.3
5	FİBER-5	10	20	2	11	325.36 ± 42.4
6	FİBER-6	10	25	1	13	633.38 ± 53.6
7	FİBER-7	12	15	2	13	315.88 ± 41.1
8	FİBER-8	12	20	1	15	534.12 ± 52.5
9	FİBER-9	12	25	1.5	11	667.55 ± 51.7

3. RESULTS AND DISCUSSION

Figure 1 presents SEM images of the produced PVA nanofibers, highlighting the influence of process parameters on fiber formation, morphology, and diameter distribution. The nanofiber structure is significantly affected by key electrospinning parameters, including concentration ratio, applied voltage, feed rate, and the distance between the needle tip and the collector. As seen in Figure 1, increasing the polymer concentration results in thicker nanofibers with more uniform structures. At lower concentrations, the nanofibers exhibit a bead-like morphology due to insufficient polymer chain entanglement. As the concentration increases, the fibers become smoother and more continuous. Applied voltage plays a critical role in fiber formation. At lower voltages (e.g., 15 kV), the nanofibers tend to have larger diameters and irregular structures due to weaker electrostatic forces. When the voltage is increased to 25 kV, the nanofibers exhibit finer diameters and more uniform structures, as the higher electric field strength promotes better stretching of the polymer jet.

The feed rate directly influences fiber diameter and uniformity. A lower feed rate (e.g., 1 mL/h) leads to thinner fibers, while a higher feed rate (e.g., 2 mL/h) results in thicker fibers with a more irregular distribution. At excessively high feed rates, the solution does not have enough time to evaporate completely, leading to defects such as beading and fiber fusion.

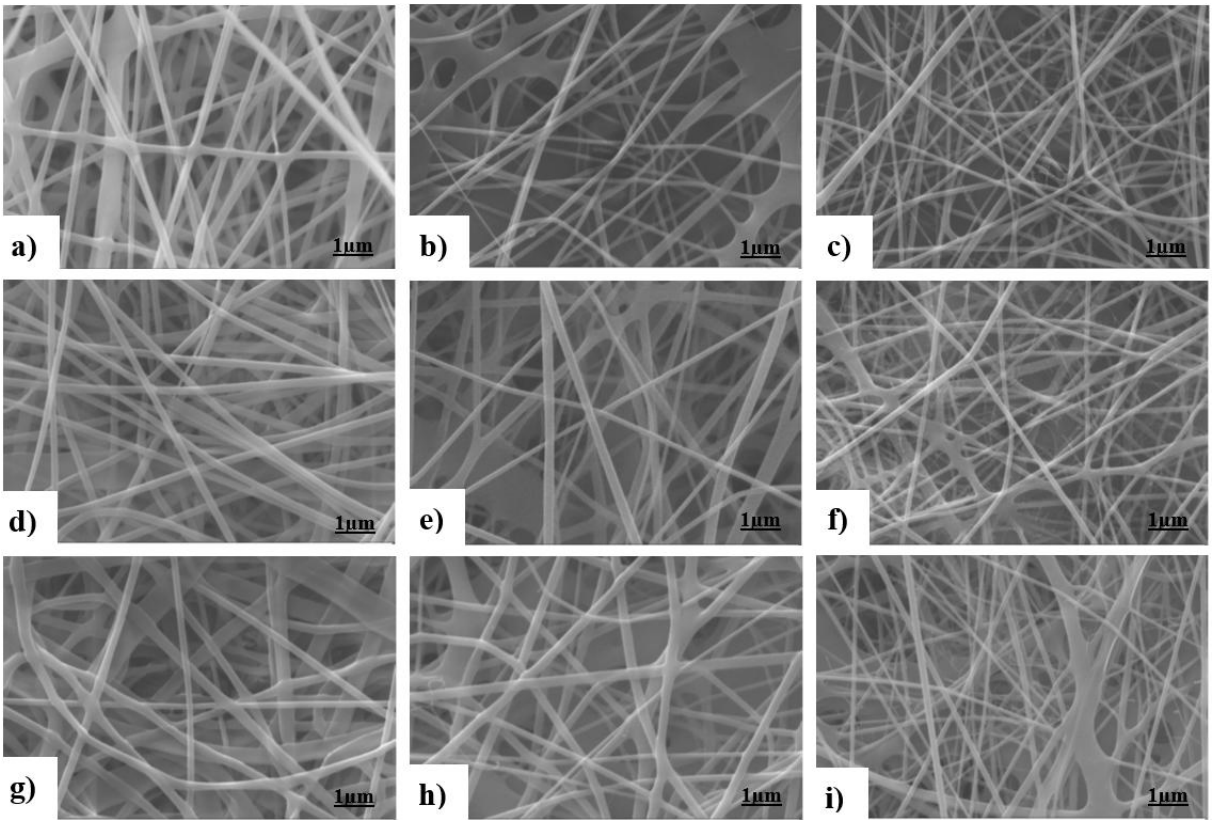


Figure 1. Produced PVA nanofibers (a) Fiber-1 b) Fiber-2 (c) Fiber-3 (d) Fiber-4 (e) Fiber-5 (f) Fiber-6 (g) Fiber-7 (h) Fiber-8 (i) Fiber-9

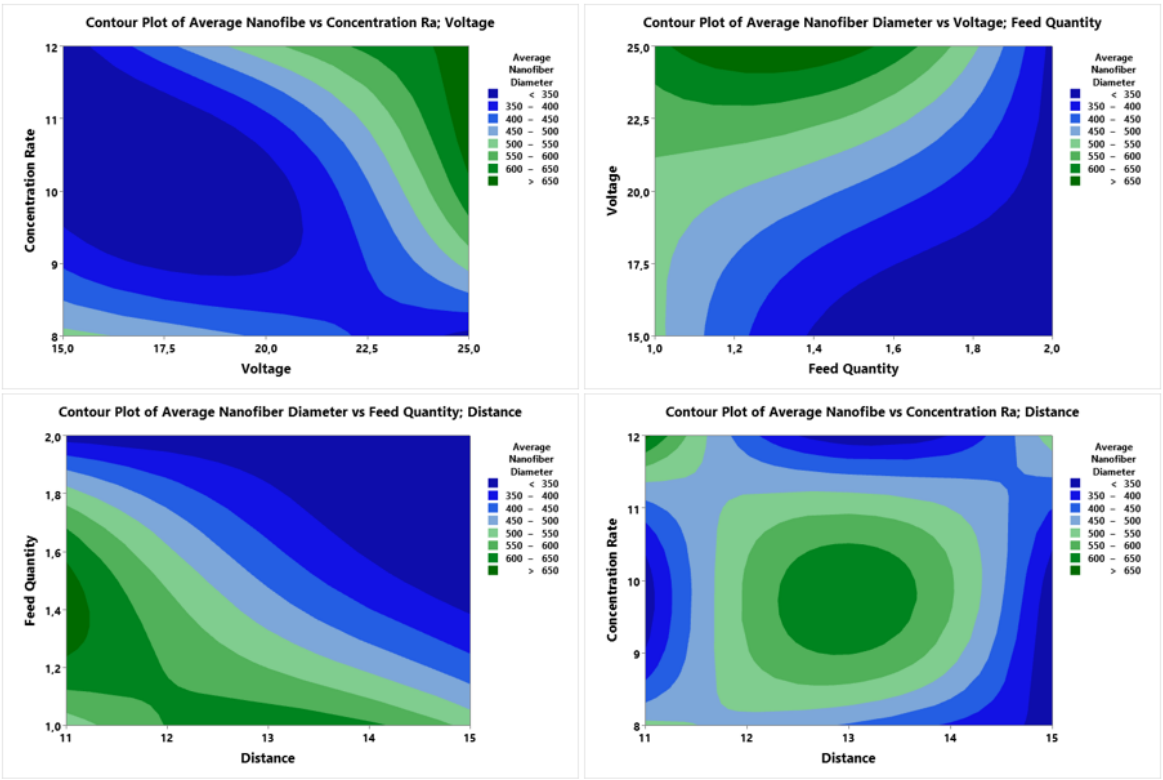


Figure 2. Relationship between variables and nanofiber diameter

According to Figure 2, the relationship between concentration ratio, voltage, and nanofiber diameter is nonlinear. While an increase in concentration generally led to larger nanofiber diameters, other parameters such as voltage and feed rate also influenced the final morphology. The lowest average nanofiber diameter was measured as 315.88±41 nm, whereas the highest reached 667.55±51.7 nm (Table 1). The results indicate that optimizing the processing parameters is crucial to controlling nanofiber dimensions effectively. The distance between the needle tip and the collector affects solvent evaporation and fiber solidification. When the distance is too short (e.g., 11 cm), fibers tend to be thicker and may exhibit incomplete solvent evaporation. In contrast, increasing the distance (e.g., 15 cm) allows for better stretching and thinner fibers but can also lead to fiber breakage if the distance is too large. Overall, Figure 1 illustrates that optimizing electrospinning parameters is crucial for achieving smooth, defect-free nanofibers with controlled diameters. The fiber diameter distribution observed in Table 1 confirms that these parameters must be carefully balanced to obtain uniform nanofibers with desirable properties.

3.2. Production and SEM Analysis of Ag and Pt Nanoparticle-Doped PVA Nanofibers

Optimization was made by considering the average nanofiber diameters obtained from SEM results, and ideal production parameters were determined. Accordingly, the production parameters of Ag and Pt nanoparticle-doped PVA nanofibers were determined as voltage 18 kV, feeding amount 1.8 mL/hour, and distance between the needle tip and collector 14 cm. Considering these parameters, 1, 3, and 5% nanoparticles by weight were added to PVA manufactured in homogeneous structures, and PVA nanofibers with Ag and Pt nanoparticles were produced.

The PEM membranes were fabricated using both pure PVA and Ag-Pt doped PVA nanofibers. The production process involved electrospinning the nanofiber mats followed by a crosslinking and stabilization step to enhance membrane durability and performance. The impregnation method used was solution casting and thermal annealing, ensuring the homogeneous distribution of Ag and Pt nanoparticles within the PVA matrix. During the process, PVA solutions containing Ag and Pt nanoparticles were electrospun onto a collector to form a uniform fibrous membrane. Subsequently, the membranes were subjected to chemical crosslinking with glutaraldehyde vapor to improve mechanical stability and water resistance. After crosslinking, the membranes were thermally annealed at controlled temperatures to optimize their structural properties and enhance ionic conductivity. The final membranes were tested for their proton conductivity and mechanical integrity before integration into PEM fuel cells.

According to the SEM analysis results in Figure 3, pure PVA nanofiber's average diameter was 271.47±16.3 nm. When 1% Ag nanoparticle by weight was added to the PVA solution, the average nanofiber diameter was 280.75±25.1 nm; when 3% Ag nanoparticle was added, it was 292.40±12.9 nm; and when 5% Ag nanoparticle was added, the average diameter is 297.62±23.8 nm and also increased when the amount of Ag nanoparticles increased. The average diameter of the nanofiber obtained by adding 1% Pt was found to be 220.10±13.9 nm. It was determined that the average diameter of the nanofiber produced by adding 3% Pt nanoparticles was 196.24±23.1 nm, and it was 5% Pt nanoparticles was 144.30±10.9 nm. As a result, it was determined that nanofiber diameters decreased as the amount of Pt nanoparticles increased.

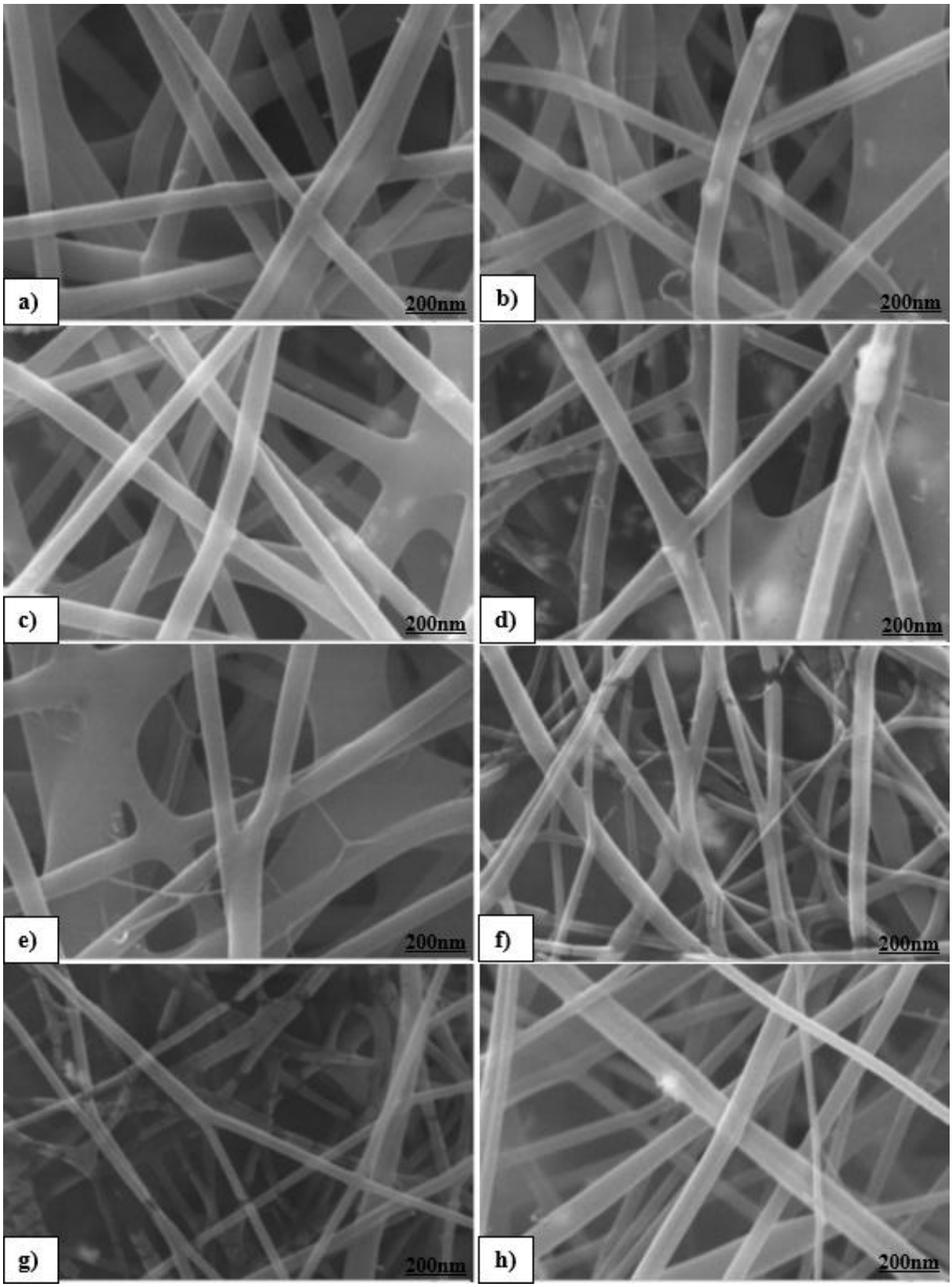


Figure 3. SEM images of pure and doped nanofibers (a) Pure PVA nanofibers for Ag nanoparticle doping (b) 1% Ag-doped (c) 3% Ag-doped (d) 5% Ag-doped (e) Pure PVA nanofibers for Pt nanoparticle doping (f) 1% Pt doped (g) 3% Pt doped (h) 5% Pt doped

3.3. Physical Characteristics of Ag/Pt Nanoparticle Doped PVA Nanofibers

The highest conductivity values in PVA nanofibers doped with Ag nanoparticles and Pt nanoparticles were determined with a 5% Ag/Pt contribution by weight. These are, respectively, the electrical conductivity of Ag nanoparticle-doped PVA nanofiber is 16.80 S/cm and Pt nanoparticle-doped PVA nanofiber is 14.90 S/cm. In this study, the highest Electrical Conductivity is 16.80 S/cm. This value belongs to PVA nanofiber with Ag nanoparticle doping of 5% by weight. Therefore, the Gas Diffusion Layer prepared for the PEM fuel cell performance test was prepared based on 5% Ag-doped PVA nanofiber.

Table 2. Physical characteristics of Ag/Pt nanoparticle doped PVA nanofibers

Contribution Rate and Material	Average Nanofiber Diameter (nm)	Electrical Conductivity (S/cm)	Thermal Conductivity (W/mK)	Maximum Static Surface Contact Angle (°)
Pure nanofibers for Ag-doped	271.47±16.3	12.60	1.198	37.32
1% Ag	280.75±25.1	15.50	1.238	36.96
3% Ag	292.40±12.9	16.10	1.450	35.69
5% Ag	297.62±23.8	16.80	1.535	34.24
Pure nanofibers for Pt-doped	315.88±20.4	12.90	1.182	76.38
1% Pt	220.10±13.9	13.80	1.053	43.09
3% Pt	196.24±23.1	14.80	0.706	26.29
5% Pt	144.30±10.9	14.90	0.670	25.27

When evaluated regarding Thermal Conduction, it was determined that the Thermal Conductivity Coefficient decreased as the amount of Pt nanoparticles added by weight increased. If the Thermal Conductivity Coefficient of 5% Pt nanoparticle added PVA nanofiber is compared with the Thermal Conductivity Coefficient of pure PVA nanofiber, 5% Pt nanoparticle added PVA nanofiber reduced the Thermal Conductivity Coefficient of pure PVA nanofiber by 43.32%. Additionally, as seen in Table 2 and Figure 5, it was determined that as Ag/Pt nanoparticles were added to PVA, its Hydrophilicity Was Enhanced.

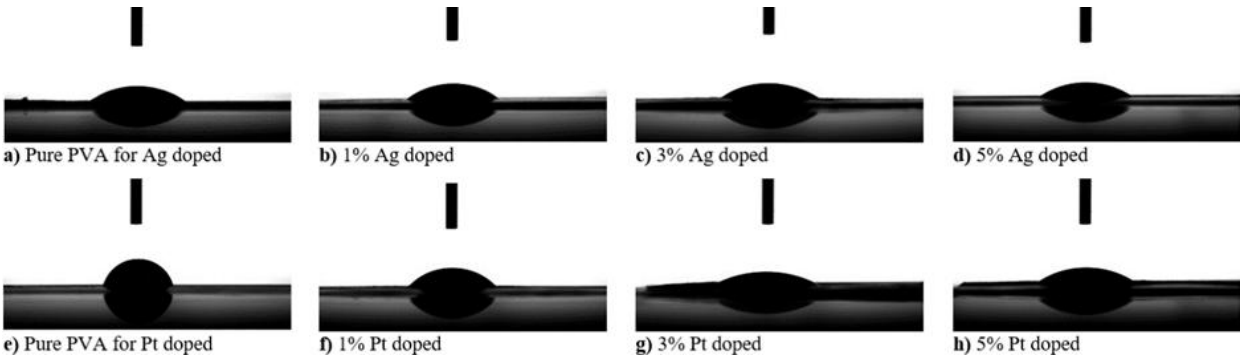


Figure 4. Static surface contact angles of pure, Ag/Pt-doped PVA drops

3.4. Pem Fuel Cell Performance of the 5% Ag-Doped Nanofiber

Pure PVA nanofiber (for Ag) without any additives and 5% Ag nanoparticle doped, which has the highest electrical conductivity (16.80 S/cm) among all the produced samples, PVA nanofiber is used on the anode side of the gas diffusion layer in the PEM fuel cell, with or without Ag additives. PEM fuel cell

performances of PVA nanofibers were examined. In these tests, a 0.6 mg/cm2 Pt-loaded electrode was used on the anode side of the fuel cell, while a 0.6 mg/cm2 Pt-loaded electrode was used on the cathode side. Toray 120 was chosen as the gas diffusion layer. In the experiments, hydrogen was given at 0.21 liters per minute and oxygen at 0.18 liters per minute.

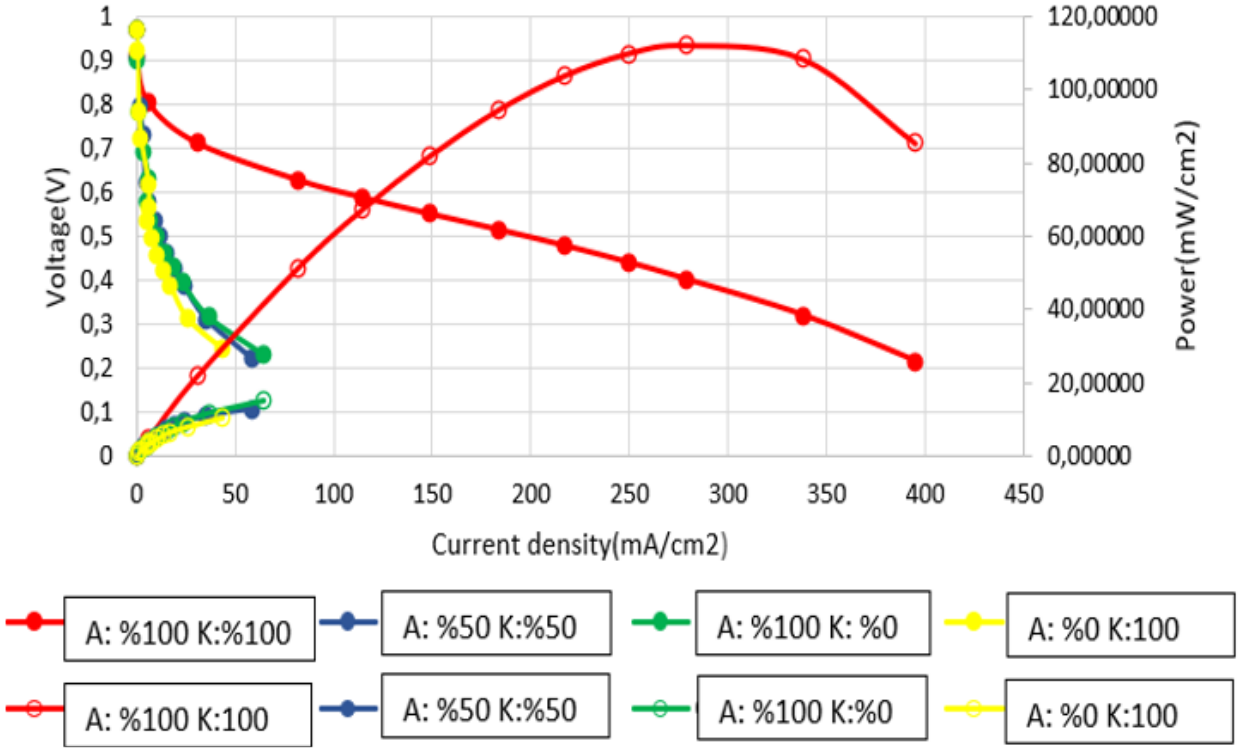


Figure 5. PEM fuel cell performance of pure PVA nanofiber (for Ag)

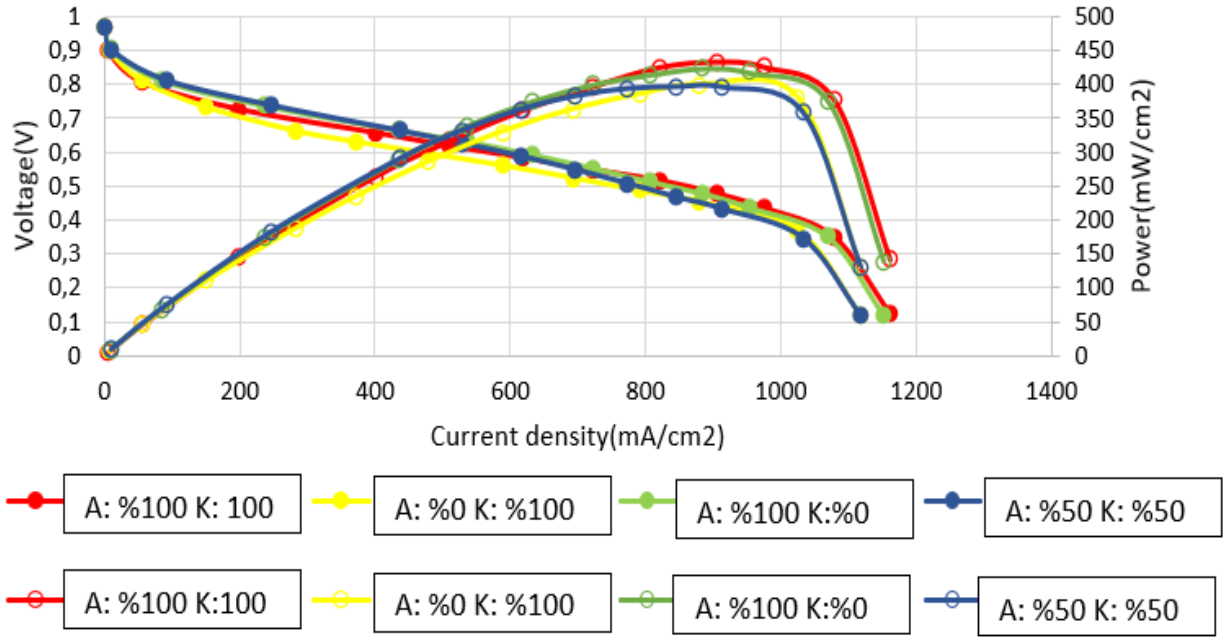


Figure 6. PEM fuel cell performance of 5 wt% Ag nanoparticle doped PVA nanofiber

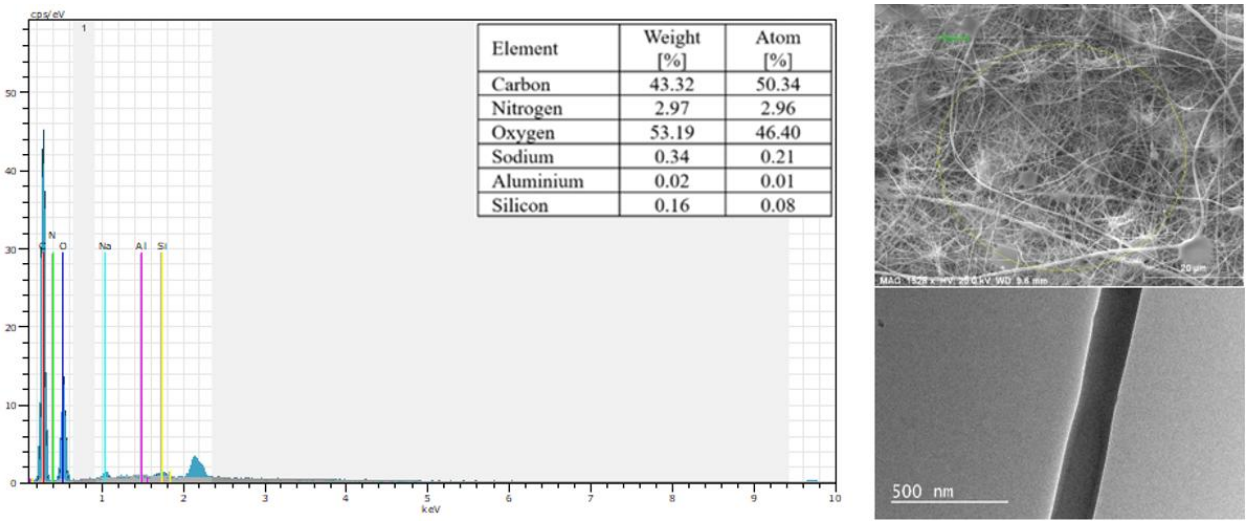
The experiments were carried out at 60 °C temperature and with different humidity conditions (anode and cathode 100% humidity; anode and cathode 50% humidity; anode dry, cathode 100%

humidity; anode 100%, cathode dry), and the results of the experiments are shown in Figure 5 and Figure 6 presented. The highest power and current density values occurred in the tests at 60 °C and when the anode and cathode were 100% humid. As the amount of Ag nanoparticles in the structure increases, the power density of 5% Ag nanoparticle-doped PVA nanofiber rises according to the current density compared to pure PVA nanofiber. This is because Ag is a material with high electrical conductivity.

The increase in power density of the fuel cell cannot be solely attributed to the enhancement of electrical conductivity. Several other critical factors influence fuel cell performance, including operating pressure, membrane compression, water management, reactant gas flow rates, and temperature control. Operating pressure affects the reaction kinetics and gas diffusion within the cell, while membrane compression influences proton conductivity and mechanical stability. Proper compression ensures optimal contact between the membrane and electrodes, reducing interfacial resistance and improving overall efficiency. Additionally, effective water management is crucial to prevent membrane dehydration or excessive water accumulation, both of which can negatively impact power output. Therefore, while electrical conductivity plays a significant role, these additional parameters must be considered when evaluating fuel cell performance.

3.5. EDS and TEM Analysis of Pure and 5%Ag Nanoparticle Doped PVA Nanofibers

EDS and TEM analyses were conducted to thoroughly investigate the effects of Ag nanoparticle doping on the elemental composition and structural properties of PVA nanofibers. Figure 7 and Figure 8 illustrate the comparative analysis of pure PVA nanofibers and those doped with 5% Ag nanoparticles, which exhibited the highest electrical conductivity among all the tested samples. The results revealed that the addition of silver nanoparticles led to a noticeable reduction in the percentages of carbon and oxygen within the nanofibers. This reduction indicates a successful integration of Ag nanoparticles into the polymer matrix, which altered the chemical composition and contributed to the improved properties of the nanofibers. Furthermore, TEM analysis provided clear evidence of the effective interaction between Ag nanoparticles and the PVA structure.

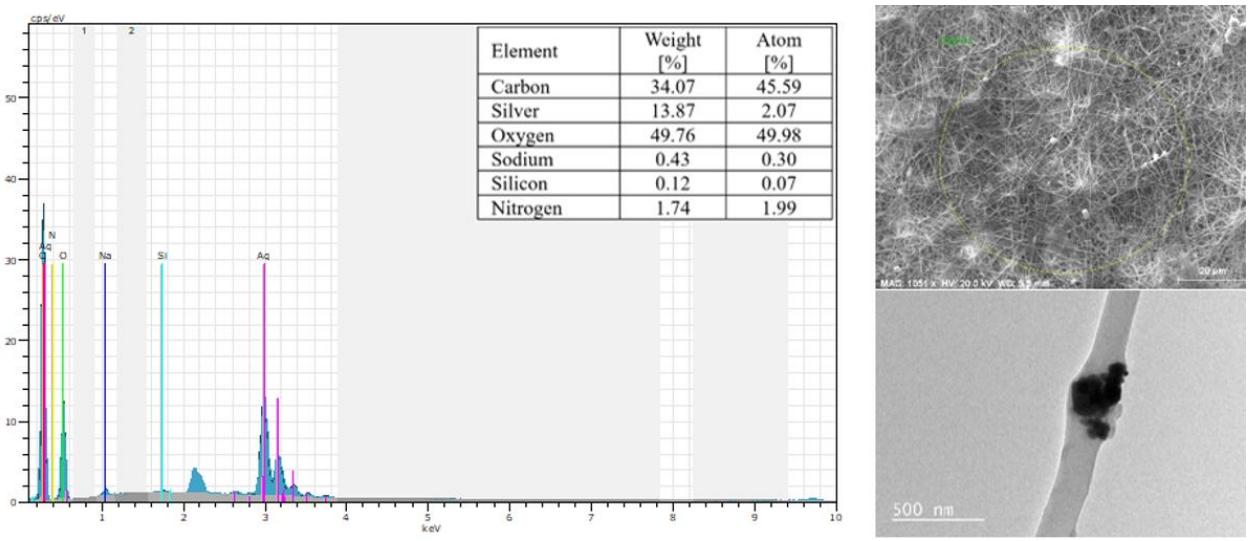


Element	Weight [%]	Atom [%]
Carbon	43.32	50.34
Nitrogen	2.97	2.96
Oxygen	53.19	46.40
Sodium	0.34	0.21
Aluminium	0.02	0.01
Silicon	0.16	0.08

Figure 7. EDS and TEM analysis of pure PVA Nanofibers

Although platinum (Pt) is a metal with high intrinsic thermal conductivity, its addition to PVA nanofibers does not necessarily enhance thermal conductivity due to several factors. The dispersion of Pt nanoparticles within the polymer matrix plays a crucial role; if the nanoparticles are not homogeneously distributed or tend to agglomerate, phonon scattering increases, leading to higher interfacial thermal resistance and limiting heat transfer efficiency. Additionally, Pt nanoparticles can alter the molecular

interactions within the PVA matrix, disrupting phonon transport since heat conduction in polymer-based systems primarily occurs through phonon interactions rather than electron movement, as in bulk metals. Structural and morphological changes introduced by Pt, such as modifications in fiber compactness and potential void formation, can further reduce effective thermal conductivity. Furthermore, the presence of Pt nanoparticles may affect the viscosity and solidification behavior of the polymer solution, influencing fiber morphology and reducing thermal transport efficiency. As a result, while Pt is thermally conductive in bulk form, its nanoscale incorporation into PVA nanofibers can lead to increased phonon scattering, interfacial resistance, and structural alterations, ultimately decreasing effective thermal conductivity.



Element	Weight [%]	Atom [%]
Carbon	34.07	45.59
Silver	13.87	2.07
Oxygen	49.76	49.98
Sodium	0.43	0.30
Silicon	0.12	0.07
Nitrogen	1.74	1.99

Figure 8. EDS and TEM analysis of 5%Ag-doped PVA Nanofibers

The uniformly distributed silver particles within the nanofibers played a significant role in enhancing their electrical properties. The increase in electrical conductivity was attributed to the high intrinsic conductivity of silver, which facilitated better charge transport within the nanofiber matrix. Similarly, the thermal conductivity of the nanofibers improved due to the efficient heat transfer facilitated by the Ag nanoparticles. These findings highlight the dual role of Ag doping in enhancing both electrical and thermal properties, making the nanofibers suitable for advanced applications, such as in PEM fuel cells and other energy systems. The results underscore the importance of nanoparticle distribution and interaction within the polymeric structure, as these factors directly influence the overall performance and potential applications of the material.

4. RESULTS AND DISCUSSION

This study focused on the effects of Ag and Pt nanoparticle doping on the thermal and electrical properties of PVA nanofibers produced using the electrospinning method. The experimental results revealed that doping PVA nanofibers with Ag nanoparticles significantly increased electrical conductivity, with the highest value achieved at a 5% doping ratio. Additionally, the thermal conductivity of Ag-doped nanofibers was enhanced, making them promising candidates for energy-related applications. In contrast, Pt nanoparticle doping improved electrical conductivity but caused a notable decrease in thermal conductivity. This indicates that the choice of nanoparticle plays a critical role in tailoring the properties of PVA nanofibers for specific applications.

The addition of Ag nanoparticles to the PVA solution can influence the solution viscosity. If Ag nanoparticles increase viscosity, the solution becomes less fluid, leading to the formation of thicker nanofibers during electrospinning. Generally, well-dispersed Ag nanoparticles contribute to higher viscosity, which affects fiber morphology by reducing jet stretching and resulting in larger fiber

diameters. In contrast, Pt nanoparticle addition appears to have the opposite effect, leading to a decrease in fiber diameter. One possible explanation is that Pt nanoparticles may influence the solidification dynamics of the PVA solution, promoting faster fiber formation. This accelerated solidification can restrict fiber elongation during electrospinning, resulting in thinner fibers.

Ag-doped nanofibers exhibited superior performance in PEM fuel cell tests, demonstrating higher power density and current density compared to pure PVA nanofibers. The improved electrical and thermal properties of Ag-doped fibers are attributed to the inherent high conductivity and optimal dispersion of Ag nanoparticles. SEM, EDS, and TEM analyses confirmed the structural and compositional changes induced by the nanoparticle doping, further validating the observed enhancements.

The study underscores the potential of nanoparticle-doped PVA nanofibers, particularly Ag-doped variants, in advancing PEM fuel cell technology and other energy-related applications. Future research aims to expand on these findings by optimizing production parameters, experimenting with additional nanoparticle types, and evaluating the long-term stability and scalability of these nanofibers. Moreover, testing on advanced computational and experimental setups may provide deeper insights into their behavior under varied operational conditions.

4. CONCLUSIONS

This study demonstrated the significant impact of Ag and Pt nanoparticle doping on the electrical and thermal properties of PVA nanofibers. Ag-doped nanofibers, especially at a 5% doping ratio, exhibited superior electrical conductivity and enhanced thermal performance, making them ideal candidates for energy-related applications such as PEM fuel cells. Conversely, Pt-doped nanofibers improved electrical conductivity but reduced thermal conductivity, highlighting the importance of nanoparticle selection based on specific application requirements. The results underline the potential of nanoparticle-doped PVA nanofibers in advancing clean energy technologies. Future work will focus on optimizing production parameters, exploring additional nanoparticle types, and assessing the long-term stability and scalability of these materials for broader industrial applications.

Declaration of Ethical Standards

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Credit Authorship Contribution Statement

Author 1: Conceptualization, Formal analysis, Investigation, Methodology, Resources, Software, Writing – original draft, Visualization **Author 2:** Methodology, Supervision, Validation, Writing – review & editing

Declaration of Competing Interest

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Data Availability

All data generated or analyzed during this study are included in this published article.

REFERENCES

[1] Malara, A., "Environmental concerns on the use of the electrospinning technique for the production of polymeric micro/nanofibers", Scientific Reports, 14(1):8293, 2024.

[2] Mowafi, S. and H. El-Sayed, "Production and utilization of keratin and sericin-based electrospun nanofibers: A comprehensive review", Journal of Natural Fibers, 20(1):2192544, 2023.

[3] Habis, C., et al., "Specific role of Al in the synthesis of electrospun Al: ZnO nanofibers: Thermal and elemental analysis", Materials Today Communications, 38:108196, 2024.

[4] Wali, A., et al., "Silver nanoparticles in electrospun ethyl hydroxy ethyl cellulose-PVA Nanofiber: Synthesis, characterization and wound dressing applications", Carbohydrate Polymer Technologies and Applications, 7:100477, 2024.

[5] George, N., et al., "Incorporating silver nanoparticles into electrospun nanofibers of casein/polyvinyl alcohol to develop scaffolds for tissue engineering", International Journal of Biological Macromolecules, 131501, 2024.

[6] Khaleel, M.R., F.S. Hashim, and A.H.O. Alkhayatt, "Preparation, characterization, and the antimicrobial activity of PVA-PVP/ZnO nanofiber films via indigenous electrospinning setup", Journal of Molecular Structure, 138325, 2024.

[7] Krishna, K., et al., "Fabrication and conductivity study of silver nanoparticles loaded polyvinyl alcohol (PVA-AgNPs) nanofibers", Materials Today: Proceedings, 42:515-520, 2021.

[8] Wang, Y., et al., "PEM Fuel cell and electrolysis cell technologies and hydrogen infrastructure development–a review", Energy & Environmental Science, 15(6):2288-2328, 2022.

[9] Abdelkareem, M.A., et al., "Environmental aspects of fuel cells: A review", Science of The Total Environment, 752:141803, 2021.

[10] Sharma, S., S. Agarwal, and A. Jain, "Significance of hydrogen as economic and environmentally friendly fuel", Energies, 14(21):7389, 2021.

[11] Patil, V., et al., "Degradation mechanisms in PEM fuel cells: A brief review", Materials Today: Proceedings, 2023.

[12] Karanfil, G., "Importance and applications of DOE/optimization methods in PEM fuel cells: A review", International Journal of Energy Research, 44(1):4-25, 2020.

[13] Singh, R., A.S. Oberoi, and T. Singh, "Heat pipes for PEM fuel cell cooling: State of the art review", Materials Today: Proceedings, 2023.

[14] Datta, A., "PEM Fuel Cell MODEL for conceptual design of hydrogen eVTOL aircraft", 2021.

[15] Ormsby, S., "Modelling and design of PEM fuel cell electric military armoured vehicles using a new real-world operation profile model", 2021.

[16] Athanasaki, G., A. Jayakumar, and A. Kannan, "Gas diffusion layers for PEM fuel cells: Materials, properties and manufacturing–A review", International Journal of Hydrogen Energy, 48(6):2294-2313, 2023.

[17] Yanilmaz, M., et al., "Centrifugally spun PVA/PVP based B, N, F doped carbon nanofiber electrodes for sodium ion batteries", Polymers, 14(24):5541, 2022.

[18] Yoon, H., et al., "Adaptive Epidermal Bioelectronics by Highly Breathable and Stretchable Metal Nanowire Bioelectrodes on Electrospun Nanofiber Membrane", Advanced Functional Materials, 2313504, 2024.

[19] Sakthivel, P., et al., "Low content of Ni-Pt nanoparticles decorated carbon nanofibers as efficient electrocatalyst for hydrogen evolution reaction", Journal of Chemical Technology & Biotechnology, 2024.

[20] Yu, H., M. Zhang, and T. Jin, "Electrospun Ag/TiO2 Heterostructured Nanofibers for Photoelectrochemical Applications", Russian Journal of Physical Chemistry A, 97(12):2786-2791, 2023.

[21] Wang, C., et al., "Controllable growth of silver nanoparticles on titanium dioxide/nitrogen-doped carbon nanofiber/molybdenum disulfide: Toward enhanced photocatalytic-activating peroxymonosulfate performance and "memory catalysis"", Chemical Engineering Journal, 479:

147752, 2024.

[22] Gao, M., et al., "Flexible nitrogen-doped carbon nanofiber-reinforced hierarchical hollow iron oxide nanorods as a binder-free electrode for efficient capacitive deionization", Desalination, 549:116360, 2023.

[23] Sharma, G.K. and N.R. James, "Flexible N-doped carbon nanofiber-polydimethylsiloxane composite containing La0. 85Sr0. 15CoO3− δ nanoparticles for green EMI shielding", ACS Applied Nano Materials, 6(7):6024-6035, 2023.

[24] Guan, J., et al., "Integrating RuCo alloy in N-doped carbon nanofiber for efficient hydrogen evolution in alkaline media", Journal of Alloys and Compounds, 942:168941, 2023.

[25] Chen, F., et al., "Hierarchical N-doped carbon nanofiber-loaded NiCo alloy nanocrystals with enhanced methanol electrooxidation for alkaline direct methanol fuel cells", Journal of Colloid and Interface Science, 646:43-53, 2023.

[26] Yang, T., et al., "Oxygen-doped carbon nanofiber nonwovens as an effective interlayer towards accelerating electrochemical kinetics for lithium-sulfur battery", Applied Surface Science, 611:155690, 2023.

[27] Wang, F., et al., "Sulfur doped hollow carbon nanofiber anodes for fast-charging potassium-ion storage", Applied Surface Science, 614:156149, 2023.

[28] Zhang, L., et al., "Rapid quantitative detection of luteolin using an electrochemical sensor based on electrospinning of carbon nanofibers doped with single-walled carbon nanoangles", Analytical Methods, 15(25):3073-3083, 2023.