

Full Length Research Paper

Electrical characterization of conducting poly(2-ethanolaniline) under electric field

Seyed Hossein Hosseini^{1*}, Ghasem Asadi² and S. Jamal Gohari³

¹Department of Chemistry, Faculty of Science, IslamShahr Branch Islamic Azad University, Tehran-Iran.

²Department of Chemistry, Faculty of Science and Engineering, Shar-e-Rey Branch, Islamic Azad University, Tehran-Ghom Express Way, Tehran-Iran.

³Department of Chemistry, Faculty of Science, Imam Hossein University, Babae Express Way, Tehran – Iran.

Accepted 23 May, 2013

We have studied conductivity and molecular weight obtained poly(2-ethanolaniline), P2EANI. P2EANI synthesized according to the best ratio of obtained molar of initiator to monomer at different reaction times. Then we measured the mass and conductivity of the obtained polymers in the best time of polymerization. Next, we repeated these reactions under different electric fields in the most appropriate time and measured the mass and conductivity of obtained polymers. As a result, intensity of the required electric field for polymerization was determined. After which the polymerization was carried out at the best electric field at different times. Finally, the best time and amount of the electric field for polymerization were determined. Moreover, we studied the doping of polymerization in the presence of an electric field by applying different dopants and other initiators. Then compared the obtained results to the results of a similar condition; but without the electric field. As a result we found the best condition for the reaction was determined as follows; the P2EANI with a high molecular weight was synthesized under the electric field, Mw=193749 g/mol, with Mw/Mn=2.3. The conductivity of the black films oxidized by ammonium peroxydisulfate and doped with dodecylbenzene sulfonic acid cast from NMP was higher than 0.118 S/cm under 10 KV/Cm² electric field and showed an enhanced resistance to aging. It can be concluded that polymers synthesized under electric field probably have better physical properties as a result of less branching and high electrical conductivity.

Key words: Polymers, chemical synthesis, electrical conductivities, electric field.

INTRODUCTION

Conducting polymers constitute an emerging class of materials. Among the organic conducting polymers, polyaniline is the only conducting polymer whose properties depend on the oxidation state, its protonation state/doping level as well as the nature of dopants. Among conducting polymers, polyaniline has received greater attention due to its advantages over other conducting polymers. Simplicity of its preparation from cheap materials, superior resistance to air oxidation, and controllable electrical conductivity by doping and

de-doping (Pron and Ranou, 2002), makes it very useful in preparing light-weight batteries (Senadeera and Pathirathne, 2004), liquid crystalline polymers (Gato et al., 2001; Hosseini and Mohammadi, 2009), optical activities (Li et al., 2004), ion exchange materials (Hosseini and Noor, 2005) and sensors (Hosseini et al., 2005, 2006; Hosseini, 2006).

A number of mechanisms for the electric field effects in the chemical reactions have been suggested, well documented, and undergone a proper theoretical

*Corresponding author. E-mail: shhosseini@iaau.ac.ir

analysis (Buchachenko, 2000). Any polar molecule is composed of at least two atoms. Furthermore, a molecule, has an inherent dipole moment with random direction, at room temperature, dipoles and hence the bulk materials are not polarized. An external electric field, applies two equal and opposite forces of any dipole and tries to adjust them with itself. If the field is sufficiently intense and there is no other effective factor, like thermal energy, polarization reaches its saturation value, $P_s = NP_m$. In which P_m is the molecular dipole moment and N is the number of molecules per unit volume. Polarization is between zero and saturation value that can be calculated using a statistical mechanism. From this point of view, the polarizability is (Reits et al., 1979): $\alpha = P_0^2/3kT$ and we have: $P = \alpha E_m$. If we show a monomer molecular dipole moment, by P_0 , for a dimer $P_m = 2P_0$, and for a polymer string that is composed of n monomers, $P_m = nP_0$. So as the polymer grows, its polarizability increases as the following: $\alpha = n^2 P_0^2/3kT$. This order will increase the electrical conductivity of conductive polymers. Therefore, effects of electric field on doping of conductive polymers can be investigated (MacDiarmid, 2001; Manoha et al., 2002).

Polyaniline and poly(2-ethanol aniline) are the most of the promising conducting polymers because of its chemical stability and high conductivity. The addition of substituent into the side chain of polyaniline enhances its solubility and processability. On the other hand, there has been no report on polymerization of poly(2-ethanol aniline) under electric or magnetic fields. Therefore, we think polymerization of poly(2-ethanol aniline) under electric field can be modified in terms of all its properties. Considering molecular weight, orientation and future applications such as liquid crystalline and optical activities, modified poly(2-ethanol aniline) can be used. Here, we present the syntheses and properties of poly(2-ethanol aniline) with a side chain group under an electric field. Therefore, the effect of applying the electric field on polymerization with specific amount of electrical conductivity and molecular weight is rather limited.

EXPERIMENTAL

Chemicals used in this study were American Chemical Society (ACS) grade. 2-Ethanol aniline (Merck) was dried with NaOH, fractionally distilled under reduced pressure from CaH_2 . Other chemicals such as, ammonium peroxydisulfate (APS), dodecylbenzene sulfonic acid (DBSA), champhor sulfonic acid (CSA), methane sulfonic acid (MSA), p-toluene sulfonic acid (PTSA), acetic acid (AA), $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$, KI and other reagents were purified as per standard procedure before use.

Instrumentals

Conductivity changes were measured with a four probe device (made to the, ASTM Standards, F 43-93). An Electric field device was applied by Hipotronics S.O. No. 004390-00, HV power supply, model 830.50 made in USA. A fourier-transform infrared spectrometer, FT-IR, (Bruker) was used in the spectral

measurements of the polymer and graft copolymer and reported (sh=sharp, w=weak, m=medium, b=broad). Proton and carbon nuclear magnetic resonance (FT- ^1H and ^{13}C NMR) spectra were recorded at 250 MHz on a Bruker WP 200 SY spectrometer. NMR data are reported in the following order: chemical shift (ppm), spin multiplicity (as singlet, doublet, triplet, quartet, multiplet, and broad peak), integration UV-Visible spectra were obtained by Perkin Elmer Lambda 15 spectrophotometer. Molecular weight was measured at 30°C with a gel permeation chromatography (GPC), (Waters Associates, model 150-C). Three styragel packed columns with different pore sizes ($10^4 - 10^6 \text{ \AA}$) were used. The mobile phase was m-cresol with flow rate of 1.5 ml/min. The thermal properties (thermo gravimetric analysis (TGA)) and differential scanning calorimetry (DSC)) of polymer were performed by STA 625-PL Thermal Science and heating rate of $10^\circ\text{C min}^{-1}$. Scanning electron microscopy (SEM) was used to study the type of surface morphology of polymer. A Cambridge S-360 SEM was used for this purpose.

Preparation of P2EANI in the absence of electric field

Project participants followed the same instructions to oxidize 0.001 mol 2-ethanol aniline hydrochloride with 0.001 mol ammonium peroxydisulfate, $(\text{NH}_4)_2\text{S}_2\text{O}_8$, in aqueous medium. 2-Ethanol aniline hydrochloride (purum; 0.1 g) was dissolved in 10 ml HCl 1 M in a 50 ml volumetric flask. Ammonium peroxydisulfate (purum; 0.228 g) was dissolved in 10 ml HCl 1 M, and then added. Both solutions were kept for different times (5, 10, 15, 20, 30, 40, 50, 60 and 120 min) at room temperature (~ 18 to 24°C). The P2EANI precipitate was collected on a filter, and washed with three 10 ml portions of 0.1 M HCl, and acetone. P2EANI hydrochloride powders were dried air and then in a vacuum at 60°C . Weighed and also their electrical conductivities were measured by four probe method (Hosseini et al., 2005, 2006).

The P2EANI powders with FeSO_4 , KI, $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$ as initiators and HClO_4 , H_2SO_4 , AA, PTSA, MSA, DBSA and CSA as dopants were synthesized in similar manner. UV (DMSO); $\lambda_{\text{max}} = 320 \text{ nm}$ (2.45 intensity). FT-IR (KBr): 3550-3100(b), 3015(w), 2930(w), 1615(m), 1450(w), 1515(sh), 1349(m), 1250(m), 1130(sh), 830(m) cm^{-1} . $^1\text{H-NMR}$ (DMSO); δ 2.45 (2H, s), 3.50 (2H, t), 3.70 (2H, t), 4.50 (broad), 7.20 (1H, s), 7.35 (1H, s), 7.55 (1H, d), 7.70 (2H, s) ppm. $^{13}\text{CNMR}$ (DMSO); δ 51.5, 54.5, 119.8, 126.5, 127.7, 128.7, 135.1 ppm.

Preparation of P2EANI under electric field

P2EANI was prepared under the same chemical circumstances but with different electric fields (5, 10, 15 and 20 KV/Cm^2), in 60 min, at room temperature. Then, P2EANI was prepared by the same reaction but, in various times (30, 45, 60, 90 and 120 min) intervals at the best amount of electric field. UV (DMSO); $\lambda_{\text{max}} = 340 \text{ nm}$ (2.80 intensity), 450 nm (0.5 intensity), 590 nm (0.3 intensity). FT-IR (KBr): 3550-3100(b), 3010(w), 2923(w), 1604(m), 1503(sh), 1341(m), 1247(m), 1156(sh), 822(m) cm^{-1} . $^1\text{H-NMR}$ (DMSO); δ 2.51 (2H, s), 3.34 (2H, t), 3.67 (2H, t), 4.61 (broad), 7.10 (1H, s), 7.30 (1H, s), 7.34 (1H, d), 7.51 (2H, s) ppm. $^{13}\text{CNMR}$ (DMSO); δ 52.0, 55.4, 121.9, 127.4, 128.9, 129.1, 136.2 ppm.

RESULTS AND DISCUSSION

Spectrometric studies

Figure 1 shows the FT-IR spectrum of P2EANI under the

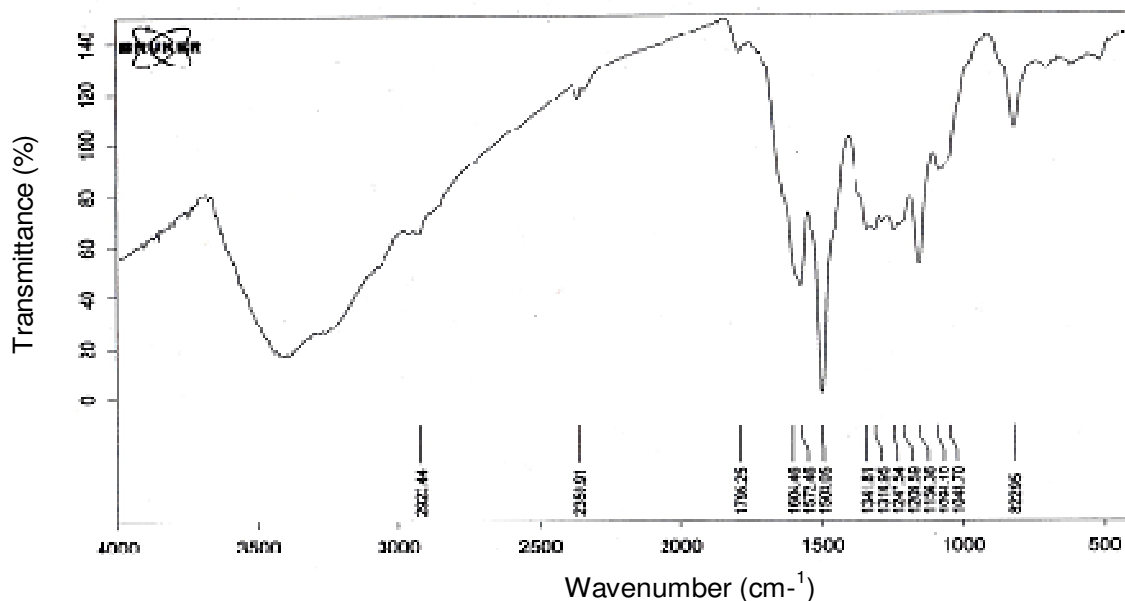


Figure 1. FT-IR spectrum of P2EANI after electric field.

electric field. The special peaks of this spectrum are 3330 cm^{-1} (O-H Stretching H-bonding), 2923 cm^{-1} (C-H stretching aliphatic), 1604 and 1503 cm^{-1} (C=C stretching aromatic) and 1156 cm^{-1} (C-O stretching) and you can see C-H stretching aromatic overlapped with OH stretching.

Figure 2a shows the UV-Vis spectrum of P2EANI prepared without an electric field at the DMSO solvent. In this spectrum the 298 nm peak relates to benzenoid diamine forms. At this spectrum the quinoid diamine from the peak cannot be seen because the polymer is lattice matrix. The UV-visible spectrum of P2EANI under electric field is shown in Figure 2b. This figure shows three peaks, 340 , 450 and 590 nm , of which two last ones are related to quinoic form of P2EANI. The two last peaks are not in Figure 2a which relates to P2EANI prepared without an electric field. As we know, by increasing the length of chain and subsequently rising the number of conjugated double bonds, a decrease in energy difference $\pi \rightarrow \pi^*$ occurs, so that it causes an increase in the wavelength. The spectrum of 340 nm region is for the second peak of aniline groups and the $\pi \rightarrow \pi^*$ is a conjugated couple system for the benzoic states and wide peak in 590 nm comes from the transfer of $\pi \rightarrow \pi^*$ quinion of aniline groups (for the polaron and bipolaron transfers).

The ^1H NMR spectrum of P2EANI under an electric field in $\text{d}^6\text{-DMSO}$ as solvent is shown in Figure 3. The peaks observed in 7.1 to 7.5 ppm related to different aromatic protons in polymer. The peak of 4.5 ppm is related to OH group of ethanol on the polymeric string. The 3.3 and 3.6 ppm regions are related to ethylenic protons and 2.5 ppm signal as well as protons of DMSO impurity.

Figure 4 shows the ^{13}C NMR spectrum of P2EANI. At this spectrum, peaks of 52.3 and 55.4 regions are related to aliphatic carbons of the ethanol group. The signals of 121.9 , 127.4 , 128.9 , 129.1 and 136.2 ppm regions are related to aromatic carbons of ring.

Thermal properties studies

Figure 5a and b shows the TGA thermograms of P2EANI before and after electric field, respectively. In comparison of figures shows that P2EANI produced under electric field is more stable than P2EANI produced in the absence of an electric field. In Figure 5b, we see that the polymer is stable up to 170°C , and loses its weight at region 170 to 280°C slightly which relates to evaporation of solvent and probable water, and ethanol groups of P2EANI begins to be destroyed and reaches its maximum value at 280°C . The 33.8% loss of molecular weight is the special characteristic of this temperature. At 390°C the lost weight is 59.5% and the polymer will be destroyed completely at 700°C , and 27.7% of initial weight remains to form the ash. Also, the peaks at 250 and 350°C , are related to exothermic states and the peaks at 280 and 390°C , are related to endothermic states of thermal treatment of the polymer that is due to weight loss of the polymer.

Scanning electron microscopic studies

Figure 6a and b shows SEM images of P2EANI synthesized in absence and presence of an electric field,

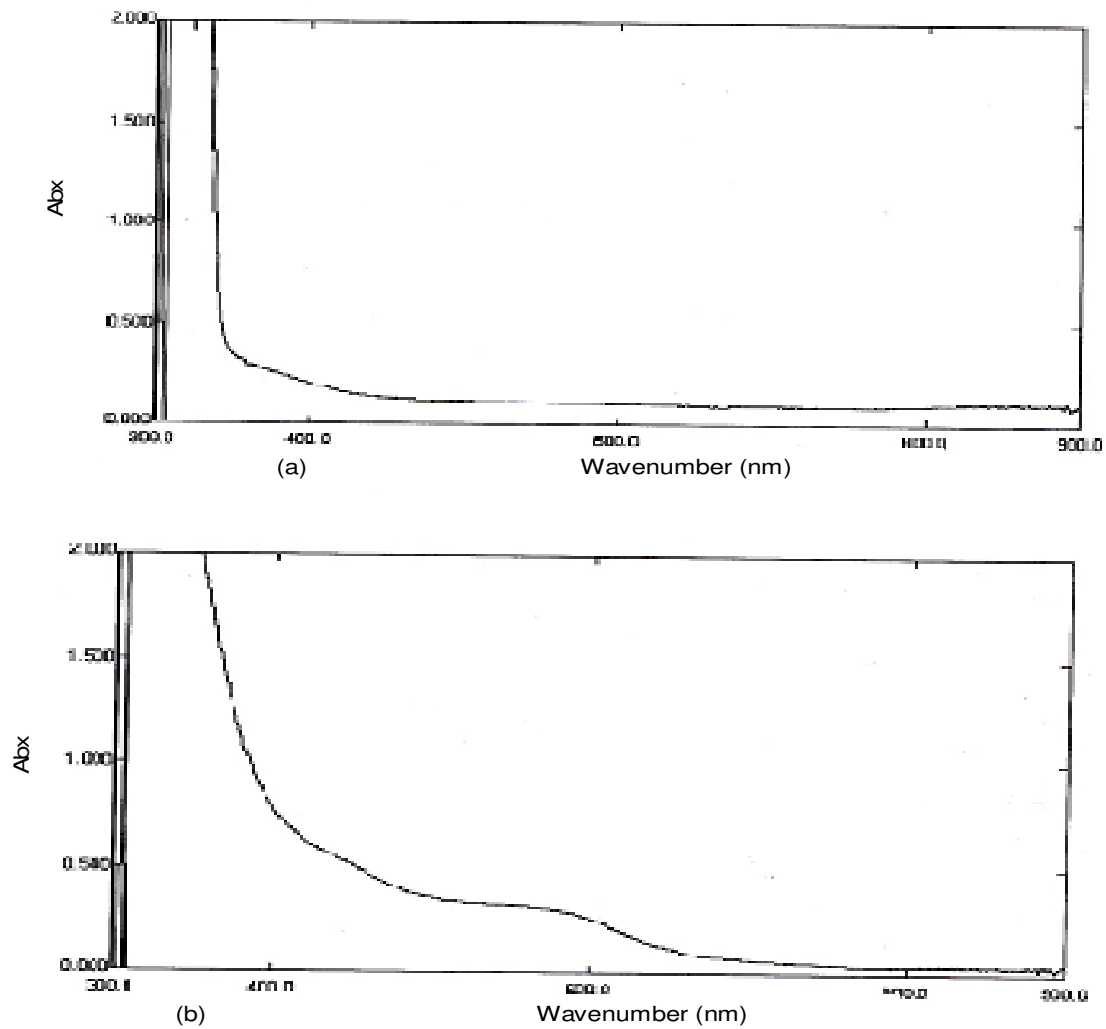


Figure 2. UV-visible of P2EANI prepared in a) absence and b) presence of electrical field in DMSO.

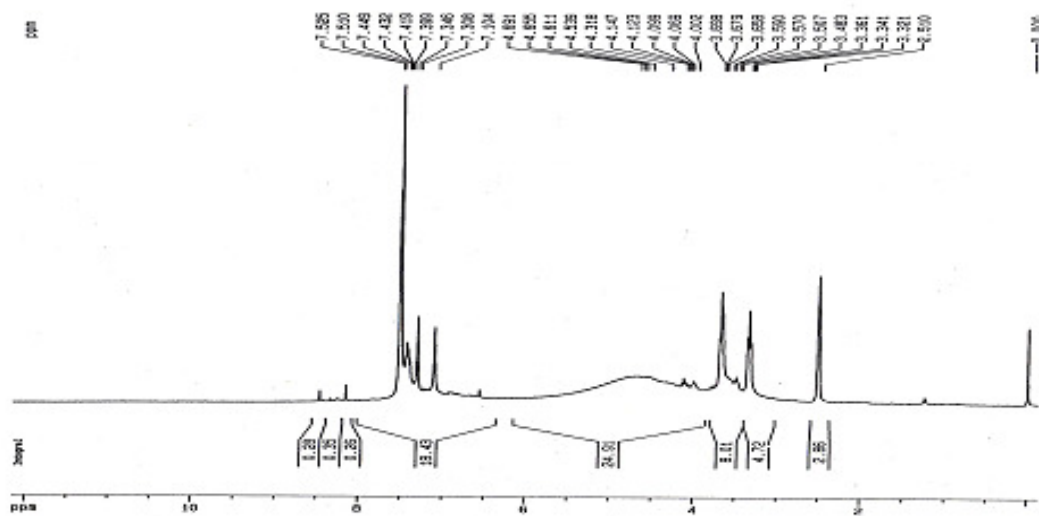


Figure 3. ¹H NMR spectrum of P2EANI after electric field.

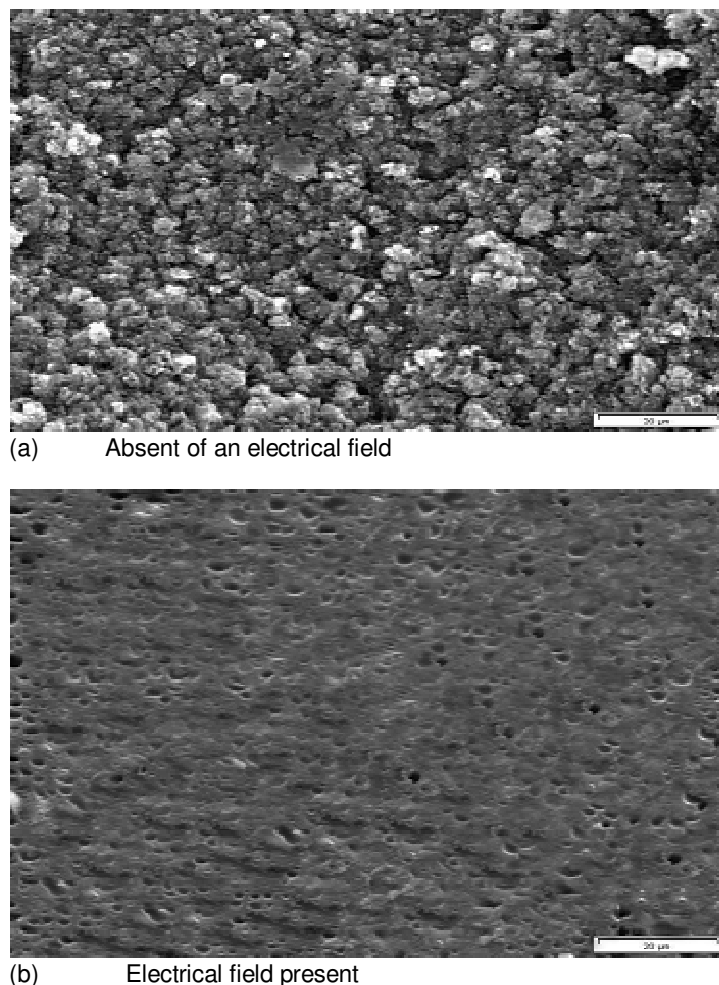


Figure 6. SEM images of P2EANI prepared in (a) absence and (b) presence electrical field.

is 2.3 and the mean weight of molecular mass is 193749 g/mol. This shows that the electric field has increased the molecular mass by a factor 2.3.

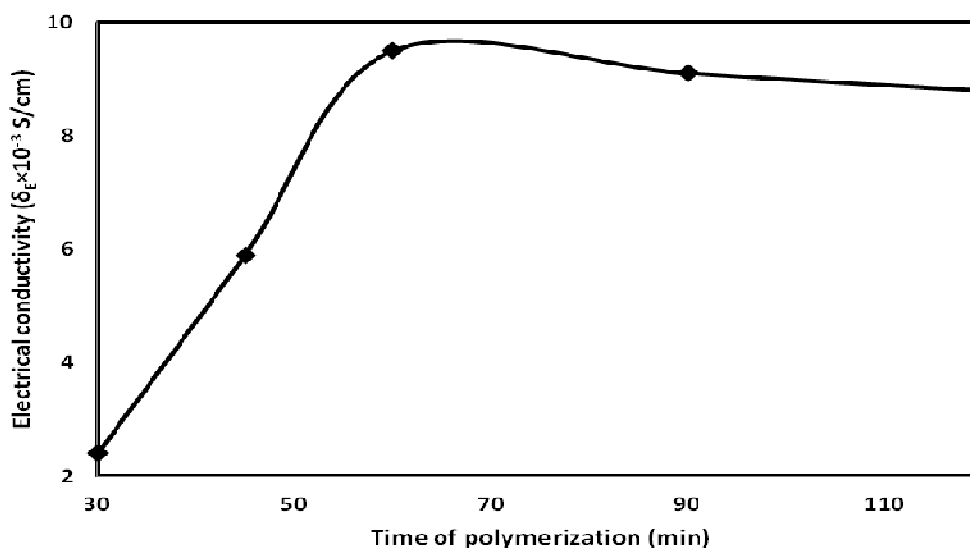
Electrical conductivity studies

The obtained polymer has a high purity because the excess initiator was readily washed with acetone. The purity was confirmed by elemental analysis. Conductivity of all samples were measured at room temperature by a four-probe method on pellets compressed at 700 MPa, 13 mm in diameter and 1 to 1.5 mm thick (Hosseini and Entezami, 2003; Hosseini et al., 2005, 2006). The 2-ethanol aniline was polymerized by using the four different initiators, such as APS, $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$, KI and FeSO_4 . For each initiator, the different dopants like HCl, HClO_4 , H_2SO_4 , AA, PTSA, MSA, DBSA and CSA were studied. Then the polymerization time for any initiator-dopant combination was changed from 30 to 120 min.

In the next step, all experiments were repeated at different electric fields. The best molar ratio (monomer/initiator) experimentally was defined as 1/1. We used this ratio in all experiments. In all experiments, we focused on the obtained mass of polymer, m , electrical conduction of the obtained polymer in the absence of an electric field, σ , electrical conduction of the obtained polymer in the presence of an electric field, σ_E , and their ratio $r = \sigma_E / \sigma$. To identify the best molar ratio of APS initiator to monomer, values 1/0.5, 1/1 and 1/2 were examined by using HCl solution as dopant. The best electrical conduction was $\sigma = 6 \times 10^{-3}$ S/cm for 1/1 ratio. Then to identify the best time of experiment, the polymerization was done for 1/1 molar ratio at different times such as 30, 45, 60, 90 and 120 min, and the best electrical conduction was $\sigma = 9.5 \times 10^{-3}$ S/cm in 60 min. In this condition, the most obtained product mass was $m = 0.24$ g too. Increasing the time does not affect the product mass, but it decreases the electrical conduction (Table 1 and Figure 7).

Table 1. Electrical conductivity of P2EANI produced by APS (HCl 1M) as initiator (1/1 mol ratio) in different times and absence of electric field.

Sample	Time of polymerization (min)	Color change time (min)	Weight of produced polymer (g)	Electrical conductivity ($\delta \times 10^{-3}$ S/cm)
1	30	5	0.21	2.4
2	45	5	0.23	5.9
3	60	5	0.24	9.5
4	90	5	0.24	9.1
5	120	5	0.25	8.8

**Figure 7.** Electrical conductivity of P2EANI in different times and absence of electric field.**Table 2.** Electrical conductivity of P2EANI produced by APS (HCl 1M) as initiator (1/1 mol ratio) in different electric field after 60 min.

Sample	Electric field (KN/C)	Color change time (min)	Weight of produced polymer (g)	Electrical conductivity ($\delta_E \times 10^{-3}$ S/cm)
1	35	6	0.21	22
2	69	7	0.28	87
3	104	7	0.29	85
4	138	8	0.28	74

In other experiments APS initiator and different dopants were used done with molar ratio of initiator to monomer, 1/1, in the 60 min, and the optimized condition under a uniform electric field with different intensities such as 5, 10, 15 and 20 KV/Cm². The most effective electric field intensity was 10 KV/Cm² in which we gained 0.28 g of product with $\sigma_E = 87 \times 10^{-3}$ S/cm at Table 2 and Figure 8. On the other hand, we repeated the electrical conductivity of P2EANI produced by APS as an initiator and different dopants in the absence of the electric field and under 10 KV/Cm² one after 60 min. These results were summarized in Table 3.

In Table 3, we see that for all dopants without an

electric field, the electrical conductivities are low while they are increased under electric field conductivities. Therefore, we also see that for APS initiator, the most effective dopants is DBSA with $m=0.35$ g, $\sigma_E=0.118$ S/cm and $r=7.87$. So imposing the polymerization by a uniform electric field causes the electrical conduction improve by a factor 7.87. Then polymerization of 2-ethanol aniline at the optimized time (60 min) and with the best molar ratio initiator to monomer, (1/1), by using FeCl₃.6H₂O as initiator, was done with different dopants in different electric field intensities. These results were compared with the ones obtained from incorporating polymer without applying electric field conditions. The results are

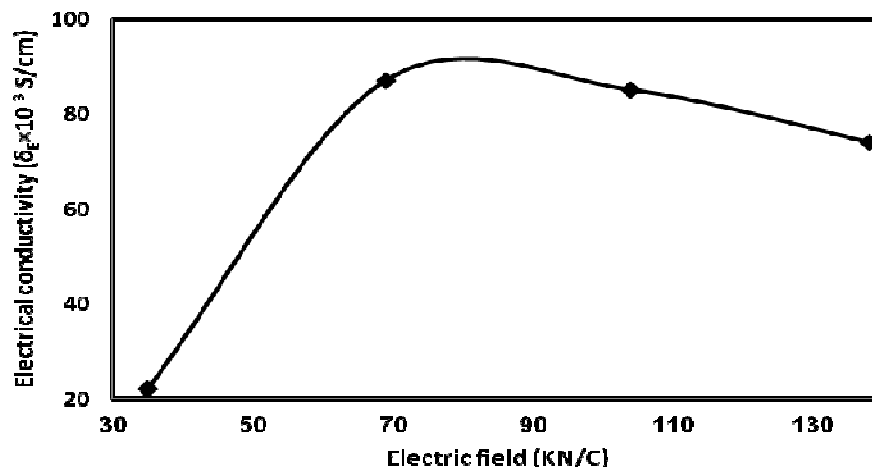


Figure 8. Electrical conductivity of P2EANI in different electric field after 60 min.

Table 3. Electrical conductivity of P2EANI produced by APS (HCl 1M) as initiator (1/1 mol ratio) with different dopants in absence and under 69 kN/C electric field after 60 min.

Dopant (1M)	Absence electric field		Under E=69 N/C		
	Weight of produced polymer (g)	Electrical conductivity ($\delta \times 10^{-3}$ S/cm)	Weight of produced polymer (g)	Electrical conductivity ($\delta_E \times 10^{-3}$ S/cm)	$r = \delta_E / \delta$
HCl	0.24	9.5	0.28	87	9.16
HClO ₄	0.24	11	0.26	89	8.09
H ₂ SO ₄	0.20	8.5	0.22	85	10.0
AA	0.18	2.1	0.21	15	7.14
MSA	0.24	4.5	0.24	42	9.33
PTSA	0.26	5.5	0.31	53	9.64
DBSA	0.29	15	0.35	118	7.87
CSA	0.27	11	0.31	105	9.54

Table 4. Electrical conductivity of P2EANI produced by FeCl₃.6H₂O as initiator (1/1 mol ratio) different dopants in absence and under 69 kN/C electric field after 60 min.

Dopant (1M)	Absence electric field		Under E=69 N/C		
	Weight of produced polymer (g)	Electrical conductivity ($\delta \times 10^{-3}$ S/cm)	Weight of produced polymer (g)	Electrical conductivity ($\delta_E \times 10^{-3}$ S/cm)	$r = \delta_E / \delta$
HCl	0.22	4.5	0.23	22	4.88
HClO ₄	0.22	5.5	0.24	25	4.54
H ₂ SO ₄	0.21	3.0	0.23	22	7.33
AA	0.17	0.3	0.19	1.5	5.0
MSA	0.22	0.9	0.22	12	13.3
PTSA	0.23	6.0	0.23	21	3.50
DBSA	0.26	7.5	0.28	35	4.67
CSA	0.24	6.5	0.26	30	4.62

summarized in Table 4. Here we see that for FeCl₃.6H₂O initiator, the best dopant is DBSA of which the best results are $m=0.28$ g, $\sigma_E = 30 \times 10^{-3}$ S/cm and $r=4.62$. In

addition, all described polymerizations were repeated by using KI as an initiator. The findings can be seen at Table 5. This table shows that for KI initiator, the best

Table 5. Electrical conductivity of P2EANI produced by KI as initiator (1/1 mol ratio) different dopants in absence and under 69 KN/C electric field after 60 min.

Dopant (1M)	Absence electric field		Under E=69 N/C		r= δ_E/δ
	Weight of produced polymer (g)	Electrical conductivity ($\delta \times 10^{-3}$ S/cm)	Weight of produced polymer (g)	Electrical conductivity ($\delta_E \times 10^{-3}$ S/cm)	
HCl	0.23	6.5	0.24	34	5.23
HClO ₄	0.24	12	0.24	38	3.17
H ₂ SO ₄	0.22	9.0	0.24	55	6.11
AA	0.19	2.5	0.21	3.0	1.20
MSA	0.23	6.5	0.24	18	2.77
PTSA	0.23	8.8	0.25	27	3.07
DBSA	0.27	19	0.30	55	2.89
CSA	0.27	25	0.31	60	2.4

Table 6. Electrical conductivity of P2EANI produced by FeSO₄ as initiator (1/1 mol ratio) different dopants in absence and under 69 KN/C electric field after 60 min.

Dopant (1M)	Absence electric field		Under E=69 N/C		r= δ_E/δ
	Weight of produced polymer (g)	Electrical conductivity ($\delta \times 10^{-3}$ S/cm)	Weight of produced polymer (g)	Electrical conductivity ($\delta_E \times 10^{-3}$ S/cm)	
HCl	0.21	2.5	0.22	15	6.0
HClO ₄	0.22	5.5	0.24	25	4.54
H ₂ SO ₄	0.23	5.5	0.24	25	4.54
AA	0.17	0.3	0.18	1.5	5.0
MSA	0.21	0.8	0.22	10	12.5
PTSA	0.22	5.5	0.23	13	2.36
DBSA	0.23	6.5	0.24	23	3.54
CSA	0.22	6.5	0.24	23	3.54

dopants are HClO₄, DBSA and CSA. The results of CSA are m=0.31 g, $\sigma_E=60 \times 10^{-3}$ S/cm and r=2.4. Finally, all above-described experiments were repeated by using FeSO₄ as an initiator. The results can be seen in Table 6. Table 6 shows FeSO₄ as initiator, and the best dopants are H₂SO₄, HClO₄ and DBSA. The results of DBSA are m=0.24g, $\sigma_E=23 \times 10^{-3}$ S/cm and r=3.54. In the experiments, we had 24 initiator–dopant combinations with widely different results. To compare the results, we collected all the best results (for initiator and dopant combination) in Table 7. This table shows all combinations in which conduction occurs, imposing electric field causes the electrical conduction to be improved. This also, shows that the best combination is APS-DBSA in which $\sigma_E=0.118$ S/cm.

Conclusion

A molecule of 2-ethanol aniline is an electroactive monomer. It can be well polymerized through connecting the head to tail, and formed conductive polymer. They

are head to head, tail to tail, or secondary connections. In this work, the electroactive monomers are arranged by using the electric field, and the head to tail connections are increased. Therefore, obtained polymer have a larger length chain, higher electrical conductivity, better space order and more appropriate physical resistance in comparison with the obtained one in the absence of electric field. The results of the experiments show that the electrical conductivity of produced P2EANI in different electric fields and the most constant time (60 min), increased with increasing intensity of electric field. But after 10 KV/Cm², the electrical conductivity has been decreased steadily.

Furthermore, the findings shows that the electrical conductivity of produced P2EANI in constant intensity of electric field – bout 10 KV/Cm²– increases with increasing the amount of time. But after about 60 min, the electrical conductivity has been decreased steadily too.

On the other hand, considering the results of applying the various types of dopants and different initiators, the best initiator was APS, and the best dopant was dodecylbenzene sulfonic acid. It seems that by increasing

Table 7. Final results for any initiator–dopant combination.

Initiator Dopant	APS		FeCl ₃ .6H ₂ O		KI		FeSO ₄	
	$\delta \times 10^{-3}$	$\delta_E \times 10^{-3}$	$\delta \times 10^{-3}$	$\delta_E \times 10^{-3}$	$\delta \times 10^{-3}$	$\delta_E \times 10^{-3}$	$\delta \times 10^{-3}$	$\delta_E \times 10^{-3}$
HCl	9.5	87	4.5	22	6.5	34	2.5	15
HClO ₄	11	89	5.5	25	12	38	5.5	25
H ₂ SO ₄	8.5	85	3.0	22	9.0	55	5.5	25
AA	2.1	15	0.3	1.5	2.5	3.0	0.3	1.5
MSA	4.5	42	0.9	12	6.5	18	0.8	10
PTSA	5.5	53	6.0	21	8.8	27	5.5	13
DBSA	15	118	7.5	35	19	55	6.5	23
CSA	11	105	6.5	30	25	60	6.5	23

the amount of time and intensity of the electric field after passing a special amount, the destructive processes in the polymer chain began as a result of increasing the length of polymer chain and dipolar moment forces. And also, due to polymeric confusion in the reaction solution, polymers involve defect reactions such as producing secondary branches on the polymer chain. Finally, mass and conductivity measurements of polymers showed that molecular weight and electric conductivity of the polymers were increased under electric field about 2 and 100 times, respectively.

REFERENCES

- Buchachenko AL (2000). Mechanism of Fe(OH)₂ (aq) photolysis in aqueous solution, *Pure Appl. Chem.*, 72:2243-2248.
- Gato H, Akagi K, Itoh K (2001). Synthesis of liquid crystalline polyaniline derivatives and their orientational behaviors under magnetic field, *Synth. Met.*, 117:91-93.
- Hosseini SH (2006). Investigation of sensing effects of polystyrene-graft-polyaniline for cyanide compounds, *J. Appl. Polym. Sci.* 101(6):3920-3926.
- Hosseini SH, Abdi Oskooe SH, Entezami AA (2005). Toxic Gas and Vapour Detection with Polyaniline Gas Sensors. *Iranian Polym. J.* 14(4):333-344.
- Hosseini SH, Dabiri M, Ashrafi M (2006). Chemical and electrochemical synthesis of conducting graft copolymer of acrylonitrile with aniline, *Polym. Int.* 55(9):1081-1089.
- Hosseini SH, Entezami AA (2003). Chemical and electrochemical synthesis of conducting poly di-heteroaromatics from pyrrole, indole, carbazole and their mixed containing hydroxamic acid groups and studies of its metal complexes, *J. Appl. Polym. Sci.*, 90:63-71.
- Hosseini SH, Mohammadi M (2009). Preparation and characterization of new poly-pyrrole having side chain liquid crystalline moieties, *Mater. Sci. Eng. C*, 29:1503-1509.
- Hosseini SH, Noor P (2005). Ion exchange properties and kinetic behaviour of polyaniline-coated silica gel for p-toluenesulphonic acid and methanesulphonic acid, *Iranian Polym. J.* 14(1):55-60.
- Li G, Zheng P, Wang NL, Long YZ, Chen ZJ, Li JC, Wan MX (2004). Optical study on doped polyaniline composite films, *J. Phys. Condens. Matter.*, 16:6195–6204.
- MacDiarmid AG (2001). A Conducting Composite of Polyaniline and Wood, *Angew. Chem. Inst. Ed.*, 40:2581-2587.
- Manoha SK, MacDiarmid AG, Epstein AJ (2002). Dependency of conductivity of selected doped conducting polymers on an unusual "Through space" electric field effect, *Polymeric Materials: Sci. Eng.* 86:1-5.
- Pron A, Ranou P (2002). Processible conjugated polymers: from organic semiconductors organic metals and superconductors, *Prog. Polym. Sci.*, 27:135-190.
- Reits JR, Milford J, Christy RW (1979). *Foundations of Electro Magnetic Theory*, Third Edition Addison, Wesley.
- Senadeera GKR, Pathirathne WMTC (2004). Utilization of conducting polymer as a sensitizer in solid-state photocells, *Res. Communications-Current Sci.* 87(3):339-342.