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Effects of Temperature, Pressure, and Frequency on Electrical Conductivity and Dielectric Behavior of PVA Nanopolymers

In this study, electrical conductivity and dielectric properties were investigated regarding the pure polyvinyl alcohol (PVA) nanopolymer among a variety of temperatures and pressures and at various operating frequencies. At various temperatures, the electrical conductivity, loss factor, and real element of the dielectric constant were determined. The temperatures were 25, 40, 80, 120, and 160 °C with pressures of 7.5, 8, 8.5, 9, and 9.5 MPa. In addition, the selected operating frequencies were 50 Hz, 100 kHz, 400 kHz, 1 MHz, and 3 MHz. Results demonstrate that the behavior of electrical conductivity has improved under the influence of temperature, pressure and frequency. Moreover, The loss factor values vary with frequency and are linearly related to both temperature and pressure.

***Keywords*: Electrical conductivity; Loss factor; Dielectrics; Nanopolymers**
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1. Introduction

Undoubtedly, materials science has witnessed vast development and covered wide spectra of compounds. Over the past decades, diverse insulating materials have been utilized as insulators for electrical systems [1,2]. Owing to the tremendous development in the field of electric power systems, insulating materials with high dielectric constant for AC and DC circuits at various frequencies and temperatures are developed [3-7]. It is well documented that polymers are electrically insulating materials because electrons are tightly bonded to the atomic structure and cannot travel freely across the material. Insulating polymers are the most often used due to their unique physical and chemical properties. The fundamental concern in industrial settings is the poor heat conductivity of polymers. [8]. Need to enhance polymers' thermal conductivity is, hence, paramount. [9-11].

Polyvinyl alcohol (PVA) is extremely important and has key qualities such as being tasteless and odorless. In addition, moderately soluble in water and ethanol, and insoluble in organic solvents. [12]. Furthermore, it is an organic polymer with several applications, particularly in biochemistry and biomedicine. This is due to its good compatibility and relatively high biodegradability in specific conditions.

Due to its electrical insulating properties, PVA is extensively studied, and due to its importance in several industries, PVA is the most commercially important water-soluble plastic in use. It is also be readily blended with a number of natural materials and can exhibit properties that are compatible with a range of applications. The inclusion of natural fibers and fillers can give further improvements in mechanical properties without compromising overall degradability. Therefore, the potential benefits of this material given its water-soluble characteristics are huge, but this must be offset against practical considerations of its long-term life cycle in changeable environmental conditions [13-16]. PVA exhibits high dielectric strength higher than 1000 kV/mm and good charge storage capacity [17].

Typically, the hydroxyl group (-OH) in PVA chemical structure gives it a somewhat basic appearance. Because of the unstable nature of its monomer form, vinyl alcohol cannot be acetate (PVAC). Then, hydrolysis of PVAC to PVA is required as the following step [18,19]. Great deal of literature studied PVA from various aspects, most notably, the thermodynamic, mechanical, and structural implications of a PVC polymer reinforced with $CaCO_3$ [20,21]. Polyethylene oxide polymer have been synthesized and decorated with $MnCl_2$ [21]. The study was conducted at operating frequencies ranged from 10 Hz to 13 MHz. Results showed that the AC conductivity has improved at high frequencies owing to the high mobility of charge carriers which is leading to enhancing the conduction mechanism. Authors of [22] have reviewed the biodegradation performance of PVA, while authors of [23] have recorded the electrical and structural properties of pure and NaBr-loaded PVA. They demonstrated an increase in conductivity with increasing temperature in pure and NaBr-doped PVA. These composites may be suitable for solid-state battery applications. In [24], pure and manganese chloride-filled PVA composite films (MPVA) have been produced. Optical study revealed that MPVA has a higher refractive index than PVA in the visible band

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up to 710 nm. From another perspective, literature examined variation characteristics of polymers, including polymer irradiation and the electrical properties of ion-irradiated polymer materials [25,26]. Although much research has been conducted, the current study focuses on the electrical and optical properties of synthetic PVA polymers at various temperatures and pressures.

2. Experimental Part

To prepare PVA nanopolymer, a white powder of pure polymer PVA (Code 8-88, Germany production) was utilized with an average of polymerization of 1400 to prepare the studied samples. The mass of samples were determined via the use of a highly accurate method sensitive electronic scale, which records the outcome straight after calibration. 25 samples were synthesized of PVA with the weight of 2 g for each sample. The 25 samples were hard-pressed into a metal mold of 1.6 cm in diameter. After that, each 5 samples were pressed under pressures of 7.5, 8, 8.5, 9, and 9.5 MPa using an ENERPAC hydraulic presses. Then each 5 samples with fixed pressure undergo heat treatment at set of temperatures 25, 40, 80, 120, 160 °C for 30 minutes, by means of an electrical oven utilized for drying, curing, smelting and heat treatment.

On completion of heat handling, some observations were recorded. Firstly, the nature and color of the PVA nanopolymer without demonstrating any changes at temperature ranged from 25-80°C. Secondly, when the temperature elevated to 120°C, the polymer begins to vaporize and subsequently change its color to a milky yellow. Lastly, at temperature of 160°C, gaseous emission and vaporization process have been clearly observed accompanied with a color transform to a dark yellow in addition to a chemical change occurring. Then, AC electrical conductivity of the studied samples was measured using the AC electrical conductivity meter, and the findings were used to calculate and obtain all the parameters. Its dielectric properties and electrical conductivity in alternating current, for instance loss tangent (tan δ), and dielectric constant's actual value were examined at number of frequencies of 50 HZ, 100 kHz, 400 kHz and 1,3 3 MHZ with the help of an Instek 8000G LCR meter, in the frequency range of 50Hz-5MHz.

3. Results and Discussion

Electrical conductivity is a well-known material attribute that indicates a material's tolerance for current flow and its capacity to transmit moving charges from one location to another. To put it another way, electrical conductivity is the measurement of the amount of electrical current that flows through a substance. Specific conductance is the name given to electrical conductivity. Further, conductivity is well-known as an intrinsic property of a substance electrical conductivity can be expressed by the following relationship [27] :

$$\sigma_{ac} = \omega \, \varepsilon_o K \, * tan \, \delta \quad (1)$$

σ_{ac} signifies the electrical conductivity. ω symbolizes angular frequency, ε_o corresponds to the permittivity, K denotes the true component of the constant dielectric and tan δ implies loss factor.

The PVA nanopolymer's electrical conductivities are computed at various operating frequencies, pressures, and temperatures. Figures (1-5) show the plotted and acquired findings. At fixed frequencies, the AC electrical conductivity values increase as the treatment temperature and pressure rise. We infer that there is a small correlation between conductivity and temperature and frequency for frequencies higher than 50 Hz. This trend suggests that when an external electric field is applied at low frequencies, charge carriers move more quickly and powerfully. recommending a greater conductivity magnitude. Conversely, charge carriers are unable to follow the rapid changes in the operating electric field, which causes the conductivity magnitudes to decrease. [27].

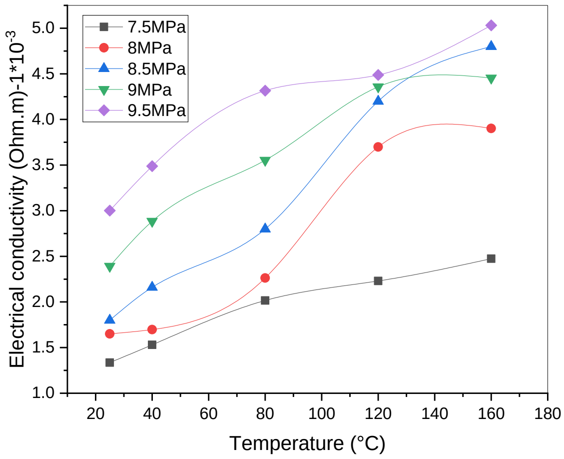

Fig. (1) Electrical conductivity behavior of the PVA at a frequency of 50 Hz

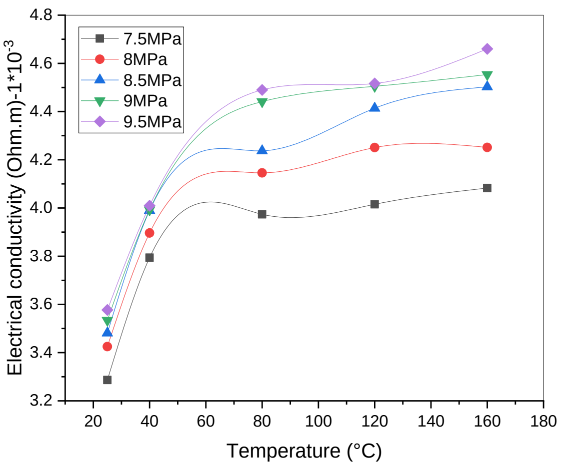

Fig. (2). Electrical conductivity behavior of the PVA at a frequency of 100 kHz

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Moreover, our analyzed findings revealed that all studied curves exhibit temperature-dependent trends at variant pressure and frequency and likewise pressure -dependent behaviors at fixed temperature and frequency. It is also evident that electrical conductivity values at constant temperature and pressure are observably enhanced. This may be due to the contribution of dissimilar types of polarization, whereas at medium frequencies four types of polarization contribute. At high frequencies, ionic and electronic polarization contribute. In addition, considerable improvement in the electrical conductivity values at higher frequencies is attributed to reducing the contribution of polarization effects.

It is essential to assess the dielectric constant of PVA Nano polymer at increased operating frequency. Consequently, this context demonstrates the real part of dielectric constant as a function of temperature and at various pressures and operating frequency. The main relations that calculate dielectric function is found somewhere else. It has been stated that the dielectric constant of a dielectric material originates as a consequence of the interactions of four types of polarizations, namely, electronic, ionic, directional and the space charge polarization [28,29]. In order for these polarizations to be revealed, the charged particle's displacement is required occurred. At an alternating operating current (AC), polarization could ensue only once the displacement of the particles follow changing along which the electric field is moving. Therefore, when Particles with charges are bulkier, they will not influence by high-frequency electric fields, leading to gradual reductions in the dielectric constant [30,31]. Figures (6-10) depict that the real component of dielectric constant are shifted downwards at higher temperature as the operating pressure and frequency improved.

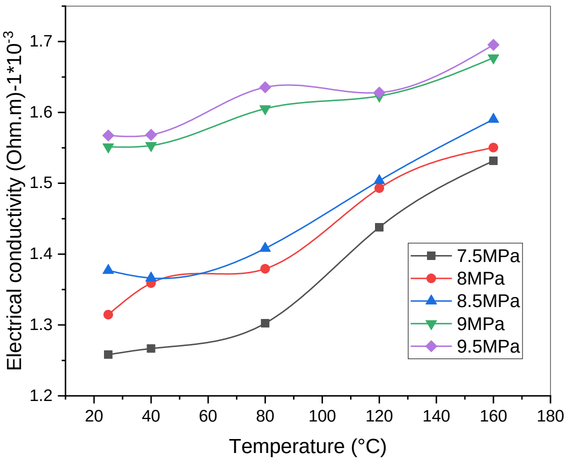

Fig. (3) Electrical conductivity behavior of the PVA at a frequency of 400 kHz

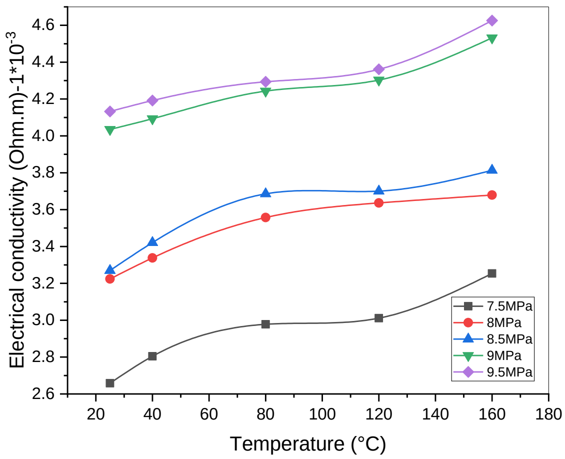

Fig. (4) Electrical conductivity behavior of the PVA at a frequency of 3 MHz

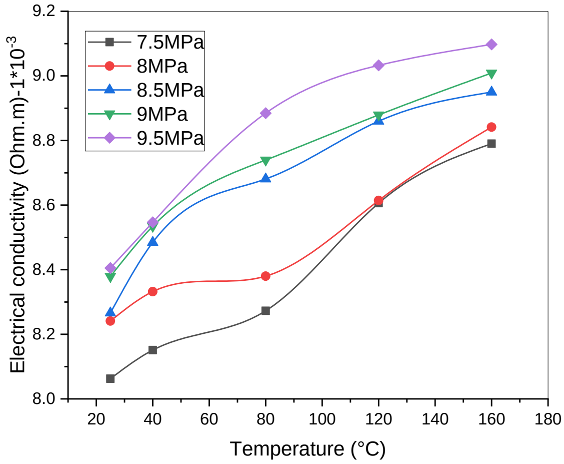

Fig. (5) Electrical conductivity behavior of the PVA at a frequency of 3 MHz

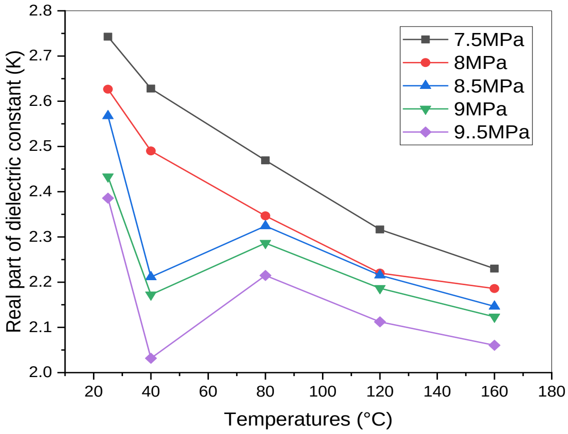

Fig. (6) Real part of dielectric constant versus temperature and at various pressures. The operating frequency is 50 Hz

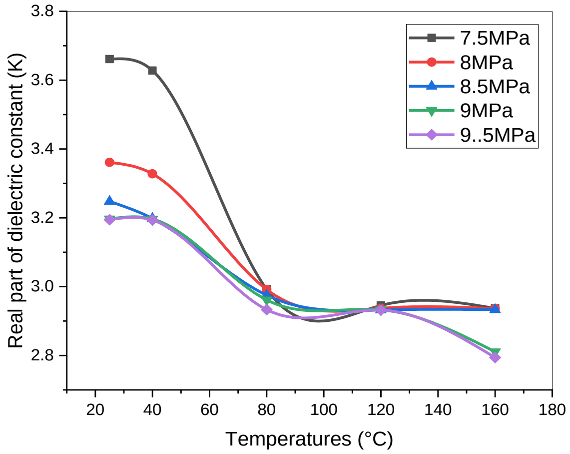

Fig. (7) Real part of dielectric constant versus temperature and at various pressures. The operating frequency is 100 kHz

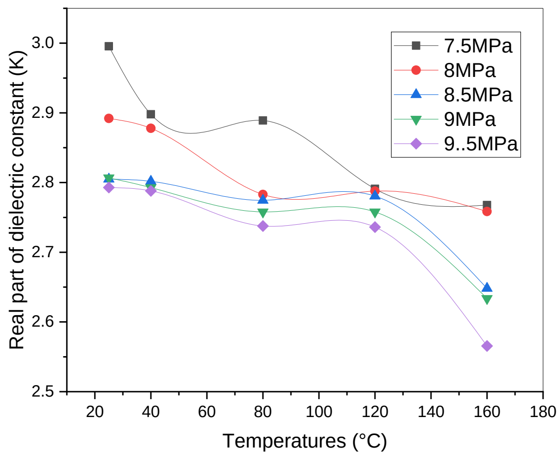

Fig. (8) Real part of dielectric constant versus temperature and at various pressures. The operating frequency is 400 kHz

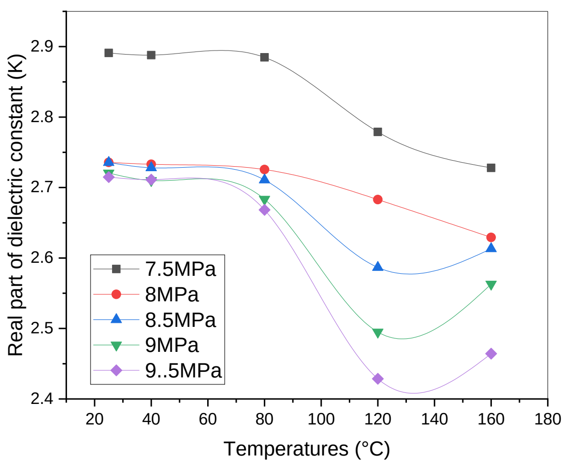

Fig. (9) Real part of dielectric constant versus temperature and at various pressures. The operating frequency is 1 MHz

The dissipation factor or loss tangent (tan δ) of polymers is an indication of the complex relative permittivity. Loss tangent reveals the energy loss in a dielectric substance via conduction, slow polarization currents, and further dissipative phenomena [32]. The peak value for a dielectric with no direct current conductivity arises at the relaxation frequency, which is temperature-related. Figures (11-15) demonstrate dissipation factor under the selected conditions. It denotes to the proportion between the amount of the real and imaginary dielectric constants, i.e. the measure of energy loss that is converted into heat, when an electric field is exposed to any insulating material, a certain amount of electrical energy is dissipated in that material, this energy is converted from electrical energy to thermal energy [33].

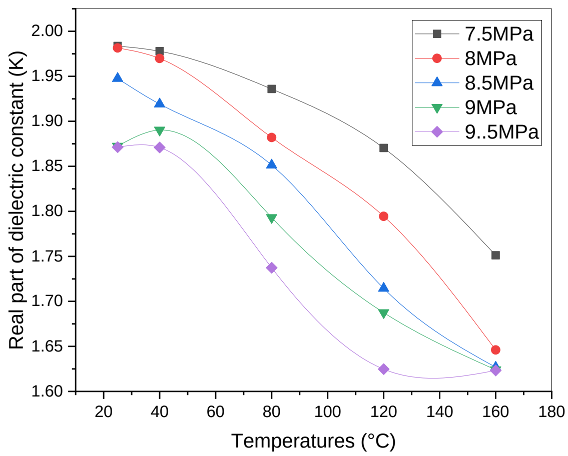

Fig. (10) Real part of dielectric constant versus temperature and at various pressures. The operating frequency is 3 MHz

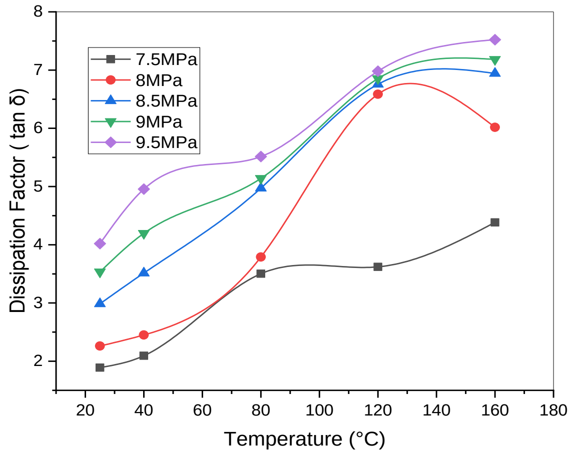

Fig. (11) Dissipation factor versus temperature and at various pressures. The operating frequency is 50 Hz

The values of the loss factor and dielectric constant of an electrical circuit are directly proportional to the temperature and pressure at certain operating frequencies. It is clear from the results that the loss factor increases with growing temperature and pressure; nonetheless, it changes through changing frequency. It is realized from the current results that at operating frequency of 50 Hz, the values of loss factor are the highest. This could be attributed to the inter polarization work and that the increase in temperature leads to an increase in the density, which helps in the growth of the steric charge, which leads to an increase in polarization, and thus the loss factor increases.

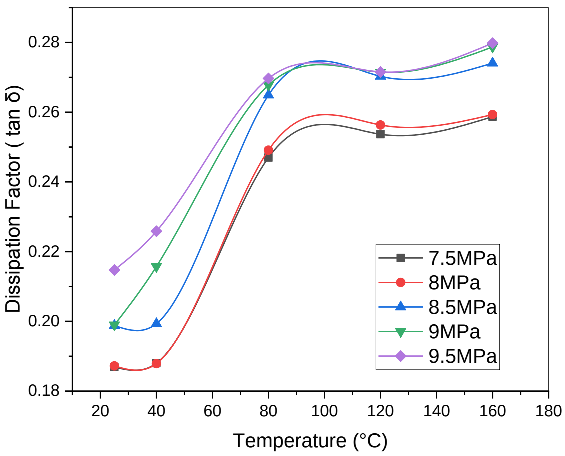

Fig. (12) Dissipation factor versus temperature and at various pressures. The operating frequency is 100 kHz

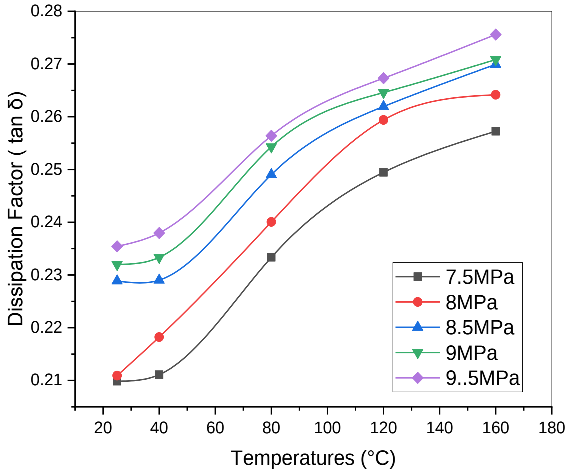

Fig. (13) Dissipation factor versus temperature and at various pressures. The operating frequency is 400 kHz

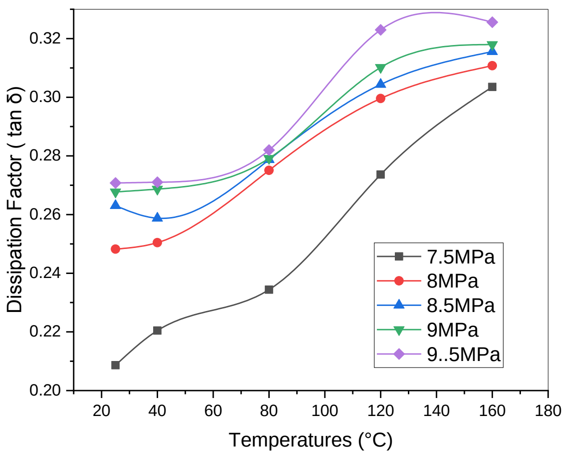

Fig. (14) Dissipation factor versus temperature and at various pressures. The operating frequency is 1 MHz

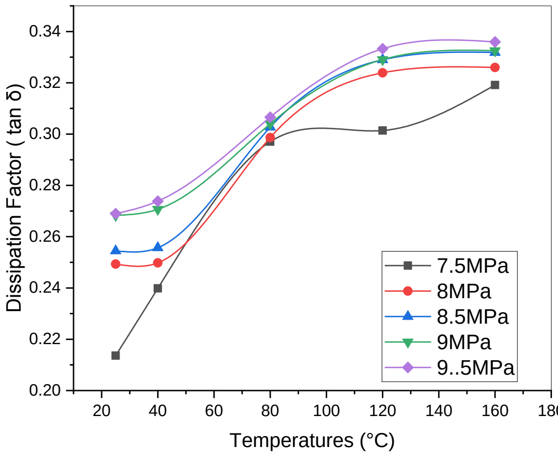

Fig. (15) Dissipation factor versus temperature and at various pressures. The operating frequency is 3 MHz

4. Conclusions

In this work, electrical conductivity, dielectric constant, and loss factor have been studied in the frequency of 50 Hz, 100 kHz, 400 kHz, 1 MHz and 3 MHz and at temperature up to 160°C. The obtained results proved that the higher the temperature values, the higher the electrical conductivity. The analysis of the real part of dielectric constant reveals a robust correlation between frequency/temperature. At high frequencies, a decrease with increasing frequency, whereas growth by rising temperature at low frequency. The loss factor is directly proportional to the pressure and temperature and changes inversely with the change in frequency. The current obtained results are promising and encouraging to further exploring dielectric and electric properties of organic polymers.

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