Preparation and Study of Some Electrical Properties of PVA-Ni(NO$_3$)$_2$ Composites

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ABSTRACT

The aim of this paper is to prepare and study the (D.C.) electrical conductivity of (PVA-Ni(NO$_3$)$_2$) composites at different temperatures. For that purpose, PVA films with Ni(NO$_3$)$_2$ salt additive were prepared with different concentrations 2, 4, 6, 8 and 10 wt. % and with thickness of 45µm by using casting technique. The experimental results for PVA-Ni(NO$_3$)$_2$) films show that the (D.C.) electrical conductivity increased with increasing the filler content and the temperature, and the activation energy was decreased with increasing the filler content.

Keywords: Polyvinyl alcohol; Casting method; Electrical properties; Composites

1. INTRODUCTION

Although many people probably do not realize it, everyone is familiar with polymers. They are all around us in everyday use, in rubber, plastics, resins and in adhesives and adhesive tapes, and their common structural feature is the presence of long covalently bonded chains of atoms.

They are an extraordinarily versatile class of materials, with properties of a given type often having enormously different values for different polymers and even sometimes for the same polymer in different physical states.

An even greater range of values is available for the electrical conductivity of polymers: the best insulating polymer may have a conductivity as low as 10^{-11} $\Omega \cdot cm^{-1}$, whereas a sample of poly acetylene doped with a few percent of a suitable donor may have a conductivity of 10^{4} $\Omega \cdot cm^{-1}$, a factor of 10^{22} higher [1].

Polyvinyl alcohol (PVA), a polyhydroxy polymer, is the largest, synthetic, water-soluble polymer produced in the world based on volume. It is produced commercially by the hydrolysis of polyvinyl acetate PVAC [2].

Polyvinyl alcohol has excellent film forming, emulsifying, and adhesive properties. It is also resistant to oil, grease and solvent. PVA is odorless and nontoxic, as well as has high oxygen and aroma barrier properties [3].

2. EXPERIMENTAL

The raw materials used in this work were as a powder of commercial polyvinyl alcohol (PVA) doped by Nickel Nitrate $Ni(NO_3)_2$ salt with weight percentages 2, 4, 6, 8 and 10 wt. %. The films were prepared using the conventional casting method by dissolving the powders with the appropriate percentages in distilled water. The powders were completely dissolved by using magnetic stirrer for about 45 minute and then placed in Petri dish (5 cm diameter). The thickness of the dried films was found to be ~45 μm measured by digital micrometer.

The method of the three-electrode cell (the method of Teflon-isolated circular electrodes) was used according to ASTM D66-257 recommendations to study the effect of additives and temperature on the volumetric conductivity of polymeric systems. The input electrical power was regulated by using a (D.C.) power supply of Phillips Harris Limited type having a voltage of 3-7 kV, the highest voltage used in this study was 1000 V. The current was measured by a Digital Solid State Electrometer (616) with sensitivity of 10^{-15} and full gradation. The temperature was changed in the range of 303-373 K by using an electrical oven of Yamato (DP61) type.

3. RESULTS AND DISCUSSION

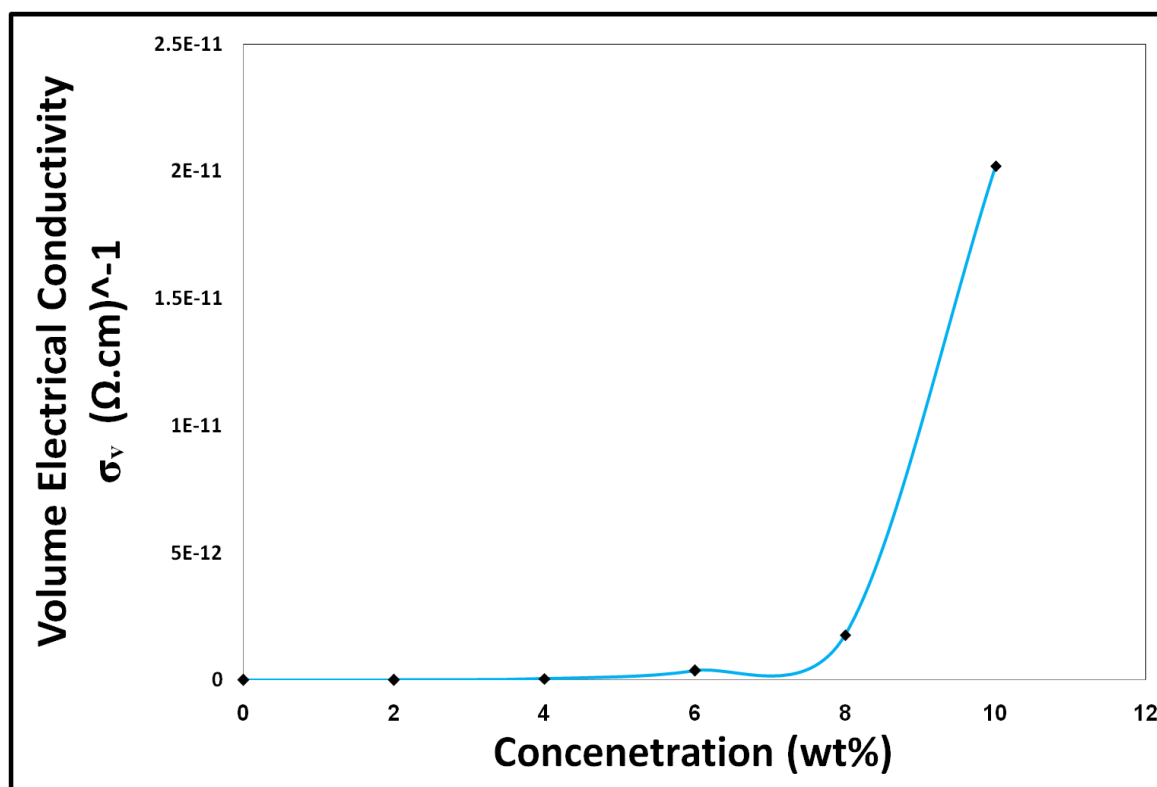The volumetric electrical conductivity (σ_V) is calculated using the equation below [4]:

$$\sigma = \sigma_O \exp(-E_{act}/k_B T) \qquad \text{.... (1)}$$

where (σ) is electrical conductivity at temperature (T), (σ_O) is electrical conductivity at absolute zero temperature, (k_B) is Boltzmann constant and (E_{act}) is activation energy.

Figure (1) shows the volume electrical conductivity $\sigma_v \, \Omega\cdot cm^{-1}$ for PVA-$Ni(NO_3)_2$ films as a function of the concentration of $Ni(NO_3)_2$ salt at room temperature. The figure shows that the electrical conductivity is slightly increasing with the increase of the concentration of $Ni(NO_3)_2$ salt up to 2 wt. %). When increasing the concentration more, the electrical conductivity increases to the large value $3.63 \times 10^{-13} \, \Omega\cdot cm^{-1}$ at the concentration 6 wt. % of $Ni(NO_3)_2$ salt and an increase in the concentration of $Ni(NO_3)_2$ salt to 10 wt. %, the electrical conductivity reaches to $2.02 \times 10^{-11} \, \Omega\cdot cm^{-1}$. The increase of electrical conductivity with increasing concentration of $Ni(NO_3)_2$ salt is caused by the increase of the charge carriers ions in which they increased with increasing filler content when the $Ni(NO_3)_2$ ions few at low concentrations and become more when the $Ni(NO_3)_2$ salt content increases.

But when the concentration of $Ni(NO_3)_2$ salt reaches to (10 wt. %), the network will be connected to each other containing the overlapping paths to allow the charge carriers to pass through, where the charge carriers with routes through which the electrical resistance is less [5,6]. Table (1) shows the values of volume electrical conductivity $\sigma_v \, \Omega\cdot cm^{-1}$ for PVA-$Ni(NO_3)_2$ films with concentration of $Ni(NO_3)_2$ salt at room temperature.

Figure (2) shows the relationship of volume electrical conductivity $\sigma_v \, \Omega\cdot cm^{-1}$ for (PVA-$Ni(NO_3)_2$) films with different concentrations of $Ni(NO_3)_2$ salt with the temperature. We note that the electrical conductivity increases with increasing the temperature, the interpretation of this is that the polymeric chains and $Ni(NO_3)_2$ salt could act as traps for the charge carriers which transited by hopping process.
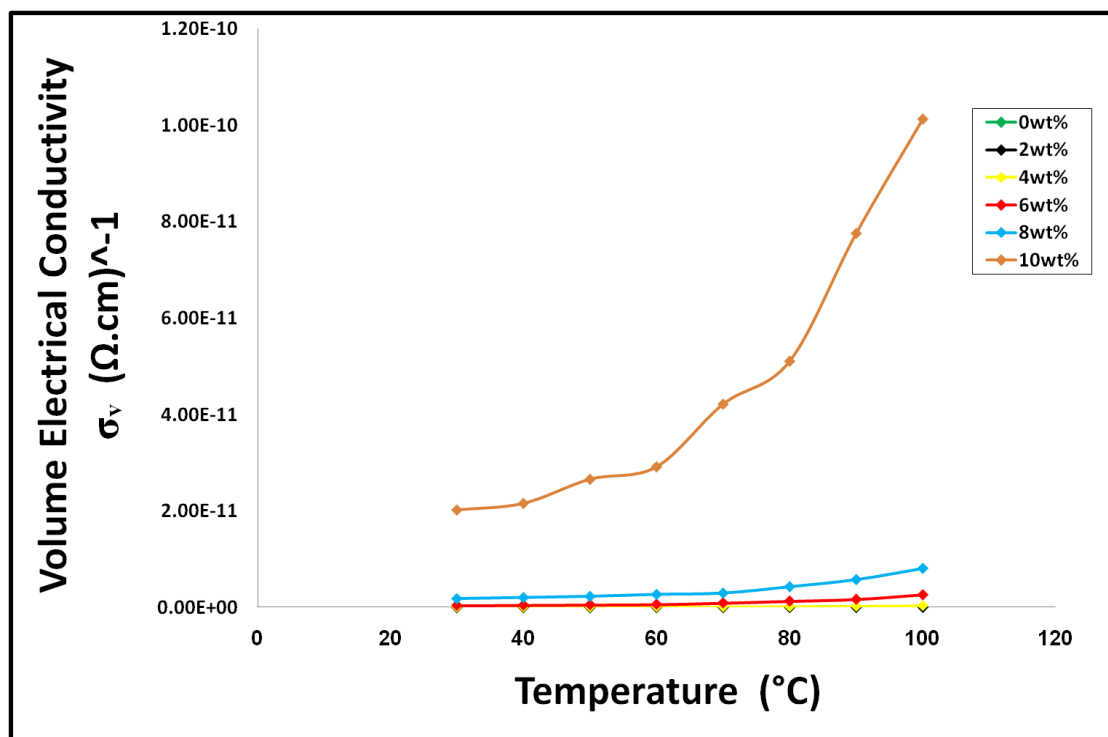
Figure 1. The volume electrical conductivity σ_v ($\Omega \cdot cm^{-1}$) for PVA-Ni(NO$_3$)$_2$ films as a function of the concentration of Ni(NO$_3$)$_2$ salt at room temperature.

Table 1. Values of volume electrical conductivity σ_v ($\Omega \cdot cm^{-1}$) for PVA-Ni(NO$_3$)$_2$ films with concentration of Ni(NO$_3$)$_2$ salt at room temperature.

Ni(NO$_3$)$_2$ (wt. %)	σ_v ($\Omega \cdot cm^{-1}$)
Pure (PVA)	2.30E-16
2	4.06E-15
4	4.29E-14
6	3.63E-13
8	1.76E-12
10	2.02E-11

By increasing the temperature, segments of the polymer begins to move, releasing the trapped charges. The released of trapped charges are intimately associated with molecular motion. The increase of electrical conductivity with the temperature is attributed to two main parameters, charge carriers and mobility of these charges. The mobility depends on the

structure and the temperature [7-9]. Table (2) shows the values of volume electrical conductivity σ_v ($\Omega \cdot cm^{-1}$) for PVA-Ni(NO$_3$)$_2$ films with different concentrations of Ni(NO$_3$)$_2$ salt with the temperature.
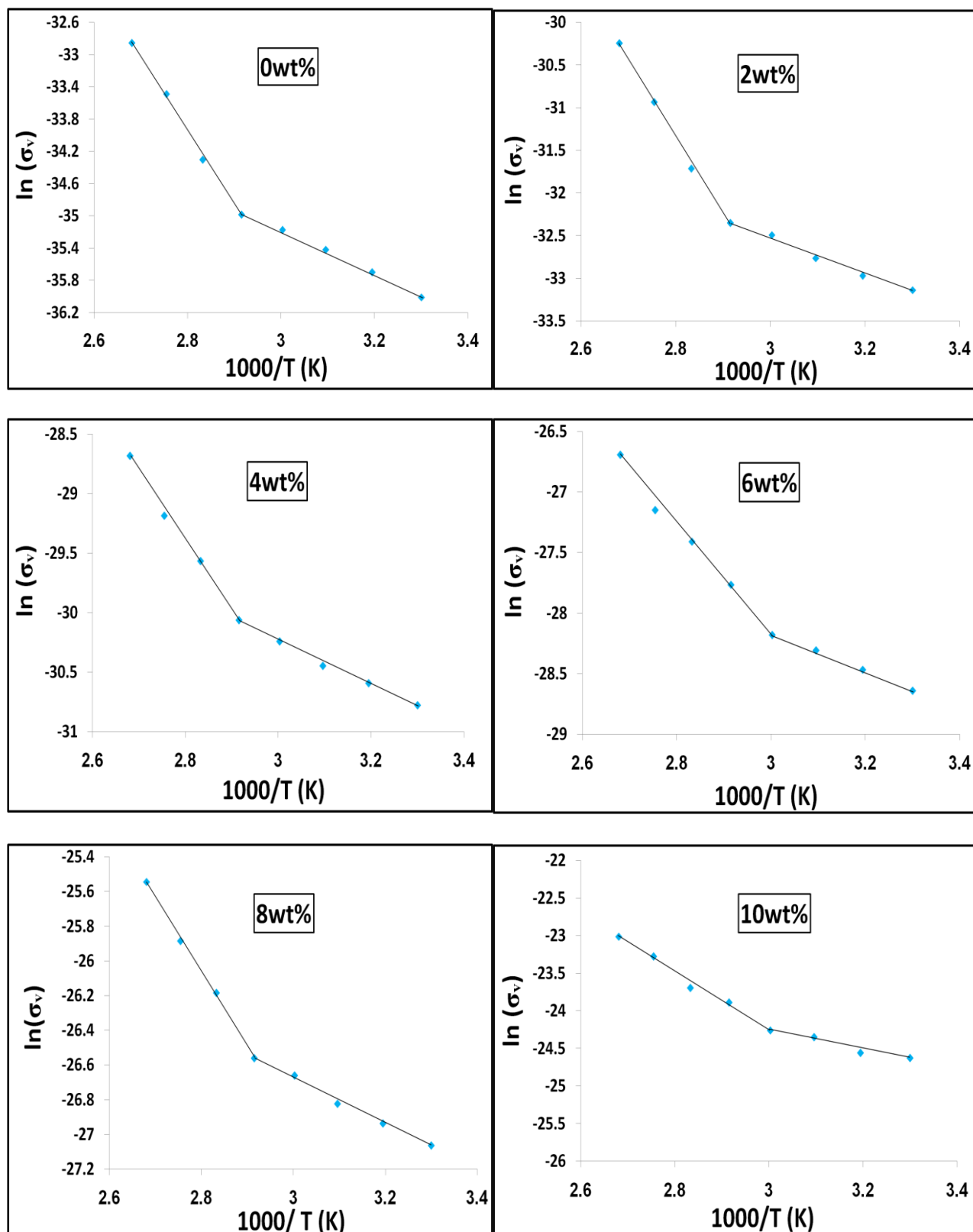

Figure 2. The relationship of volume electrical conductivity σ_v ($\Omega \cdot cm^{-1}$) for PVA-Ni(NO$_3$)$_2$ films with different concentrations of Ni(NO$_3$)$_2$ salt with the temperature.

Figure (3) shows the relation between $\ln\sigma_v$ and the inverse of absolute temperature for (PVA-Ni(NO$_3$)$_2$) films with different concentrations of Ni(NO$_3$)$_2$) salt. It is clear from this figure that there are two transport mechanisms, giving rise to two activation energies (Ea_1) and (Ea_2). (Ea_1) at lower temperatures range 303-333 K, where the conduction mechanism is due to carrier excited into the localized states at the edge of the band and (Ea_2) at higher temperatures range 343-373 K, where the conduction mechanism is due to carrier excited into the extended states beyond the mobility edge [8].

By adding low concentrations of Ni(NO$_3$)$_2$ salt the values of the activation energy are decreasing as a result of the impact of space charge. The addition of low concentrations creates local energy levels in the energy gap (E_g) which could act as traps for charge carriers, which move by hopping among these levels. By increasing the Ni(NO$_3$)$_2$ salt concentration, the activation energy decreases as a result of the increase of local centers.

The low values of the activation energy for PVA-Ni(NO$_3$)$_2$ films are attributed to the formation of a continuous network of Ni(NO$_3$)$_2$ salt that contains paths inside the composites and allows the charge carriers to pass through and this leads to decrease the activation energy [7,10], as shown in the Figure (3). Table (3) shows the values of activation energy in (eV) for PVA-Ni(NO$_3$)$_2$ films with different concentrations of Ni(NO$_3$)$_2$ salt.

Figure 3. The relation between $\ln\sigma_v$ and the inverse absolute temperature for PVA-Ni(NO$_3$)$_2$ films with different concentrations of Ni(NO$_3$)$_2$ salt.

Table 2. Values of volume electrical conductivity σ_v ($\Omega \cdot cm^{-1}$) for PVA-Ni(NO₃)₂ films with different concentrations of Ni(NO₃)₂ salt with the temperature.

T (°C)	σ_v ($\Omega \cdot cm^{-1}$) of PVA-Ni(NO$_3$)$_2$					
	Pure	2 wt. %	4 wt. %	6 wt. %	8 wt. %	10 wt. %
30	2.30E-16	4.06E-15	4.29E-14	3.63E-13	1.76E-12	2.02E-11
40	3.14E-16	4.81E-15	5.17E-14	4.33E-13	2.00E-12	2.15E-11
50	4.15E-16	5.90E-15	5.99E-14	5.07E-13	2.24E-12	2.66E-11
60	5.29E-16	7.74E-15	7.34E-14	5.77E-13	2.64E-12	2.91E-11
70	6.40E-16	8.91E-15	8.79E-14	8.74E-13	2.92E-12	4.21E-11
80	1.27E-15	1.68E-14	1.44E-13	1.25E-12	4.24E-12	5.10E-11
90	2.86E-15	3.67E-14	2.11E-13	1.62E-12	5.73E-12	7.76E-11
100	5.39E-15	7.32E-14	3.50E-13	2.56E-12	8.06E-12	1.01E-10

Table 3. Values of activation energy in (eV) for PVA-Ni(NO₃)₂ films with different concentrations of Ni(NO₃)₂ salt.

Ni(NO₃)₂ (wt. %)	303 – 333 K	343 – 373 K
	E_{a1} (eV)	E_{a2} (eV)
Pure (PVA)	0.24	0.76
2	0.18	0.59
4	0.15	0.49
6	0.13	0.38
8	0.11	0.36
10	0.10	0.31

4. CONCLUSION

1) The (D.C.) electrical conductivity for PVA-Ni(NO$_3$)₂ films increases with increasing of filler content (wt. %) and temperature.
2) The activation energy for PVA-Ni(NO$_3$)₂ films decreases with increasing of the filler content (wt. %).

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