VOL. 19, NO. 18, SEPTEMBER 2024 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

THE EFFECT OF ADDITION SODIUM IODIDE ON THE THERMAL PROPERTIES OF (PEO) THIN FILM

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ABSTRACT

In this study, the thermal properties of polyethylene (PEO) thin films dispersed with a fixed amount of dopants of sodium iodide 0.1% by weight (0.1% wt.) were investigated. The thermal conductivity and thermal resistivity of pure PEO thin films and the prepared ones doped with sodium iodide composites have been studied at different temperatures. It was found that the thermal conductivity of these films increases with the increase in temperature and with the ones that doped with 0.1% sodium iodide.

Keywords: PEO, sodium iodide, thermal conductivity, thermal resistivity.

Manuscript Received 23 July 2024; Revised 7 October 2024; Published 14 December 2024

1. INTRODUCTION

Materials can be classified as metals, ceramics, or polymers; each one has its advantages and disadvantages. Metals are strong, tough, and inexpensive, but are heavy, chemically reactive, and limited to service temperatures below 1000 ºC. Ceramics are hard, chemically stable, and useful at high temperatures, but they are brittle and difficult to fabricate. Polymers are light, and easy to process, but are relatively weak and they are limited to lower service temperatures below 300 ºC [1].

Polymers are macro-molecules with high molecular weight formed by linking together a large number of small molecules called monomers. The process of joining these monomers is called polymerization. Plastics are a group of synthetic polymers made up of chains of atoms or molecules. Typically, most polymers used for practical applications fall in the molecular weight range of 5000 to 20000 g/mol [2].

Because of their desired qualities that made them preferable to other commercial materials, conductive polymer composites (CPC) have sparked a lot of interest in various industrial applications. The change from insulating to conductive behavior is achieved by adding various conducting elements such as metallic particles, carbon or steel fibers, aluminum flakes, and iodine. The additive Sodium iodide is an important aspect of these qualities. Thermoplastic polyethylene is a good insulator in general. Polymers containing conductive fillers make them conductive materials. These fillers provide the composite with its conducting qualities [3]. The study of CPC for numerous industrial applications has sparked a lot of interest. The effect of the addition of conductive particles to insulating polymers on their electrical characteristics was studied by Romas, M. Al-Juma ily, A., … *et al* [4].

Polyethylene oxide (PEO) has good electrical and thermal insulation properties, it is a white solid with a melting point of around (65 ºC), low toxicity, and low glass transition temperature (-65 ºC) which allows transport of the ion at the surrounding temperature. PEO is the best polymer used, because of its large solvating power with ions, good process ability, and outstanding mechanical properties [5-7].

A dopant is a small amount of impurity injected into a semiconductor lattice or crystal to improve optical and electrical properties. AsF_5, I_2, C, and Br_2 are the most common dopants employed to influence polymer conductivity Sodium iodide is called an acceptor, because it receives an electron from a host atom and creates hole carriers. When an electric field is applied, the acceptor atom becomes negatively charged and current flow results from the drift motion of holes made by acceptors, as well as holes and electrons produced by valence-band disruption [8].

Sodium iodide is a white, crystalline salt with the chemical formula NaI. It is a kind of scintillation crystal with good properties. It has very high luminescence efficiency with a melting point of 661 °C. It is used in radiation detection, treatment of sodium iodide deficiency, nuclear medicine, and in many other applications, such as x-ray detectors with high spectroscopic quality. Sodium iodide crystallizes in a face-centered cubic (FCC) structure with space group a = 6.479 Aº, with four sodium and four iodide atoms per unit cell [9].

Sodium iodide, when doped in polymers, may reside at various sites. It may go into the polymer chains, reside at the amorphous/crystalline and diffuse preferentially through the amorphous region forming a charge transfer complex (CTC), or may exist in the form of molecular aggregates between the polymer chains [10].

The thermal, electrical, and mechanical characterization is essential for the industrial development of thin films of new polymers, blends, composites, and advanced materials that can be used as optical devices, filters, polarizers, total reflectors, and narrow pass-band filters [11]. In this study, the thermal properties (conductivity and resistivity) of pure thin films of PEO and

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ARPN Journal of Engineering and Applied Sciences

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the ones that doped with sodium iodide composites were investigated at various temperatures (30 -55) ºC.

2. EXPERIMENTAL

In this study, the materials examined are pure thin films of PEO and the prepared ones doped with sodium iodide composites.

A. Preparation of Thin Films

Poly ethylene oxide and solid sodium iodide were blended in methanol as a convenient solvent. The mixture was mixed with a rotary magnet for two days to get a homogeneous mixture. Then, the mixture was directly cast on a glass mold to form a delicate film. The film was dried at room temperature for two days. Finally, all films were dried completely in the oven at a temperature of 40 ºC for another two days.

The thickness of the prepared PEO composites was measured by a sensitive digital Vernier caliper with uncertainty (± 0.001) mm. The thickness of all PEO composite films was measured at six different spot places, chosen randomly, and the average value was calculated. The average value of thicknesses of PEO composite films is almost 70 µm.

B. Measurements of Thermal Properties

The thermal conduction in solid PEO polymer electrolytes is produced by lattice vibration waves (phonon), free electrons and impurities existing in their structure, and ions transport (as major contributors). The measurement of the thermal conductivity of PEO polymer is too difficult because its value is relatively small (0.2 - 0.4 W/m.°C).

The thermal conductivity (k) for the prepared electrolyte PEO thin films dopant in (0.1% wt.) sodium iodide was measured at various temperatures (30 - 55) ºC. The measurements at higher temperatures were impossible to perform because the melting point of PEO is about 65 ºC.

The setup of the components used for thermal conductivity measurements of PEO composite films are shown in Figures 1 and 2. In Figure 1 the thermocouple amplifier (AD594) instrument was used. In Figure-2 (a), the sample holder consists of two test disk samples, a heater, two sheets of Teflon used as insulators, five thermocouples, Teflon tapes, and aluminum plates. The oven, power supply, and stopwatch are also used. The Schematic diagram of the sample holder is shown in Figure-2 (b).

Figure-1. Thermocouple amplifier instrument.

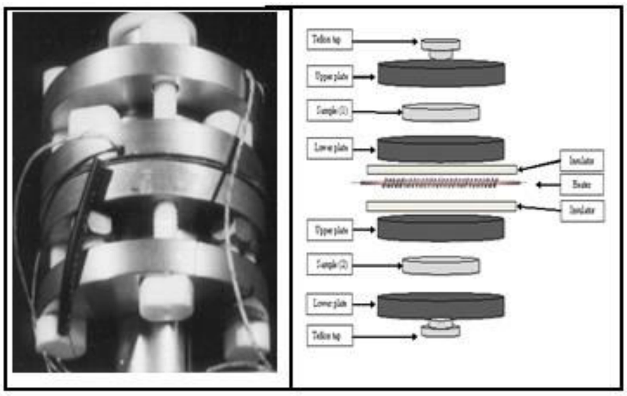

Figure-2. a) The sample holder b) Schematic diagram of the sample holder.

The thermal conductivity in (W/m.ºC) was calculated using the following relation:

$$k = IV \frac{L}{2A\Delta T} \tag{1}$$

Where I is the pulse current (Ampere), V is the pulse voltage (Volt), L is the sample thickness (m), ΔT is the temperature difference between T1 and T_2 (ºC) at steady state, and A is the sample area (m^2). The factor 2 in the above equation for using two specimens.

The average value of thermal conductivity was determined by the following equation:

$$k = \frac{k_1 + k_2}{2} \tag{2}$$

Where k_1 and k_2 are the thermal conductivities of the two used specimens.

Thermal properties characterize the response of a material to the application of heat. The temperature of a solid object and its dimensions increase when it absorbs energy in the form of heat. The energy may be transported to cooler regions of the sample if temperature gradients exist, and ultimately, the sample melts.

Heat conduction in solids is mediated mainly by the phonons or elastic waves only, as a result of the molecular vibration of the lattice, where there are no free electrons. The thermal conductivity of polymers can be described by Debye and Eiermann model [12] as follows:

$$k = \frac{1}{3} c_{\upsilon} \rho \upsilon \lambda \tag{3}$$

Where, ρ is the volume density, υ is the propagation speed of the phonons through the lattice, c_{υ} Is the heat capacity of phonons per unit volume, and λ is the mean free path between two successive collisions in such processes as geometrical scattering and scattering by other phonons.

3. RESULTS AND DISCUSSIONS

In the present study, the thermal properties of pure PEO and PEO doped with (0.1% wt.) sodium iodide thin films were measured at various temperatures (30 - 55) ^{0}C. The thermal conductivity and thermal resistivity of these films were determined.

Figure-3 shows the relationship between the thermal conductivity (k) and the temperature (T) for pure PEO and PEO doped with (0.1% wt.) sodium iodide composites. It is noticed that the thermal conductivity (k) increases with increasing temperature. As the temperature increases, the lattice phonons, impurities ions, and existing electrons are activated, and thus the thermal conductivity increases.

Figures 4 and 5 show the relationship between the thermal conductivity (k) and the PEO thin films doped in various percentages of sodium iodide (0.0 - 0.1% wt.). It is noticed, that the thermal conductivity (k) increases with the increase in the percentage of the dopant sodium iodide. Thus dispersing sodium iodide dopant in the PEO matrix increases the thermal conductivity of the polymer electrolyte and decreases its thermal resistance which could be helpful in thermal applications. Thermal conductivities increase with increasing the dopant concentration, this increase could be due to compactness created by increasing the percentage of the dopant sodium iodide, which increases the heat transfer among phonons diffusion [13].

Figure-5 shows the relationship between the thermal resistivity (r = 1/ k) of the pure PEO thin films and PEO doped with (0.1% wt.) sodium iodide composites and the temperature. Since the thermal resistivity is a reciprocal of the thermal conductivity (r = 1/ k), the thermal resistivity of the pure PEO thin films and PEO doped with (0.1% wt.) sodium iodide composites decreases with increasing temperature.

The thermal conduction mechanism in a PEO polymer matrix filled with sodium iodide particles is largely influenced by the formed conductive paths [12]. The thermal conductivity varies with the rearrangement of sodium iodide particles in transport paths and their distribution in the polymer matrix [13].

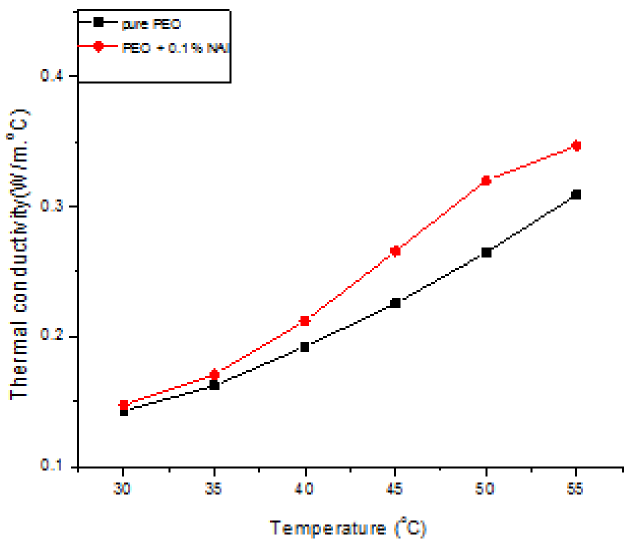

Figure-3. Thermal conductivity at various temperatures (30-55) ^{0}C for pure PEO thin films and PEO doped with (0.1% wt.) sodium iodide composites.

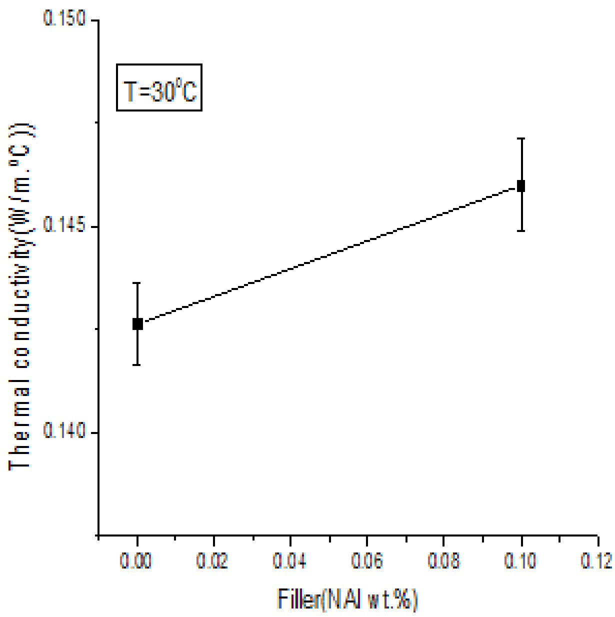

Figure-4. The thermal conductivity of PEO thin films at various concentrations of the dopant sodium iodide (0.0- 0.1% wt.)

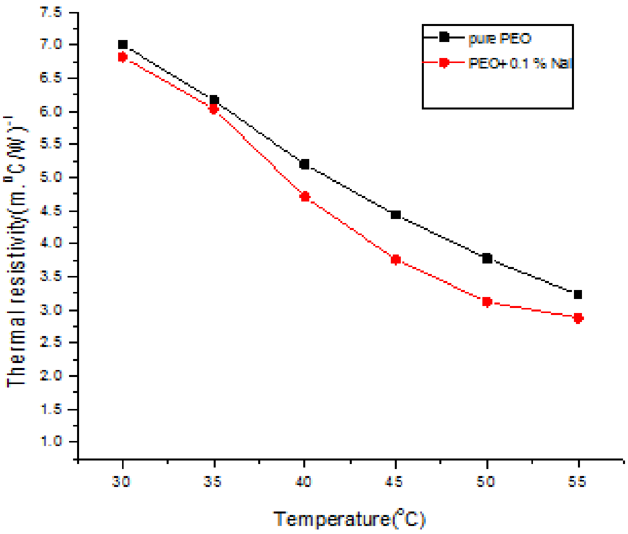

Figure-5. The Variation of thermal resistivity (r = 1/ k) of pure PEO thin films and PEO doped with (0.1% wt.) sodium iodide composites with temperature.

Table-1 reports the values of the thermal conductivity (k) and resistivity (r) for the pure PEO thin films and PEO doped with (0.1% wt.) sodium iodide thin films, (k) is equal to 0.140 (W/m.°C) for pure (PEO) thin film and becomes 0.150 (W/m.°C) for PEO thin film doped with (0.1% wt.) sodium iodide. Thus the sodium iodide dopant has a large effect on the enhancement of the thermal conduction of the prepared thin films.

Table-2 represents the variation of thermal and electrical conductivities of the PEO doped with sodium iodide thin films. Both the thermal and electrical conductivity values increase with increasing the dopant content of sodium iodide in POE thin films.

Figure-6 shows the relationship between the AC conductivity of pure PEO thin films and PEO doped with (0.1% wt.) sodium iodide composites and the frequency.

The increase in electronic conductivity caused by doped sodium iodide is referred to as a concentration of sodium iodide effect. In a solid polymer electrolyte, electrons and charges move in a liquid-like manner, whereas electron movement through the polymer matrix is aided by the large amplitude of polyethylene oxide segmental motion.

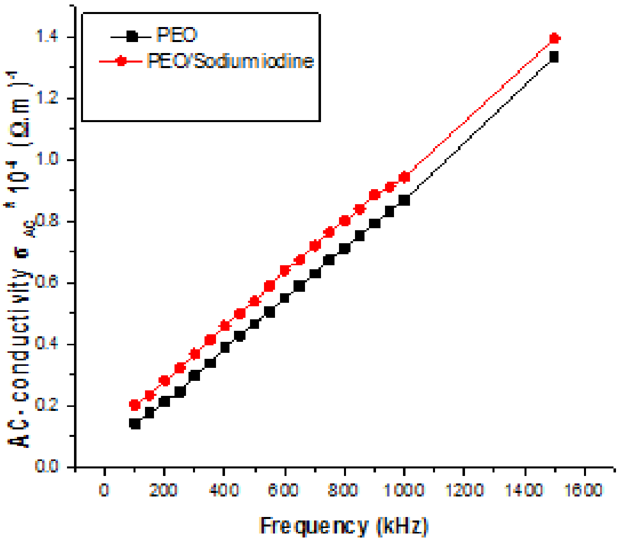

Figure-6. The relationship between AC conductivity of pure PEO thin films and PEO doped with (0.1% wt.) sodium iodide composites and the frequency.

Table-1. The values of thermal conductivity, thermal resistivity, and thermal resistance for pure PEO thin films and PEO doped with (0.1 % wt.) sodium iodide composites at a temperature of 30 °C.

Polymer electrolyte composite	**Thermal conductivity(k) (W/m.°C)**	**Thermal resistivity (r) (m.°C/W)**	**Thermal resistance × 10^{-4} (R) (m^2.°C/W)**
Pure PEO	0.140	7.01	4.91
PEO doped with (0.1% wt.) sodium iodide	0.150	6.67	4.79

Table-2. The values of the thermal and electrical conductivities of pure PEO thin films and PEO doped with (0.1 % wt.) Sodium iodide composites.

Polymer electrolyte composite	**Thermal conductivity(k) (W/m.°C)**	**Electrical conductivity (σ_{AC})×10^{-6} (Ohm. m)$^{-1}$**
Pure PEO	0.140	0.05
PEO doped with (0.1% wt.) sodium iodide	0.150	0.03

4. CONCLUSIONS

The thermal properties of pure (PEO) and PEO doped with (0.1% wt.) sodium iodide thin films were studied. From the results, we deduced that:

a) The thermal conductivity of the PEO composites increases with the increase of the concentration of the dopant sodium iodide. This may be due to the ions/and electrons of the added sodium iodide that activated the PEO thin films and thus increased their thermal conductivity. This increase also could be referred to as compactness created by increasing the percentage of the dopant sodium iodide, which increases the heat transfer among phonons diffusion.

b) Thermal conductivity of the PEO composites increases with increasing temperature. As the temperature increases, the lattice phonons of PEO films become more active.

c) Electronic conductivity of PEO thin films increases with the concentration of the dopant sodium iodide. The increase caused by doped sodium iodide is referred to as a concentration of sodium iodide effect. Electrons and charges move in a liquid-like manner, whereas electron movement through the polymer matrix is aided by the large amplitude of PEO segmental motion.

d) Fitting the obtained results to proposed empirical physical laws seems to be reasonable.

ACKNOWLEDGEMENT

The authors acknowledge Applied Science Private University, Amman, Jordan, for the full support granted to this research article.

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