REFERENCES

1. Scrosati, B. 1993. Applications of Electroactive Polymers. UK: Chapman and Hall.
2. Troung, T. 1997. Conducting polymer: A novel alternative material. Chemistry in Australia. 20-22.
3. Shirakawa, H., et al. 1977. Synthesis of electrically conducting organic polymers: Halogen derivatives of polyacetylene, $(CH)_x$. J. Chem. Soc. Chem. Commun. 578-580.
4. Patil, A. O., et al. 1988. Optical properties of conducting polymers. Chem. Rev. 88:183-200.
5. Tanawadee, L.; Supawan, T.; Prapaipit, C.; and Anantasin, T. 1992, october. Chemical synthesis of electrical conductive polypyrrole. 18th Congress on Science and Technology of Thailand. 27-29
6. Blythe, A. R. 1979. Conduction in polymer. Electrical properties of polymer. UK: Cambridge University Press.
7. Zoppi, R. A., and De Paoli M. A. 1996. Chemical preparation of conductive elastomeric blends: Polypyrrole/EPDM-II. Utilization of matrices containing crosslinking agents, reinforcement fillers and stabilizers. Polymer 37: 1999-2009.
8. Ruckenstein, E., and Yang, S. 1993. Processable conductive polypyrrole/poly (alkylmethacrylate) composites prepared by an emulsion pathway. Polymer 34: 4655-4660.
9. Hearn, M. J.; Fletcher, I. W.; Church, S. P.; and Armes, S. P. 1993. Characterization of polypyrrole fiber composites by time-of-flight secondary ion mass-spectrometry and vibrational spectroscopy. Polymer 34: 262-266.

10. Kelkar, D. S., and Bhat, N. V. 1993. Composite films of Nylon-6 polypyrrole thermal behavior, mechanical-properties and electrical conduction. Polymer 34: 986-989.

11. Kang, T. J.; Miyata, S.; and Miyaki, Y. 1993. Preparation and morphology of electrically conductive and transparent poly(vinylchloride)-polypyrrole composite films. Polym. Bull. 31: 593-599.

12. Sata, T. 1993. Anti-organic fouling properties of composite membranes prepared from anion-exchange membranes and polypyrrole. J. Chem. Soc. Chem. Commun. 1122-1124.

13. Sata, T.; Kishimoto, F.; and Oqura, S. 1993. High acid retention properties of composite membranes prepared from anion-exchange membranes and poly (pyrrole). J. Chem. Soc. Chem. Commun. 1159-1160.

14. Kathirgamanathan, P. 1993. Novel cable shielding materials based on the impregnation of microporous membranes with inherently conducting polymers. Adv. Mater. 5: 281-283.

15. Matencio, T.; Mano, V.; Felisberti, M. I.; and De Paoli M. A. 1994. Electrochemical study of poly(vinyl chloride) polypyrrole blends. Electrochim. Acta. 39: 1393-1400.

16. Omastova, M.; Kosina, S.; Pionteck, J.; Janke, A.; and Pavlinec, J. 1996. Electrical properties and stability of polypyrrole containing conducting polymer composites. Synth. Met. 81: 49-57.

17. Atkins, P.W. 1994. Physical Chemistry. 5th ed. UK: Oxford University Press.

18. Duke, C. B., and Gibson, H. W. 1982. Polymer conductive. Encyclopedia of Chemical Technology. 18: 755-793.

19. Duke, C. B., and Schein, L. B. 1980. Organic solids: is energy-band theory enough? Phys. Today. 33: 42-48.

20. Su, W.P.; Schrieffer, J. R.; and Heeger, A. J. 1979. Solitons in polyacetylene. Phys. Rev. Lett. 42: 1698-1701.

21. Mandal, B. M.; Banerjee, P.; and Bhattacharyya, S. N. 1996. Polypyrrole (Processable Dispersions). Polymeric Materials Encyclopedia 9: 6670-6678.

22. Machida, S.; Miyata, S.; and Techagumpuch, A. 1989. Chemical synthesis of highly electrically conductive polypyrrole. Synth. Met. 31: 311-318.

23. Street, G. B. et al. 1982. Preparation and characterization of neutral and oxidized polypyrrole films. Mol. Cryst. Liq. Cryst. 83: 253-264.

24. Nalwa, H. S. Magnetic susceptibility of polypyrrole and polythiophene conducting polymers. J. Polym. Sci. Part C: Polym. Lett. 26: 351-355.

25. Brédas, J. L.; Scott, J. C.; Yakushi, K.; and Street, G. B. 1984. Polarons and bipolarons in polypyrrole: Evolution of the band structure and optical spectrum upon doping. Phys. Rev. B. 30: 1023-1025.

26. Yakushi, K.; Lauchlan, T. C.; Clarke. C.; and Street, G. B. 1983. Optical study of polypyrrole perchlorate. J. Chem. Phys. 79: 4774-4778.

27. Scott, J. C.; Pfluger, P.; Krounbi, M. T.; and Street, G. B. 1983. Electron-spin-resonance studies of pyrrole polymers: Evidence for bipolarons. Phys. Rev. B. 28: 2140-2145.

28. Fesser, K.; Bishop, A. R.; and Campbell, D. K. 1983. Optical absorption from polarons in a model of polyacetylene. Phys. Rev. B. 27: 4804-4825.

29. Yassar, A.; Roncali, J.;and Garnier, F. 1987. Aqueous suspension of conducting material from polypyrrole-coated submicronic latex particles. Polym. Commun. 28: 103-104.

30. Armes, S. P., et al. 1991. Conducting polymer-colloidal silica composites. Polymer 32: 2325-2330.

31. Holm, R. 1946. Electric Contacts. Stockholm: Hugo Gebers.

32. Spinks, G. M.; Eisazadeh, H.; and Wallace, G. C. 1996. Conductive polymer colloids. Polymeric Materials Encyclopedia 2: 1421-1431.

33. Aldissi, M., and Armes, S. P. 1991. Colloidal dispersions of conducting polymers. Prog. Org. Coat. 19: 21-58.

34. Bay, R. F. C.; Armes, S. P.; Pickett, C. J.; and Ryder, K. S. 1991. Poly(1-vinylimidazole-co-4-aminostyrene): steric stabilizer for polyaniline colloids. Polymer 32:2456-2460.

35. Ruckenstein, E., and Chen, J. H. 1991. Effect of surface active pyrrole on the conductivity of polypyrrole composites. J. Appl. Polym. Sci. 43:1209-1218.

36. Ruckenstein, E., and Paek, J. S. 1991. New method for the preparation of thick conducting polymer composites. J. Appl. Polym. Sci. 42: 925-934.

37. Omastova, M.; Pionteck, J.; and Kosina, S. 1996. Preparation and characterization of electrically conductive polypropylene/polypyrrole composites. Eur. Polym. J. 32: 681-689.

38. Meng, O., and Chi, M. C. 1998. Conductive polymer composites prepared by polypyrrole-coated poly(vinyl chloride) powder: relationship between conductivity and surface morphology. Polymer 39:1857-1862.

39. Lascelles, S. F., and Armes, S. P. 1997. Synthesis and characterization of micrometre-sized, polypyrrole-coated polystyrene latexes. J. Mater. Chem. 7: 1339-1347.

40. Lascelles, S. F. et al. 1997. Surface characterization of micrometre-sized, polypyrrole-coated polystyrene latexes: Verification of a 'core-shell' morphology. J. Mater. Chem. 7:1349-1355.

41. Armes, S. P., and Vincent, B. 1987. Dispersion of electrical conducting polypyrrole particles in aqueous media. J. Chem. Soc. Chem. Commun. 288-290.

42. Cooper, C. E., and Vincent, B. 1989. Electrically conducting organic films and beads based on conducting latex particles. J. Phys. D.: Appl. Phys. 22:1580-1585.

43. Digar, M. L.; Bhattacharyya, S. N.; and Mandal, B. M. 1994. Dispersion polymerization of pyrrole using poly(vinyl methyl ether) as stabilizer. Polymer 35: 377-382.

44. Sosnowski, S.; Li, L.; Winnik, M. A.; Clubb, B.; and Shivers, R. 1994. Morphology of melt-pressed latex films examined by scanning and freeze-fracture electron microscopy. J. Polym. Sci. Part B: Polym. Phys. 32: 2499-2508.

45. Armes, S. P.; Aldissi, M.; Hawley, M.; Beery, J. G.; and Gottesfeld, S. 1991. Morphology and structure of conducting polymers. Langmuir 7: 1447- 1452.

46. Hunt, B. J., and James, M. I. 1993. Polymer Characterization. UK: Blackie Academic & Professional.

47. Harrick, N. J. 1967. Internal Reflection Spectroscopy. New York: John Wiley & Sons.

APPENDICES

APPENDIX A

Electrical conductivity measurement by van de Pauw method

Van der Pauw method is the technique for measuring conductivity (σ) of sample, which has constant thickness but arbitrary shape. First, four ohms contacts are made at the edge of the sample (Figure A-1). Then applied suitable current (I_{12}) through contact 1 and 2 and measured potential different (V_{34}) between contact 3 and 4. In this case, the suitable current (I_{12}) is assigned to the three values by use the resistance 100 KΩ, 200 KΩ, and 300 KΩ, respectively. The obtained data is shown in Table A-1.

Table A-1 Current and potential data measuring as I_{12} and V_{34}, respectively

	Current (Ampere)	Potential(Volt)
100 KΩ	$I_{12(1)}$	$V_{34(1)}$
200 KΩ	$I_{12(2)}$	$V_{34(2)}$
300 KΩ	$I_{12(3)}$	$V_{34(3)}$

The resistance is obtained by plotting the graph of current and voltage value from Table A-1. The slope, which is the resistance, is assigned to R_1. In the other way, I_{23} is applied through contacts 2 and 3 and potential different, V_{41} is measured to obtain the group of data in the same method, and R_2 is obtained.

Continuously, R_1 and R_2 are taken into the Equation A-1 to obtain the electrical conductivity.

$$\exp^{(-\pi R_1 d \sigma)} + \exp^{(-\pi R_1 d \sigma)} \qquad \text{(A-1)}$$

Where d is the thickness of the sample and σ is the electrical conductivity.

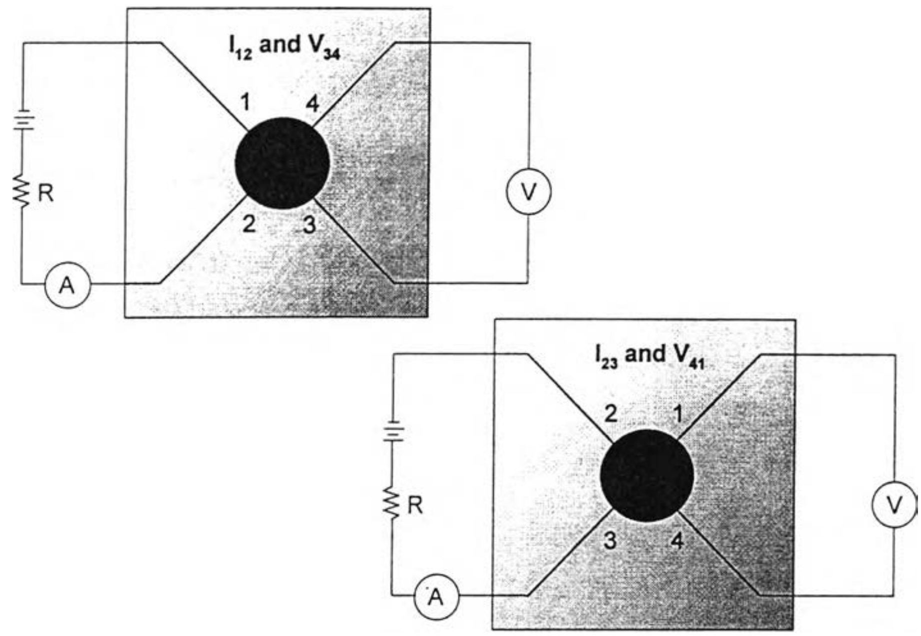

Figure A-1 Conductivity measurement by van der Pauw method

Next, the current electrode is changed around the sample disc, get I_{12}, I_{23}, I_{34}, I_{41} and corresponding potential different V_{34}, V_{41}, V_{12}, V_{23}, respectively. Then calculate σ_1, σ_2, σ_3, σ_4 from equation 3.1. Finally obtain more accurate conductivity, Equation A-2.

$$\sigma = (\sigma_1+\sigma_2+\sigma_3+\sigma_4)/4 \qquad \text{(A-2)}$$

σ = average conductivity

Contact resistance between the measurement electrodes and the composite sample is reduced by painting electrodes directly on to the surface of the sample. Suitable paints are silver dispersions or Aquadag (an aqueous dispersion of colloidal graphite).

Calculation of electrical conductivity

Computer program for calculating conductivity was constructed follow equation A-1 from van der Pauw method by using program 'GWbasic' language. The detail of the program is shown below:

```
ok
List
10  INPUT "  SAMPLE THICKNESS = ",D
20  INPUT "  Resistance No.1 = ",R1
30  INPUT "  Resistance No.2 = ",R2
40  M=3.141527*D
50  R=R1
60  S=R2
70  A=M*R
80  B=M*S
90  C=(A+B)*.5
100 X=.69314/C
110  I=EXP(-A*X)+EXP(-B*X)
120  IF  I <=0.00001 THEN GOTO 150
130  X=X*I
140 GOTO 110
150 PRINT "        Conductivity =";X
ok
```

Example for calculation the electrical conductivity of polymer sample

After the electrical data (V and I) at 4 points of polymer sample were obtained, the slope of the graph plotting between potential and current, R (Resistance), cound be obtained by least square fit technique. Then, the resistance values from each sample which have the correct least square fit will be calculated by computer program.

Sample

1. Thickness d_1 = 0.040 cm

d_2 = 0.042 cm

d_3 = 0.044 cm

d_4 = 0.041 cm

Average thickness d = 0.042 cm

2. The slope of the graph from V and I data

Group 1 I_{12} V_{34} : 0.79, 0.5 ; 0.39, 0.3 ; 0.24, 0.1

Group 2 I_{23} V_{14} : 0.79, 0.8 ; 0.40, 0.4 ; 0.25, 0.2

from group 1 we obtained R_1 = 0.68

from group 2 we obtained R_2 = 1.09

3. Calculation program

Run

SAMPLE THICKNESS = 0.042

Resistance No.1 = 0.68

Resistance No.2 = 1.09

Conductivity = 6.050098

Ok

In principle, $\sigma 1$, $\sigma 2$, $\sigma 3$, $\sigma 4$ could be calculated by changing the current electrodes around. These values were averaged to obtain the final value that was the average conductivity of the sample.

APPENDIX B

The electrical conductivity of polypyrrole composites

TableB-1 Electrical conductivity of Polystyrene/Polypyrrole composites

Sample code	Pyrrole: PS ratio	Reaction time(hour)	Conductivity(Scm^{-1})		Average (Scm^{-1})
			#1	#2	
PS01	0.1	1	1.53	1.53	1.53
PS02	0.2	1	2.70	2.73	2.72
PS03	0.5	1	7.13	8.01	7.57
PS04	0.8	1	8.26	7.94	8.10
PS05	1	1	10.85	9.11	9.98
PS06	0.1	2	-	-	-
PS07	0.2	2	3.35	1.71	2.53
PS08	0.5	2	5.44	5.23	5.34
PS09	0.8	2	1.33	1.06	3.20
PS10	1	2	4.41	4.55	4.48
PS11	0.1	3	3.21	2.99	3.10
PS12	0.2	3	2.24	2.38	2.31
PS13	0.5	3	2.78	2.84	2.81
PS14	0.8	3	2.35	2.16	2.26
PS15	1	3	3.40	3.06	3.23
PS16*	0.1	Mixed	5.18	7.21	6.51
PS17*	0.2	Mixed	7.04	7.46	7.25
PS18*	0.5	Mixed	9.90	7.56	8.73

* Study in 50% methanol/water at 1 hour polymerization time

TableB-2 Electrical conductivity of Poly(vinyl chloride)/Polypyrrole composites

Sample code	Pyrrole: PVC ratio	Reaction time(hour)	Conductivity(Scm^{-1})		Average (Scm^{-1})
			#1	#2	
PVC01	0.1	1	-	-	-
PVC02	0.2	1	-	-	-
PVC03	0.5	1	5.60	5.06	5.33
PVC04	0.8	1	9.79	9.25	9.52
PVC05	1	1	10.14	9.90	10.02
PVC06	0.1	2	0.11	0.09	0.10
PVC07	0.2	2	2.16	2.33	2.24
PVC08	0.5	2	8.16	7.21	7.68
PVC09	0.8	2	7.00	7.82	7.41
PVC10	1	2	6.48	7.25	6.86
PVC11	0.1	3	0.19	0.17	0.18
PVC12	0.2	3	0.88	1.09	0.98
PVC13	0.5	3	2.20	1.74	1.97
PVC14	0.8	3	1.71	1.46	1.58
PVC15	1	3	1.14	1.14	1.14
PVC16*	0.1	Mixed	0.43	0.57	0.50
PVC17*	0.2	Mixed	2.25	2.60	2.42
PVC18*	0.5	Mixed	4.05	3.08	3.56

* Study in 50% methanol/water at 1 hour polymerization time

TableB-3 Electrical conductivity of Polypyrrole powder prepared by dispersion polymerization

Sample code	Pyrrole: PVP ratio	Solvent	Conductivity(Scm^{-1})		Average (Scm^{-1})
			#1	#2	
PVP01	0.1	Methanol	0.15	0.15	0.15
PVP02	0.5	Methanol	0.23	0.25	0.24
PVP03	0.8	Methanol	1.12	1.20	1.16
PVP04	0.1	Water	15.93	16.02	15.98
PVP05*	0.5	Water	6.82	6.24	6.53
PVP06	0.8	Water	2.87	2.87	2.87
PVP07	0.1	Mixed	42.43	41.55	41.99
PVP08	0.5	Mixed	16.71	14.58	15.64
PVP09	0.8	Mixed	0.91	0.89	0.90
PVP10*	0.5	2 hour	7.72	6.94	7.33
PVP11*	0.5	3 hour	13.02	16.74	14.88

* Study in water at 1, 2, 3 hour polymerization time

TableB-4 Conductive stability of Polystyrene/Polypyrrole composites

Sample code	Storing time (week)	Conductivity (Scm^{-1})		Average (Scm^{-1})
		#1	#2	
PS01	0	1.53	1.53	1.53
	2	1.41	1.34	1.38
	4	1.08	1.04	1.06
	6	1.06	1.36	1.21
	8	0.82	1.03	0.92
	10	0.88	0.86	0.87
PS02	0	2.70	2.73	2.72
	2	2.65	2.48	2.56
	4	1.64	1.72	1.68
	6	1.49	2.06	1.78
	8	1.25	1.34	1.30
	10	1.08	0.92	1.00
PS03	0	7.13	8.01	7.57
	2	6.33	5.43	5.88
	4	4.28	4.16	4.22
	6	3.94	3.91	3.92
	8	3.52	3.61	3.56
	10	3.49	3.37	3.43
PS04	0	8.26	7.94	8.10
	2	2.86	2.09	2.48
	4	1.62	1.72	1.68
	6	1.19	0.98	1.08
	8	0.87	0.77	0.82
	10	0.70	0.72	0.71
PS05	0	10.85	9.11	9.98
	2	3.36	3.90	3.63
	4	2.41	2.78	2.60
	6	1.65	1.81	1.73
	8	1.32	1.63	1.48
	10	1.09	1.15	1.12

TableB-5 Conductive stability of Poly(vinyl chloride)/Polypyrrole composites

Sample code	Storing time (week)	Conductivity (Scm^{-1})		Average (Scm^{-1})
		#1	#2	
PVC03	0	5.60	5.06	5.33
	2	2.00	2.29	2.14
	4	1.60	1.41	1.50
	6	1.25	1.13	1.19
	8	0.82	0.80	0.81
	10	0.77	0.71	0.74
PVC04	0	9.79	9.25	9.52
	2	3.99	3.88	3.94
	4	3.04	3.24	3.14
	6	4.44	2.95	3.70
	8	1.81	1.80	1.80
	10	1.24	1.14	1.19
PVC05	0	11.54	8.50	10.02
	2	3.50	2.88	3.19
	4	2.19	2.04	2.12
	6	1.79	1.56	1.68
	8	1.25	0.99	1.12
	10	1.00	1.04	1.02

APPENDIX C

Attenuated total reflectance FT-IR spectroscopy [46]

The Attenuated total reflectance FT-IR spectroscopy is a sampling technique based on internal reflection spectroscopy (IRS). The ATR technique rely on the intimate contact of a sample with the surface of a high refractive index, infrared transparent character or ATR prism, see Figure C-1(a),(b). IR radiation entering the prism at an angle greater than the critical angle and internally reflected within the prism. Its energy was attenuated by absorption of the sample attached to the prism [47].

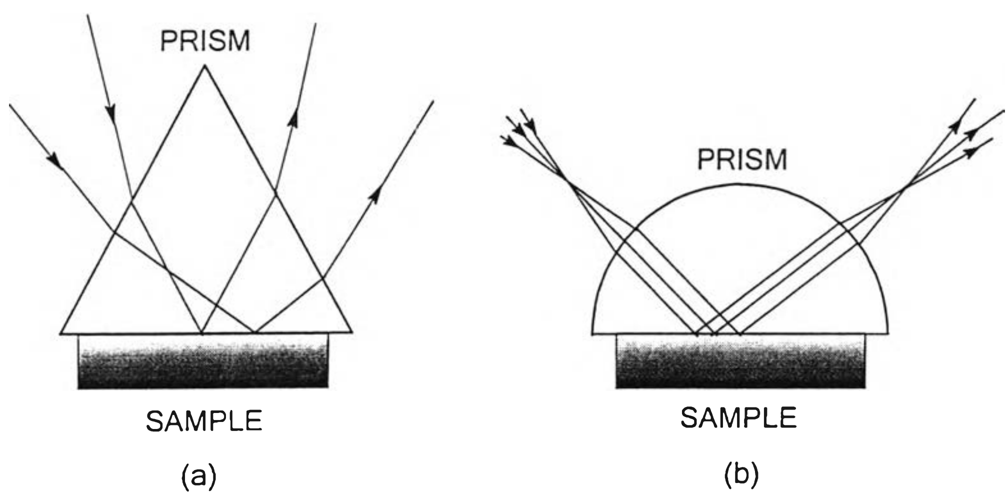

Figure C-1 Schematic diagram of internal reflection spectroscopy

Since smooth film cannot be fabricated from the samples being investigated, casting onto the surface of prism is employed (see Figure C-2). Droplets of suspended sample obtained by dispersing dry powders in methanol were put on the prism. After the solvent was completely removed. The sample on the surface of the ATR prism was analyzed by ATR FT-IR spectroscopy.

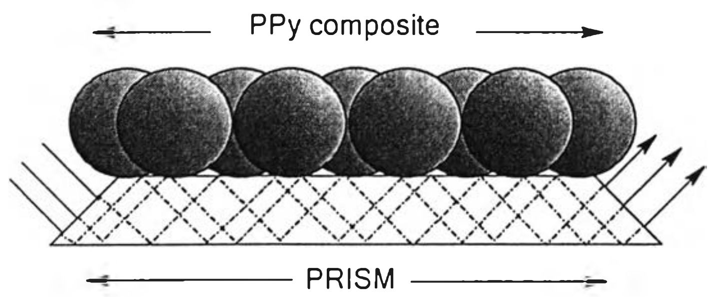

Figure C-2 ATR FT-IR study model for polypyrrole coating composite

The incident angle is important for obtaining absorption band. If the incident angle is small, the inner layer of polymer sample will be detected. Thus, in this investigation an incident angle of 45 ° was employed to observe the outer layer only of polymer composite.

APPENDIX D

FT-IR Spectra

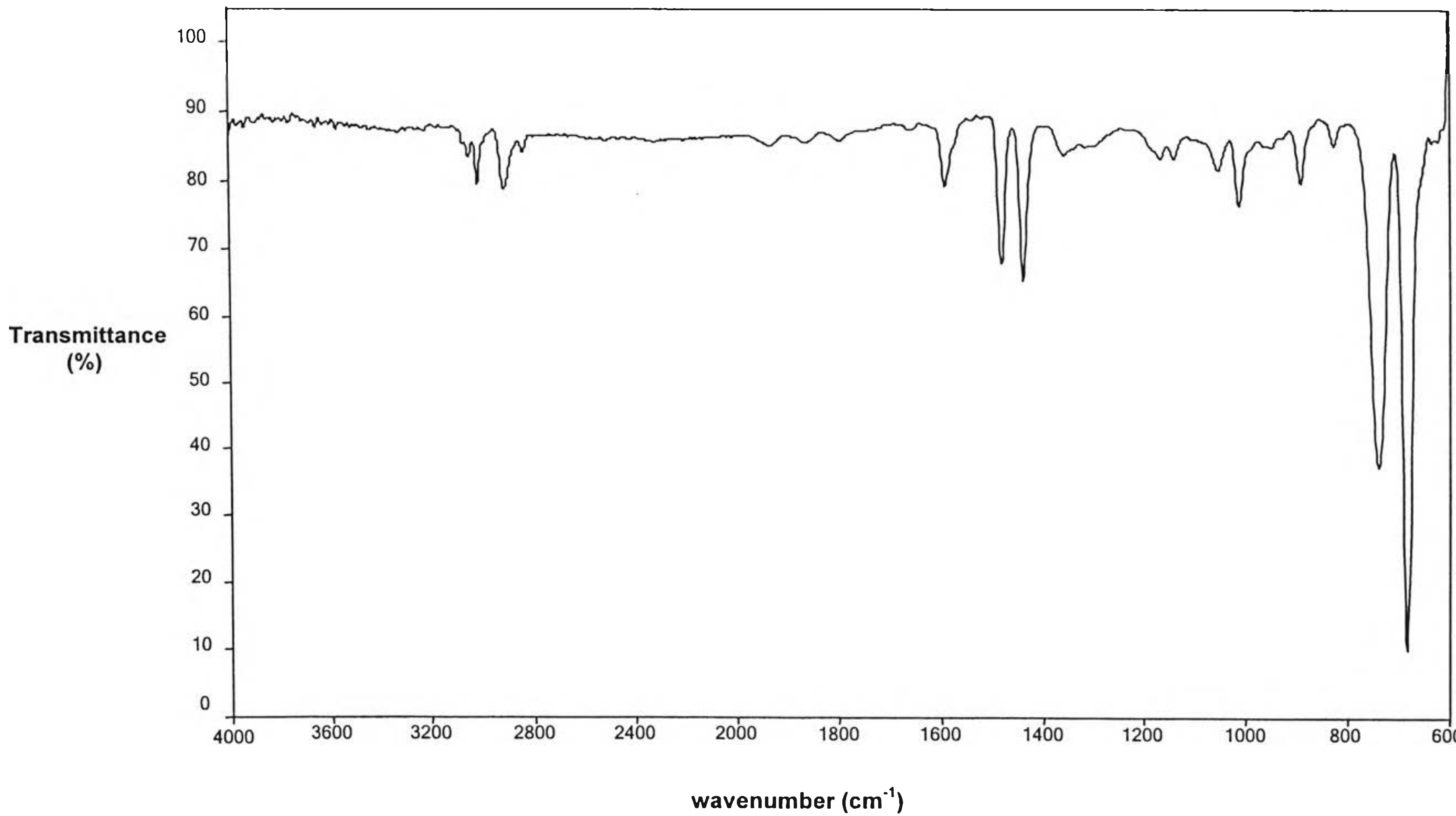

Figure D-1 FT-IR spectrum (ATR) of Polystyrene

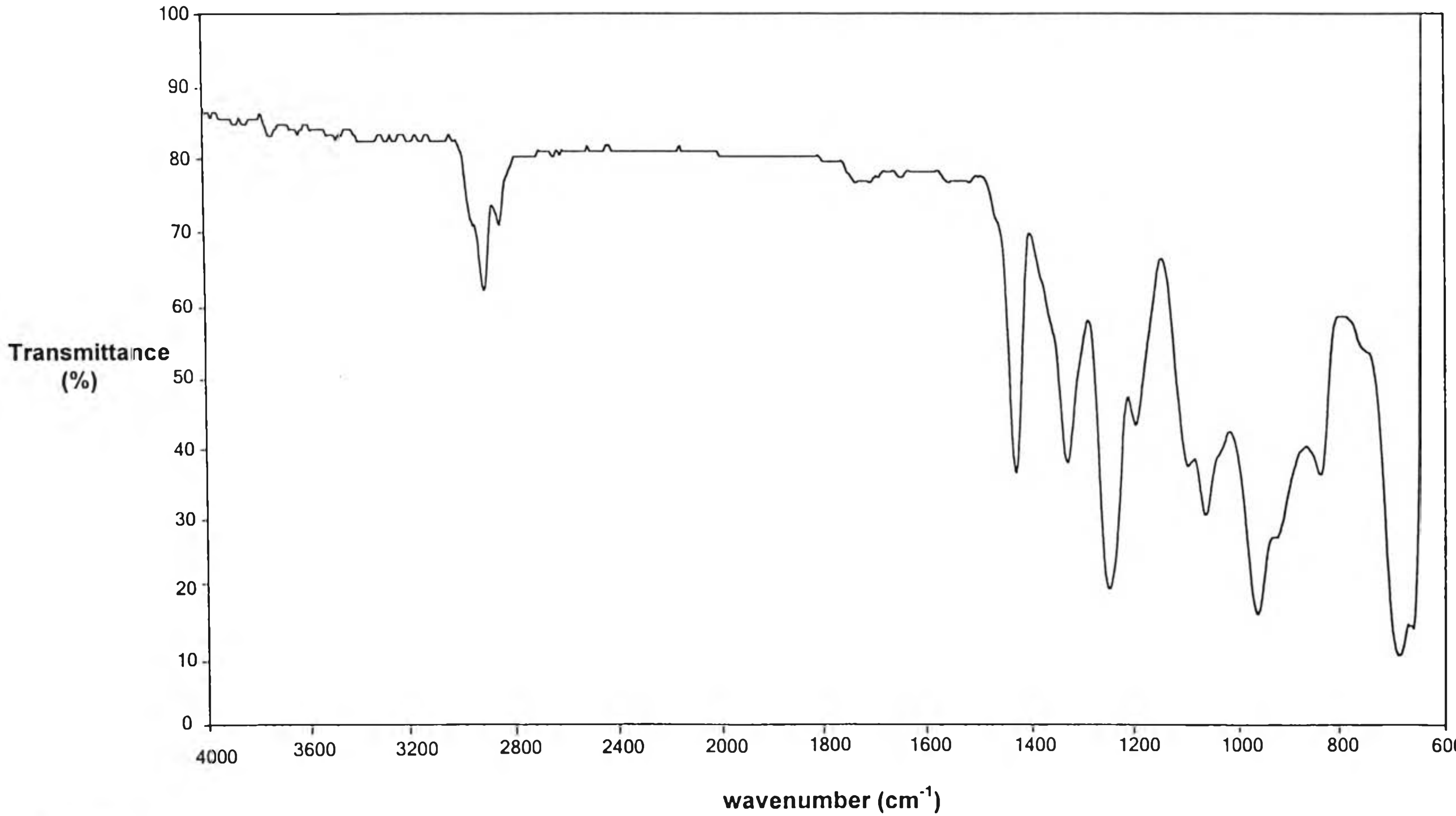

Figure D-2 FT-IR spectrum (transmission) of Poly(vinyl chloride)

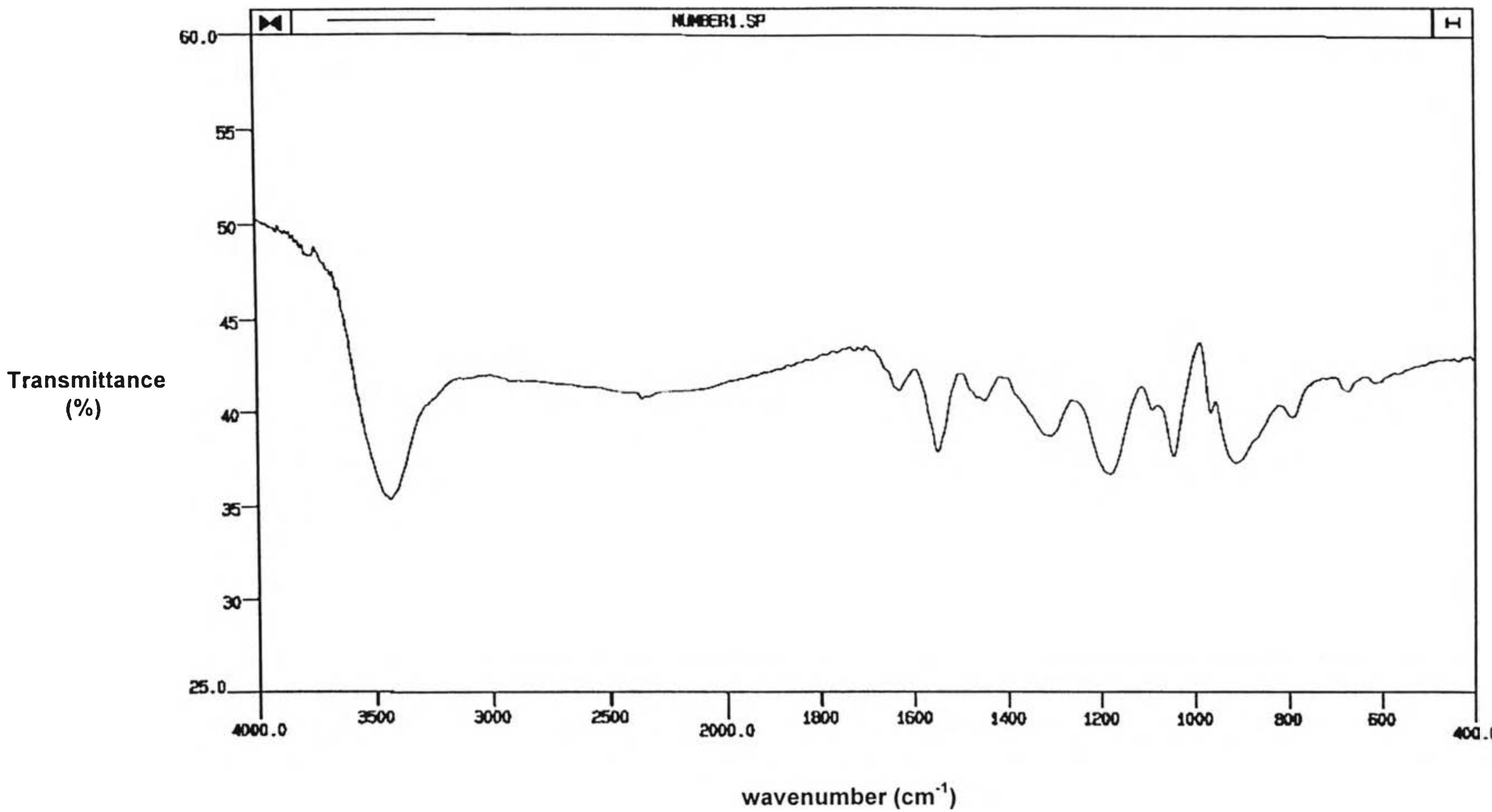

Figure D-3 FT-IR spectrum (transmission) of pure polypyrrole

VITA

Mr. Somchoke Lauhasurayotin was born on November 9, 1973 in Bangkok, Thailand. He received Bachelor of Science degree in Chemistry from Kasetsart University in 1995. He started his Master's degree at Chulalongkorn University with the program of Petrochemistry and Polymer Science in 1996 and then finished his graduate study in 1999.