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Enhancing the Electrical and Thermal Conductivities of Polystyrene

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Abstract: Polystyrene is a poor conductor of both heat and, electricity. In this study, effort was made to enhance the conductivities of this polymer by incorporating metal salts viz: Pb $(NO_3)_2$, $CoCl_2.6H_2O$ and $ZnSO_4.7H_2O$ at different concentrations (0.2M, 0.4M, 0.6M. 0.8M and 1.0M). It was observed from the results that the electrical and thermal conductivities of PS were indeed enhanced. The conductivity increased with increase in the concentration of each metal. The trend is $ZnSO_4.7H_2O > CoCl_2.6H_2O > Pb(NO_3)_2$ for both electrical and thermal conductivities.

Key words: Electrical conductivity · Enhancement · Metal salts · Polystyrene and thermal conductivities

INTRODUCTION

The idea that plastic should be made to conduct electrically, would have been considered absurd since all carbon based polymers have always been regarded as insulators and most of their applications are based on these intrinsic properties [1, 2]. Polyethylene and poly tetra fluoro ethylene are among the best insulating materials in electrical industries [3]. This idea is fast changing with the development of new polymers that have high degree of electrical and thermal conductivities [1, 4]. This prospect of materials combining the properties of plastics and metals has led to a search for applications made attractive because improved polymers no longer suffer from such draw backs as low stability, processing difficulties and brittleness [5].

Technically almost all known conductive polymers are semi-conductors due to their band structures and electronic mobility [6]. However, zero band gap conductive polymers may behave like metal. The movement of electrons in conductive polymers is lower than in organic semi-conductor. This discovery is interesting as it opens the way in understanding the fundamental chemistry and physics of ð band macromolecules. It also offers the promise of achieving a new generation of polymers which exhibit the electrical and optical properties of metals or semiconductors as well as retain the attractive mechanical properties and processing advantages of polymers [6].

Electrically conducting polymers are new class of materials which have the properties of semiconductors or metals when suitably doped with donor or acceptor species. Charge transfer agents effect this oxidation or reduction and by so doing convert insulating polymers to a conducting materials [7]. In solids, thermal conductivity results from lattice vibrations and conduction by electrons [8].

Experimental

Preparation of the Reagents: Concentrated molar standard solutions of Pb (NO_3), $CoCl_2.6H_2O$ and $ZnSO_4.7H_2O$ were prepared in deionized water as stock. Serial dilution method was used to prepare different concentrations (0.2M, 0.4M, 0.6M, 0.8M and 1.0M) of the salt solution.

Sample Preparation: The polystyrene sample was crushed and each 12.0g was weighed and transferred into each of the sixteen beakers. 50.0cm^3 each of the toluene solvent was also added to each beaker with continuous stirring until there was complete dissolution.

Preparation of Conducting Polymer: 20.0cm^3 of the prepared metal salt solution Pb $(NO_3)_2$ was added to each of the 5 beakers containing dissolved sample of PS. The 6th beaker contained only the sample solution. The different concentrations used were 0.2M, 0.4M, 0.6M, 0.8M and 1.0M. Each mixture was stirred thoroughly.

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The precipitate of PS formed was allowed to stand for 2 days for the total evaporation of the solvent. The solution was filtered off and PS formed was moulded into circular tablets. The same method was adopted for $CoCl_2.6H_2O$ and $ZnSO_4.7H_2O$

Determination of Electrical Conductivity: The method employed was as in ref. [9]. The voltage and resistance were measured using a Digital Mastech Multimeter. This was performed by connecting one end of the wire to a source of power supply of 3 volts and the other end was placed on the polymer tablet. The resistance readings were taking at constant voltage and the current was calculated using the equation:

$$V = IR \quad (1)$$

where V = voltage, I = current, R = resistance

The resistivity was obtained from the eqn:

$$R = lL/A \quad (2)$$

R = resistance, l = resistivity, L = length, A = cross sectional area of the sample.

$$K = 1/ l \quad (3)$$

K = conductivity of the sample.

Determination of Thermal Conductivity: The thermal conductivity of the circular PS tablet was determined by applying the Lee's Disc method [7]. The thermal conductivity was calculated using the formula:

$$K = MCd\theta/dt \times 1/A \times d/dT \quad (4)$$

where,

M = Mass of the metal slab,
C = Specific heat of the metal slab,
$d\theta/dt$ = Rate of cooling metal at 0°C,
dT = Difference in temperature
A = Area and d = thickness of the sample

RESULTS AND DISCUSSION

On addition of $20.0cm^3$ of the salt solution of a particular concentration, the mixture formed two layers, the inorganic layer being the salt solution and the solvent organic layer being the polystyrene solution. The resistance value of the control i. e. pure PS was not detected by the Digital Multimeter. This is not surprising as PS is known to be an insulator.

Figure 1 depicts the enhanced electrical conductivities of PS doped with varying concentrations of the metal salts. The salts $Pb(NO_3)_2$, $CoCl_2.6H_2O$ and $ZnSO_4.7H_2O$ all enhanced in electrical conductivities of PS as the metal concentration increases. This is in agreement with Ref. [10] that electrical conductivity of a solution depends mainly on its concentration and charges formed. On comparison of the three salts, it was observed that $Pb(NO_3)_2$ has the highest resistivity (lowest conductivity) for each concentration followed by $CoCl_2.6H_2O$ and $ZnSO_4.7H_2O$ [10]. Zinic and cobalt are in period four while lead is in period six. In the case of ionic radius, it decreases across the period and increase down the group. Lead has the highest ionic radius followed by cobalt and zinic. So, Zn^{2+} will interact more intimately with polystyrene molecules than Co^{2+} and Pb^{2+} because the migration of electrons will be faster and this will result in higher conductivity than Co^{2+} and Pb^{2+}. Also, zinic has the least electronegativity value. The order is Zn < Co < Pb. Based on these observations it is not suprising that zinc enhanced electrical conductivity more than cobalt and lead.

The effect of incorporating metal salts $Pb(NO_3)_2$, $CoCl_2.6H_2O$ and $ZnSO_4.7H_2O$ on thermal conductivity of PS as shown above indicates that undoped PS conducts some heat. The conduction of heat by the control may be due to the presence of adventitious materials such as intiator fragments, polymerization inhibitors and other impurities. The conductivity increases with increase in concentration. PS conducst heat mostly by the vibration of atoms about their equilibrium position in the crystal. In addition to the vibrating atoms, the doped PS has free ions or charges. These free ions contribute to the thermal conduction. The stronger the ionic charge the more its effect on the thermal conduvtivity. Zn^{2+} with smaller ionic size, has higher mobility and therefore will conduct heat faster and more efficiently. Co^{2+} in the same period as Zn^{2+} will also contribute to the thermal conductivity of PS but not as efficiently as Zn^{2+} due to its larger ionic size. Pb^{2+} has the least thermal conductivity among the three ions. This is due to its additional shells leading to increased ionic size and slower ionic mobility; hence lowerest thermal conductivity.

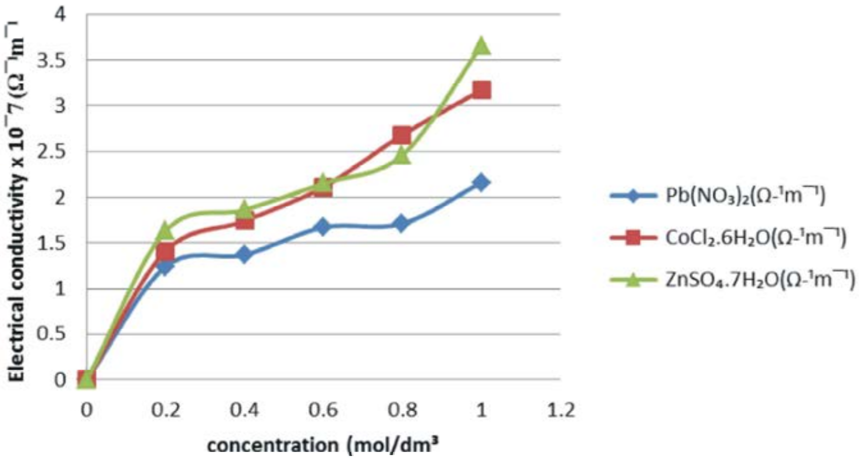

Fig. 1: Effect of incorporating metal salts on electrical conductivity of PS

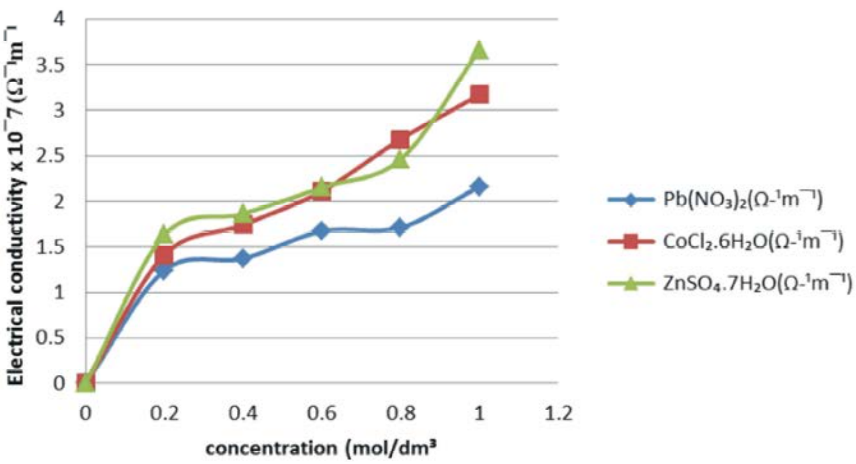

Fig. 2: Effect of incorporating metal salt on the thermal conductivity of PS

CONCLUSION

There was enhancement on the electrical and thermal conductivities of PS when doped with metal salt solution.

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