REFERENCES

Anbarasan, R., Vasudevan, T., and Gopalan, A. (1999). Chemical grafting of aniline and o-toluidine onto poly(ethylene terephthalate) fiber. Journal of Applied Polymer Science, 73, 121-128.

Anbarasan, R., Muthumani, N., Vasudevan, T., Gopalan, A., and Wen, Ten-Chin (2001a). Chemical grafting of polyaniline onto nylon 66 fiber in different media. Journal of Applied Polymer Science, 79, 1283-1296.

Anbarasan, R., Jayaseharan, J., Sudha, M., and Gopalan, A (2001b). Peroxosalts initiated graft copolymerization of aniline onto rayon fiber-a kinetic approach. Journal of Applied Polymer Science, 81, 468-478.

Bhadani, Suraj, N., Kumari, M., Sen Gupta, Sumanta K., and Sahu, Guru, C. (1996). Preparation of conducting fibers via the electrochemical polymerization of pyrrole. Journal of Applied Polymer Science, 64(6), 1073-1077.

Christelle, B., Steven, P.A., Mohamed, M.C., Carole B., and Maria O. (1998). Surface characterization of polyaniline-coated polystyrene latexes. Langmuir, 14, 5032-5038.

Christelle, B., Steven, P.A., Stuart, F.L., Shen, Y.L., and Heather, M.E. Stanley. (1998). Synthesis and characterization of micrometer-sized, polyaniline-coated polystyrene latexes. Langmuir, 14, 2032-2041.

Collins G.E., and Buckley L.J. (1996). Conductive polymer-coated fabrics for chemical sensing. Synthetic Metals, 78, 93-101.

Dhawan, S.K., Singh, N., and Venkatachalam, S. (2002). Shielding behaviour of conducting polymer-coated fabrics in X-band, W-band and radio frequency range. Synthetic Metals, 129, 3, 261-267.

Funkhouser, G.P., Arevalo, M.P., Glatzhofer, D. T., and O'Rear, E. A. (1995). Solubilization and adsolubilization of pyrrole by sodium dodecyl sulfate: Polypyrrole formation on alumina surfaces. Langmuir, 11, 1443-1447.

Collins, G.E., and Buckley, L.J. (1996). Conductive polymer-coated fabrics for chemical sensing. Synthetic Metals, 78, 93-101.

Han, M.G., Cho, S.K., Oh, S.G. and Im, S.S. (2002). Preparation and characterization of polyaniline nanoparticles synthesized from DBSA micellar solution. Synthetic Metals, 126, 53-60.

Irina, S., Andrea, R., and Jaroslav, S. (2001). In-situ polymerized polyaniline films 3. Film formation. Synthetic Metals, 123, 503-507.

Jin, X., and Gong, K. (1996). Diffusion-deposition of polyaniline onto textiles with high electric conductivity and improved adhesion. Journal of Coated Fabrics, 26, 36-44.

Kim, M. S., Kim, H. K., Byun, S. W., Jeong, S. H., Hong, Y. K., Joo, J. S., Song, K. T., Kim, J. K., Lee, C. J., and Lee, J. Y. (2002). PET fabric/polypyrrole composite with high electrical conductivity for EMI shielding. Synthetic Metals, 126, 233-239.

Kim, S.H., Seong, J.H., and Oh, K.W. (2002). Effect of dopant mixture on the conductivity and thermal stability of polyaniline/Nomex conductive fabric. Journal of Applied Polymer Science, 83, 2245-2254.

Kuhn, H.H., Kimbrell, Jr., and William C. (1990). US Patent 4975317.

Kuhn, H.H. (1997). Adsorption at liquid/solid interface: conductive textiles based on polypyrrole. Textile Chemist and Colorist, 29(12), 11-21.

Lai, C., Harwell, J.H., and O'Rear, E.A. (1995). Formation of poly-(tetrafluorothylene) thin film on alumina by admicellar polymerization. Langmuir, 11(3), 905-911.

Oh, K.W., Kim, S.H., and Kim, E.A. (2001a). Improve surface characteristics and the conductivity of polyaniline-nylon 6 fabrics by plasma treatment. Journal of Applied Polymer Science, 81, 684-694.

Oh, K.W., and Hong, K.H. (2001b). Thermal stability of conductive polyaniline-nylon 6 composite fabrics doped by a mixture of protonic acids. Textile Research Journal, 71, 726-731.

Oh, K.W., Hong, K.H., and Kim, S.K. (1999). Electrically conductive textiles by *in-situ* polymerization of aniline. Journal of Applied Polymer Science, 74, 2094-2101.

O'Haver, J.H., Harwell, J.H., Snodgrass, L.J. and Waddelt, W.H. (1994). In situ formation of polystyrene in adsorbed surfactant bilayers on precipitated silica. Langmuir, 10(8), 2588-2593.

Pisuntornsug, C. (2001). The modifications of cotton properties by admicellar polymerization. Master Degree's Thesis, Polymer Science Program, The Petroleum and Petrochemical College, Chulalongkorn University.

Pongmala, M. (2002). Preparation of conductive fabric. Master Degree's Thesis, Polymer Science Program, The Petroleum and Petrochemical College, Chulalongkorn University.

Rosen, M.J. (1989). "Surfactant and Interfacial Phenomenon,"2nd ed. Wiley, New York.

Sakhalkar, S.S., and Hirt, D.E. (1995). Admicellar polymerization of polystyrene on glass fibers. Langmuir, 11(9), 3369-3373.

Shi, G., Xu, J., and Fu, M. (2002). Raman spectroscopic and electrochemical studies on the doping level changes of polythiophene films during their eletrochemical growth processes. Journal of Physical Chemistry, 106, 288-292.

Skotheim, T.A., Elsenbaumer, B.L., and Reynolds, J.R. Eds. (1998). Electrically Conducting Textiles. Handbook of Conducting Polymer, 2nd Ed., Marcel Dekker, USA.

Tessier, D., Dao, L.H., Zhang, Z., King, M.K., and Guidoin, R. (2000). Polymerization and surface analysis of electrically-conductive polypyrrole on surface-activated polyester fabrics for biomedical applications. Journal of Biomaterial Science-Polymer Edition , 11(1), 87-99.

Vidanapathirana, K.P., Careem, M.A., Skaarup, S., and West, K. (1999). The Influence of Preparation Conditions on the Electrical Conductivity of Poly N-Methylpyrrole Films. Solid State Ionics, 123, 287-92.

Wu, J., Harwell, J.H., and O'Rear, E.A. (1987). Two-dimensional reaction solvents:surfactant bilayers in the formation of ultrathin films. Langmuir, 3(4), 531-537.

Zotti, G., Zecchin, S., Berlin, A., Schiavon, G., and Giro, G. (2001). Multiple adsorption of polythiophene layers on ITO/glass electrodes and their optical,

electrochemical, and conductive properties. Chemistry of Materials, 13, 43-52.

Yuan, W.L., O'Rear, E.A., Cho, G., Funkhouser, G.P. and Glatzhofer, D.T. (2001). Thin Polypyrrole Films Formed on Mica and Alumina with and without Surfactant Present: Characterization by Scanning Probe and Optical Microscopy, Thin Solid Films, 385, 96-108.

APPENDICES

Appendix A Surface Resistivity of Coated Fabrics

Table A1 Surface resistivity of polypyrrole coated cotton fabric

Surfactant concentration (mM)	Pyrrole					
	Oxidizing agent:monomer ratio					
	1:1			2:1		
	Monomer concentration (mM)					
	5	10	15	5	10	15
1.0 (< CMC)	2.320E+12	5.823E+09	-	3.591E+11	3.510E+08	-
1.2 (@ CMC)	2.057E+12	3.888E+08	7.293E+07	4.443E+10	2.290E+08	1.547E+07
1.2+0.15 M NaCl	1.949E+11	2.328E+08	4.465E+07	1.188E+10	3.959E+07	1.942E+07
1.2+0.5 M NaCl	1.403E+11	1.297E+07	4.450E+06	1.048E+10	1.882E+07	2.322E+06
1.2+1 M NaCl	1.567E+11	6.162E+07	6.742E+06	9.642E+10	2.515E+07	5.959E+06
1.2+1.5 M NaCl	1.837E+12	5.558E+08	3.556E+07	6.599E+11	2.078E+08	3.511E+07
1.4 (> CMC)	2.082E+12	5.374E+09	-	1.318E+12	4.595E+09	-

Table A2 Surface resistivity of poly(*N*-methylpyrrole) coated cotton fabric

Surfactant concentration (mM)	*N*-methylpyrrole					
	Oxidizing agent:monomer ratio					
	1:1			2:1		
	Monomer concentration (mM)					
	5	10	15	5	10	15
1.2 (@ CMC)	2.903E+14	5.936E+13	2.061E+14	1.872E+14	3.011E+13	7.478E+13
1.2+0.15 M NaCl	1.816E+14	5.649E+13	1.634E+13	8.376E+13	1.872E+13	4.345E+12
1.2+0.5 M NaCl	4.247E+13	1.334E+13	5.678E+12	1.330E+13	1.304E+12	2.908E+11
1.2+1 M NaCl	6.736E+13	1.350E+13	6.002E+12	8.217E+13	3.758E+12	3.685E+11
1.2+1.5 M NaCl	8.505E+13	4.936E+13	6.391E+12	1.588E+14	4.235E+12	4.067E+11

Table A3 Surface resistivity of polyaniline coated cotton fabric

Surfactant concentration (mM)	Aniline					
	Oxidizing agent:monomer ratio					
	1:1			2:1		
	Monomer concentration (mM)					
	5	10	15	5	10	15
1.0 (< CMC)	3.352E+12	7.026E+11	-	3.591E+12	3.398E+12	-
1.2 (@ CMC)	3.057E+12	6.416E+11	5.067E+11	3.443E+12	2.243E+12	5.881E+11
1.2+0.15 M NaCl	2.649E+12	6.354E+11	2.977E+11	3.388E+12	1.979E+12	5.385E+11
1.2+0.5 M NaCl	2.403E+12	3.394E+11	1.054E+11	2.848E+12	1.918E+11	4.200E+11
1.2+1 M NaCl	3.038E+12	4.450E+11	1.779E+11	3.142E+12	2.158E+11	4.306E+11
1.2+1.5 M NaCl	3.137E+12	6.820E+11	2.447E+11	3.259E+12	3.115E+11	6.158E+11
1.4 (> CMC)	3.298E+12	7.026E+11	-	3.377E+11	4.284E+12	-

Table A4 Surface resistivity of polythiophene coated cotton fabric

Surfactant concentration (mM)	Thiophene					
	Oxidizing agent:monomer ratio					
	1:1			2:1		
	Monomer concentration (mM)					
	5	10	15	5	10	15
1.0 (< CMC)	3.382E+12	9.085E+11	-	3.490E+12	9.559E+11	-
1.2 (@ CMC)	3.357E+12	8.980E+11	7.150E+11	3.453E+12	9.481E+11	8.900E+11
1.2+0.15 M NaCl	2.949E+12	7.841E+11	6.519E+11	3.213E+12	8.504E+11	8.720E+10
1.2+0.5 M NaCl	2.603E+12	6.141E+11	5.467E+10	2.848E+12	7.129E+11	7.613E+10
1.2+1 M NaCl	2.938E+12	6.768E+11	7.565E+11	3.010E+12	7.559E+11	8.720E+10
1.2+1.5 M NaCl	3.337E+12	6.820E+11	8.775E+11	3.096E+12	7.629E+11	9.810E+10
1.4 (> CMC)	3.308E+12	8.306E+11	-	3.368E+12	9.368E+11	-

Table A5 Surface resistivity of polypyrrole coated polyester fabric

Surfactant concentration (mM)	Pyrrole					
	Oxidizing agent:monomer ratio					
	1:1			2:1		
	Monomer concentration(mM)					
	5	10	15	5	10	15
1.0 (< CMC)	2.861E+12	1.217E+08	-	3.673E+10	1.403E+08	-
1.2 (@ CMC)	8.027E+11	1.914E+08	8.858E+07	4.318E+09	6.962E+07	2.375E+07
1.2+0.15 M NaCl	6.675E+11	6.413E+06	6.399E+06	9.748E+08	8.492E+06	4.157E+06
1.2+0.5 M NaCl	2.974E+10	1.077E+06	1.268E+06	2.636E+07	2.152E+06	5.919E+05
1.2+1 M NaCl	7.974E+10	1.226E+06	8.890E+05	7.383E+07	4.118E+06	1.060E+06
1.2+1.5 M NaCl	9.974E+10	6.502E+06	7.380E+05	7.795E+07	7.175E+06	8.006E+06
1.4 (> CMC)	2.974E+12	5.669E+07	-	1.139E+10	6.784E+08	-

Table A6 Surface resistivity of poly(*N*-methylpyrrole) coated polyester fabric

Surfactant concentration (mM)	*N*-methylpyrrole					
	Oxidizing agent:monomer ratio					
	1:1			2:1		
	Monomer concentration (mM)					
	5	10	15	5	10	15
1.2 (@ CMC)	9.173E+15	5.744E+15	1.474E+14	5.933E+15	1.955E+14	6.151E+12
1.2+0.15 M NaCl	1.010E+14	2.861E+14	2.397E+13	5.351E+14	2.898E+13	1.404E+12
1.2+0.5 M NaCl	2.101E+13	1.017E+12	1.920E+11	3.238E+13	5.410E+11	5.197E+10
1.2+1 M NaCl	3.417E+14	1.618E+13	7.189E+11	3.814E+13	5.435E+11	1.482E+10
1.2+1.5 M NaCl	3.605E+14	3.560E+13	3.913E+11	3.876E+14	5.876E+11	1.262E+10

Table A7 Surface resistivity of polyaniline coated polyester fabric

Surfactant concentration (mM)	Aniline					
	Oxidizing agent:monomer ratio					
	1:1			2:1		
	Monomer concentration (mM)					
	5	10	15	5	10	15
1.0 (< CMC)	6.861E+13	9.181E+12	-	7.673E+13	5.933E+12	-
1.2 (@ CMC)	6.027E+13	7.417E+12	2.869E+11	4.318E+13	3.749E+12	2.297E+12
1.2+0.15 M NaCl	5.675E+12	3.310E+12	1.980E+11	9.748E+12	2.729E+12	1.242E+12
1.2+0.5 M NaCl	5.933E+11	4.918E+11	1.113E+11	2.636E+12	6.026E+11	4.247E+11
1.2+1 M NaCl	6.259E+11	5.690E+11	1.264E+11	7.383E+12	6.888E+11	7.226E+11
1.2+1.5 M NaCl	7.741E+11	6.264E+11	5.153E+11	7.795E+12	1.853E+12	8.091E+11
1.4 (> CMC)	8.974E+12	7.216E+12	-	1.139E+13	5.888E+12	-

Table A8 Surface resistivity of polythiophene coated polyester fabric

Surfactant concentration (mM)	Thiophene					
	Oxidizing agent:monomer ratio					
	1:1			2:1		
	Monomer concentration (mM)					
	5	10	15	5	10	15
1.0 (< CMC)	7.398E+13	6.068E+12	-	7.560E+13	6.811E+12	-
1.2 (@ CMC)	6.460E+13	4.855E+12	3.409E+12	7.024E+13	5.423E+12	3.953E+12
1.2+0.15 M NaCl	4.450E+13	3.387E+12	2.596E+12	5.886E+13	5.359E+12	7.978E+11
1.2+0.5 M NaCl	8.476E+12	1.942E+11	1.016E+11	3.197E+13	8.427E+11	4.610E+11
1.2+1 M NaCl	1.090E+13	5.476E+12	5.880E+11	4.435E+13	6.158E+12	6.582E+11
1.2+1.5 M NaCl	2.119E+13	6.775E+12	6.768E+11	6.775E+13	7.476E+12	8.980E+11
1.4 (> CMC)	7.521E+13	1.391E+13	-	7.549E+13	1.926E+13	-

Appendix B Volume resistivity of Coated Fabrics

Table B1 Volume resistivity of polypyrrole coated cotton fabric

Surfactant concentration (mM)	Pyrrole					
	Oxidizing agent:monomer ratio					
	1:1			2:1		
	Monomer concentration(mM)					
	5	10	15	5	10	15
1.0 (< CMC)	2.159E+11	7.572E+08	-	1.063E+11	1.261E+09	-
1.2 (@ CMC)	1.936E+10	5.797E+08	1.439E+07	1.443E+10	8.168E+08	1.049E+07
1.2+0.15 M NaCl	2.452E+09	1.057E+07	1.064E+07	2.052E+09	1.326E+08	6.362E+06
1.2+0.5 M NaCl	2.244E+09	8.897E+06	1.236E+06	1.010E+09	1.785E+06	1.182E+06
1.2+1 M NaCl	1.198E+09	7.186E+06	6.397E+05	1.548E+09	3.284E+06	1.495E+06
1.2+1.5 M NaCl	2.448E+09	1.437E+07	8.696E+05	1.740E+09	2.774E+06	1.917E+06
1.4 (> CMC)	4.376E+10	2.490E+09	-	2.004E+10	1.637E+09	-

Table B2 Volume resistivity of poly(*N*-methylpyrrole) coated cotton fabrics

Surfactant concentration (mM)	*N*-Methylpyrrole					
	Oxidizing agent:monomer ratio					
	1:1			2:1		
	Monomer concentration (mM)					
	5	10	15	5	10	15
1.2 (@ CMC)	8.958E+13	1.084E+13	5.009E+12	4.750E+13	5.153E+12	6.085E+11
1.2+0.15 M NaCl	8.555E+12	5.153E+12	5.327E+11	1.472E+13	3.096E+12	2.209E+11
1.2+0.5 M NaCl	3.464E+12	7.279E+11	5.091E+10	1.786E+12	5.204E+11	1.920E+10
1.2+1 M NaCl	1.572E+13	1.105E+12	6.311E+10	2.591E+12	7.279E+11	5.405E+10
1.2+1.5 M NaCl	1.846E+13	2.943E+12	7.018E+10	3.020E+12	8.485E+11	6.373E+10

Table B3 Volume resistivity of polyaniline coated cotton fabric

Surfactant concentration (mM)	Aniline					
	Oxidizing agent:monomer ratio					
	1:1			2:1		
	Monomer concentration (mM)					
	5	10	15	5	10	15
1.0 (< CMC)	3.459E+11	3.437E+11	-	3.663E+11	2.729E+11	-
1.2 (@ CMC)	2.936E+11	2.219E+11	1.782E+11	3.122E+11	2.509E+11	2.424E+11
1.2+0.15 M NaCl	1.452E+11	1.832E+10	1.544E+10	3.052E+11	1.982E+11	3.002E+10
1.2+0.5 M NaCl	1.121E+10	1.098E+10	1.022E+10	1.010E+11	1.919E+10	2.115E+10
1.2+1 M NaCl	1.198E+11	1.127E+11	1.116E+11	4.548E+11	4.802E+11	2.424E+11
1.2+1.5 M NaCl	2.448E+11	1.873E+11	1.575E+11	7.740E+11	5.730E+11	4.849E+11
1.4 (> CMC)	3.376E+11	2.729E+11	-	8.004E+11	5.933E+11	-

Table B4 Volume resistivity of polythiophene coated cotton fabric

Surfactant concentration (mM)	Thiophene					
	Oxidizing agent:monomer ratio					
	1:1			2:1		
	Monomer concentration (mM)					
	5	10	15	5	10	15
1.0 (< CMC)	3.814E+11	3.714E+11	-	3.955E+11	3.857E+11	-
1.2 (@ CMC)	3.508E+11	2.967E+11	4.603E+10	3.886E+11	3.753E+11	5.583E+11
1.2+0.15 M NaCl	2.967E+11	2.428E+11	1.047E+10	3.549E+11	3.313E+11	7.417E+10
1.2+0.5 M NaCl	1.236E+11	1.119E+11	1.046E+10	2.427E+11	2.135E+11	3.681E+10
1.2+1 M NaCl	1.729E+11	1.519E+11	3.318E+10	2.372E+11	2.202E+11	6.131E+10
1.2+1.5 M NaCl	2.003E+11	1.980E+11	4.129E+10	2.985E+11	2.730E+11	6.869E+10
1.4 (> CMC)	3.512E+11	2.814E+11	-	3.814E+11	2.933E+11	-

Table B5 Volume resistivity of polypyrrole coated polyester fabric

Surfactant concentration (mM)	Pyrrole					
	Oxidizing agent:monomer ratio					
	1:1			2:1		
	Monomer concentration(mM)					
	5	10	15	5	10	15
1.0 (< CMC)	4.501E+09	7.841E+07	-	4.158E+09	1.226E+07	-
1.2 (@ CMC)	9.297E+08	5.486E+07	2.368E+06	4.337E+08	2.275E+06	1.692E+06
1.2+0.15 M NaCl	7.845E+07	4.465E+06	7.430E+05	5.396E+07	1.220E+06	8.167E+05
1.2+0.5 M NaCl	1.335E+07	2.966E+06	5.839E+05	3.179E+06	5.670E+05	3.925E+05
1.2+1 M NaCl	6.973E+07	3.973E+06	6.199E+05	4.342E+07	7.274E+05	6.046E+05
1.2+1.5 M NaCl	8.717E+07	4.833E+06	6.862E+05	6.455E+07	1.220E+06	9.279E+05
1.4 (> CMC)	5.959E+08	9.155E+06	-	2.855E+08	2.098E+08	-

Table B6 Volume resistivity of poly(*N*-methylpyrrole) coated polyester fabrics

Surfactant concentration (mM)	*N*-Methylpyrrole					
	Oxidizing agent:monomer ratio					
	1:1			2:1		
	Monomer concentration (mM)					
	5	10	15	5	10	15
1.2 (@ CMC)	1.152E+14	1.503E+12	2.289E+11	2.606E+13	2.562E+12	3.061E+10
1.2+0.15 M NaCl	1.913E+13	2.374E+12	4.065E+10	6.020E+12	5.417E+11	2.249E+10
1.2+0.5 M NaCl	1.368E+12	1.710E+11	8.550E+09	1.024E+12	5.833E+10	7.101E+09
1.2+1 M NaCl	1.384E+13	1.193E+11	9.826E+09	8.535E+12	2.168E+11	9.758E+09
1.2+1.5 M NaCl	2.671E+13	8.680E+11	7.062E+10	9.279E+12	5.348E+11	1.275E+10

Table B7 Volume resistivity of polyaniline coated polyester fabric

Surfactant concentration (mM)	Aniline					
	Oxidizing agent:monomer ratio					
	1:1			2:1		
	Monomer concentration (mM)					
	5	10	15	5	10	15
1.0 (< CMC)	3.018E+12	7.812E+11	-	4.158E+12	9.256E+11	-
1.2 (@ CMC)	2.150E+12	6.310E+11	2.271E+10	5.659E+12	8.752E+11	4.907E+11
1.2+0.15 M NaCl	4.377E+12	4.329E+11	1.347E+10	3.396E+12	6.760E+11	3.408E+11
1.2+0.5 M NaCl	8.900E+11	7.855E+10	1.171E+10	3.179E+11	9.563E+10	5.647E+10
1.2+1 M NaCl	9.411E+11	9.559E+10	5.649E+10	6.342E+11	3.256E+11	6.357E+10
1.2+1.5 M NaCl	1.886E+12	1.460E+11	6.260E+10	1.455E+12	4.849E+11	8.453E+10
1.4 (> CMC)	2.985E+12	2.244E+11	-	3.292E+12	5.026E+11	-

Table B8 Volume resistivity of polythiophene coated polyester fabric

Surfactant concentration (mM)	Thiophene					
	Oxidizing agent:monomer ratio					
	1:1			2:1		
	Monomer concentration (mM)					
	5	10	15	5	10	15
1.0 (< CMC)	2.967E+12	5.826E+11	-	3.033E+12	7.260E+11	-
1.2 (@ CMC)	2.322E+12	4.162E+11	2.517E+11	2.781E+12	7.067E+11	4.272E+11
1.2+0.15 M NaCl	1.675E+12	2.369E+11	1.808E+11	2.509E+12	5.383E+11	3.427E+11
1.2+0.5 M NaCl	1.214E+12	1.030E+11	1.491E+10	1.890E+12	4.613E+10	5.368E+10
1.2+1 M NaCl	1.405E+12	1.209E+11	3.272E+10	2.142E+12	5.209E+10	8.669E+10
1.2+1.5 M NaCl	2.158E+12	1.613E+11	5.585E+10	2.340E+12	5.780E+10	1.613E+11
1.4 (> CMC)	3.338E+12	3.126E+11	-	3.390E+12	4.914E+11	-

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