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# APPENDICES

## APENDIX A Properties and Toxicity Data of Sulfur Dioxide ( $SO_2$ )

**Physical Properties**

| | |
|---|---|
| Color | : Colorless |
| Boiling point | : -10 °C |
| Melting point | : -75.5 °C |
| Solubility | : 10 g / 100 mL in water at 20 °C |

**Odor** : Pungent odor detectable at 0.3 to 5 ppm

**Vapor Density** : 2.26 ( air = 1.0 )

**Vapor Pressure** : 1779 mmHg at 21 °C

**Flash Point** : Noncombustible

**Toxicity Data***

| | |
|---|---|
| LC inhal (rat) | : 2520 ppm (6590 mg / $m^3$, 1 hour) |
| LC inhal (human) | : 1000 ppm (2600 mg / $m^3$, 10 minutes) |
| PEL (OSHA) | : 5 ppm (13 mg / $m^3$) |
| TLV-TWA (ACGIH) | : 2 ppm (5.2 mg / $m^3$) |
| STEL (ACGIH) | : 5 ppm (13 mg / $m^3$) |

**Major Hazards**

- Intensity irritating to the skin, eyes and respiratory tract; moderate acute toxicity.
- Inhalation of high concentrations may cause death as a result of respiratory paralysis and pulmonary edema.
- Exposure to 400 to 500 ppm is immediately dangerous, and 1000 ppm for 10 minutes is reported to have caused death in humans.
- Exposure to concentrations of 10 to 50 ppm for 5 to 15 minutes causes irritation of the eyes, nose and throat, choking and coughing.

**Flammability and Explosibility** : Noncombustible

**Reactivity and Incompatibility** : Contact to some powdered metals and with alkali metals such as sodium or potassium may cause fires and explosions. Liquid sulfur dioxide will attack some forms of plastics, rubber and coatings.

* <u>Note</u>

1. **LC inhal : Limit concentration** = the atmospheric concentration which results in 50 % death.
2. **PEL (OSHA) : Permissible Exposure Limits** = the maximum allowable concentrations of US. Occupational Safety and Health Administration.

3. **TLV-TWA (ACGIH) : Threshold limit value - Time weight average** = the allowable concentration that permitted to work within 8 h from The American Conference of Governmental Industrial Hygienists.
4. **STEL ( ACGIH ) : Short Time Exposure limit** = the allowable concentration that permitted to work and break every 15 min from The American Conference of Governmental Industrial Hygienists.

## APPENDIX B Determination of Geometric Correction Factor ( K )

Geometric correction factor (K) is a correction factor that takes into account of geometric effects. It depends on the configuration and probe tip spacing. K factor can be determined by comparing the specific resistivity of standard material detected from the constructed four-point probe detector with the specific resistivity from chemical handbook.

In this experiment, the standard materials that we used were copper sheets and aluminium sheets. Sheet resistivities of these materials were measured by using the four-point probe detector. The geometric correction factor was computed from Equation B-1 and shown in Table B-1 :

$$K = \frac{\rho_{ref}}{R_S \times t} \qquad \text{(B-1)}$$

where

| | | |
|---|---|---|
| $K$ | = | Geometric correction factor |
| $\rho_{ref}$ | = | known resistivity from the chemical handbook ($\Omega$.cm) |
| $R_S$ | = | sheet resistivity ($\Omega$) |
| $t$ | = | sheet thickness (cm) |

**Table B-1 Data of K factor determination**

| Material | $\rho_{real}$ ($\Omega$.cm) | $R_s$ ($\Omega$) | t (cm) | $R_s \times t$ ($\Omega$.cm) | K |
|---|---|---|---|---|---|
| Copper | $1.678\times10^{-6}$ | 0.06707 | $127\times10^{-4}$ | $8.518\times10^{-4}$ | $1.97\times10^{-3}$ |
| Copper | $1.678\times10^{-6}$ | 0.07500 | $127\times10^{-4}$ | $9.525\times10^{-4}$ | $1.92\times10^{-3}$ |
| Aluminium | $2.650\times10^{-6}$ | 0.01545 | 0.09 | $1.395\times10^{-3}$ | $1.89\times10^{-3}$ |
| Aluminium | $2.650\times10^{-6}$ | 0.1460 | 0.01 | $1.460\times10^{-3}$ | $1.82\times10^{-3}$ |
| | | | | **$K_{avg}$** | **$1.86\times10^{-3}$** |

In our experiment, we found that we have to multiply the specific resistivity of polypyrrole films measured from the Four-Point Probe system by $1.86\times10^{-3}$ to get the correct specific resistivity.

## APPENDIX C Calculation of Atom Mole Ratios from Elemental Analyzer of DBSA-doped Polypyrrole

The weigh percents of C, H, N, and S in the DBSA-doped polypyrrole prepared by using various DBSA concentration were determined by element analyzer. Raw data and the resulting doping levels were calculated by using Equation 2.1 and are shown in Table C-1

**Table C-1 Raw data from element analyzer and the resulting doping level**

| [DBSA] ( M) | Weigh (%) | | | | doping level (%) |
|---|---|---|---|---|---|
| | C | H | N | S | |
| 0.12 | 61.95 | 7.60 | 8.70 | 4.74 | **23.79** |
| 0.15 | 63.48 | 7.89 | 8.55 | 5.09 | **26.00** |
| 0.20 | 65.37 | 8.27 | 8.35 | 5.45 | **28.50** |
| 0.25 | 68.24 | 8.59 | 8.47 | 5.81 | **29.95** |
| 0.30 | 64.64 | 8.31 | 7.23 | 5.91 | **35.70** |
| 0.35 | 64.10 | 8.24 | 7.04 | 5.93 | **36.78** |
| 0.40 | 63.36 | 8.22 | 6.49 | 6.09 | **40.98** |
| 0.45 | 65.84 | 8.63 | 5.99 | 6.72 | **48.99** |

The atom mole ratios of C, H, N, S and O in DBSA-doped polypyrrole can be used to roughly indicate the chemical structure. The C, H, N, S and O mole ratios of 0.12 M DBSA-doped polypyrrole, for example, were calculated as followed :

1. The oxygen content was determined by difference with weight of C, H, N and S obtained from the elemental analysis.

$$O = 100 - 61.95 - 7.60 - 8.70 - 4.74 = 17.01 \%$$

2. Mole ratio of each element was computed by dividing the weigh ratio by each molecular weight.

| | | |
|---|---|---|
| C | = 61.95 / 12 | = 5.163 mole |
| H | = 7.60 / 1.008 | = 7.540 mole |
| N | = 8.70 / 14 | = 0.621 mole |
| S | = 8.70 / 32.06 | = 0.148 mole |
| O | = 17.01 / 32.06 | = 1.063 mole |

3. Because each pyrrole ring contains one N atom, the mole ratio of each element was normalized with one N atom. This means that mole ratio of each element was divided by mole ratio of N.

| | | |
|---|---|---|
| C | = 5.163 / 0.621 | = 8.307 |
| H | = 7.540 / 0.621 | = 12.133 |
| N | = 0.621 / 0.621 | = 1.000 |
| S | = 0.148 / 0.621 | = 0.238 |
| O | = 1.063 / 0.621 | = 1.711 |

4. Because the dopant that used in this work was DBSA ($C_{18}H_{29}O_3S$) and the %doping level of 0.12 M DBSA-doped polypyrrole is 23.79 %, so $(C_{18}H_{29}O_3S)_{0.238}$ should be presented. The atom mole ratios of C, H, O and S in DBSA anions that compensated the polypyrrole chains were calculated as followed :

C = 8.307 - (mole of C contained in pyrrole ring)

= 8.307 - 4 = 4.037

H = doping level × 29

= 0.238 × 29 = 6.900

S = doping level = 0.238

O = doping level × 3

5. Finally, the mole ratios of C, H and N in a pyrrole ring were

$$C = 4$$

$$H = 12.133 - (\text{mole of H contained in DBSA})$$

$$= 12.133 - 6.900 = 5.233$$

$$N = 1$$

The atom mole ratio of other doping level DBSA-doped polypyrrole was calculated as described above and the results are shown in Table 3.1.

## APPENDIX D Electrical Property Data

### D-1 Effect of Aging Time

Sample : 0.15 M - 0.40 M DBSA-doped polypyrrole films

Testing conditions : Applied current = 2.7 μA

Testing temperature = 18 $^{o}C$

Atmosphere = 1 atm $N_2$

**Table D-1 Effect of aging time on the specific conductivity for the DBSA-doped polypyrrole with various DBSA concentrations (Figure 3.8)**

| no. of days stored | $\sigma_{dc}$ (S/cm) | | | | | |
|---|---|---|---|---|---|---|
| | 0.15 M DBSA | 0.20 M DBSA | 0.25 M DBSA | 0.30 M DBSA | 0.35 M DBSA | 0.40 M DBSA |
| 1 | 0.2549 | 0.3027 | 0.6266 | 0.9797 | 1.4381 | 1.4707 |
| 2 | 0.2891 | 0.2734 | 0.3097 | 0.9690 | 1.6774 | 1.6933 |
| 3 | 0.2967 | 0.2536 | 0.5833 | 1.2401 | 1.5406 | 1.4922 |
| 5 | 0.2461 | 0.5067 | 0.6836 | 1.1399 | 1.4519 | 1.3299 |
| 8 | 0.2258 | 0.6009 | 0.5396 | 1.3396 | 1.6212 | 1.1480 |
| 10 | 0.2870 | 0.6655 | 0.8858 | 1.3262 | 1.8432 | 1.5720 |
| 15 | 0.3050 | 0.7038 | 0.8769 | 1.4468 | 1.7793 | 1.6570 |
| 20 | 0.3579 | 0.8391 | 1.0976 | 1.6719 | 1.5557 | 1.4643 |
| 25 | 0.4748 | 0.8931 | 1.3536 | 1.7362 | 1.9194 | 1.8032 |
| 30 | 0.5437 | 0.9377 | 1.4809 | 1.8350 | 1.9991 | 1.9267 |
| 35 | 0.6721 | 0.9467 | 1.5716 | 1.9494 | 1.9817 | 2.0987 |

| no. of days stored | $\sigma_{dc}$ (S/cm) | | | | | |
|---|---|---|---|---|---|---|
| | **0.15 M DBSA** | **0.20 M DBSA** | **0.25 M DBSA** | **0.30 M DBSA** | **0.35 M DBSA** | **0.40 M DBSA** |
| 40 | 0.6752 | 0.9558 | 1.6075 | 1.9291 | 1.9782 | 1.9947 |
| 50 | 0.6826 | 1.0820 | 1.6105 | 1.9798 | 2.0387 | 2.0292 |
| 60 | 0.6938 | 1.0927 | 1.6273 | 2.0209 | 2.1335 | 2.1222 |
| 70 | 0.7047 | 1.1007 | 1.6327 | 2.0457 | 2.1243 | 2.2020 |

**D-2 Statistical Test**

Sample : 0.30 M DBSA-doped polypyrrole films Batch 1 and Batch 2

Testing conditions : Applied current = 2.7 μA

Testing temperature = 18 $^oC$

Atmosphere = 1 atm $N_2$

**Table D-2 X-bar charts of the specific conductivity for 0.30 M DBSA-doped polypyrrole at 18 $^oC$ (Figure 3.9)**

| Sample No. | $\sigma_{dc}$ (S/cm) | |
|---|---|---|
| | **Batch 1** | **Batch 2** |
| 1 | 2.0795 | 1.9372 |
| 2 | 2.0880 | 1.9472 |
| 3 | 2.0694 | 1.9759 |
| 4 | 2.0941 | 1.9890 |
| 5 | 1.9698 | 2.0639 |
| 6 | 2.0631 | 2.0553 |
| 7 | 1.9925 | 1.9627 |
| 8 | 1.9617 | 2.0618 |
| 9 | 2.0796 | 1.9445 |
| 10 | 2.0815 | 2.0117 |
| **Mean** | **2.0479** | **1.9949** |
| **SD.** | **0.0518** | **0.0502** |
| **Control limit (Mean ± SD.)** | **1.9961 - 2.0997** | **1.9447 - 2.0451** |
| **Specification (Mean ± 3 SD.)** | **1.8925 - 2.2033** | **1.8443 - 2.1455** |
| **%CV (SD. × 100 / Mean )** | **2.53** | **2.52** |

## D-3 Effect of Applied Current

Sample : 0.15 M - 0.30 M DBSA-doped polypyrrole films

Testing conditions : Applied current = 0.5 - 2.7 μA

Testing temperature = 18 $^{o}C$

Atmosphere = 1 atm $N_2$

**Table D-3 Effect of the applied current on the specific conductivity of the DBSA-doped polypyrrole films at 18 $^{0}C$ (Figure 3.10)**

| Applied current (μm) | $\sigma_{dc}$ (S/cm) | | | | | |
|---|---|---|---|---|---|---|
| | 0.15 M DBSA | 0.30 M DBSA | | | | 0.40 M DBSA |
| | | 1st | 2nd | Mean | SD. | |
| 0.5 | 0.6368 | 1.8668 | 1.9001 | 1.8834 | 0.0235 | 1.8668 |
| 1.0 | 0.6483 | 1.9007 | 1.8997 | 1.9002 | 0.0007 | 1.9007 |
| 1.5 | 0.6608 | 1.9290 | 1.9005 | 1.9249 | 0.0345 | 1.9290 |
| 2.0 | 0.6701 | 1.9493 | 1.9213 | 1.9353 | 0.0197 | 1.9493 |
| 2.5 | 0.6734 | 1.9258 | 1.9165 | 1.9211 | 0.0066 | 1.8917 |
| 2.7 | 0.6778 | 1.9867 | 1.9542 | 1.9758 | 0.0188 | 1.9867 |

## D-4 Effect of Dopant Concentration

Sample : 0.15 M - 0.40 M DBSA-doped polypyrrole films

Testing conditions : Applied current = 2.7 μA

Testing temperature = 18 °C

Atmosphere = 1 atm $N_2$

**Table D-4 Effect of DBSA concentration on the specific conductivity of the DBSA-doped polypyrrole films at 18 °C (Figure 3.11)**

| [DBSA] (M) | $\sigma_{dc}$ (S/cm) | | | |
|---|---|---|---|---|
| | 1st | 2nd | Mean | S.D. |
| 0.15 | 0.6701 | 0.6766 | 0.6734 | 0.0046 |
| 0.20 | 1.0165 | 0.8489 | 0.9327 | 0.1185 |
| 0.25 | 1.6244 | 1.4157 | 1.5201 | 0.1475 |
| 0.30 | 1.9337 | 1.7632 | 1.8485 | 0.1205 |
| 0.35 | 1.9806 | 1.9006 | 1.9406 | 0.0565 |
| 0.40 | 2.0696 | 1.9580 | 2.0138 | 0.0789 |

## D-5 Effect of Testing Temperature

Sample : 0.14 M - 0.40 M DBSA-doped polypyrrole films

Testing conditions : Applied current = 2.7 μA

Testing temperature = 18 °C - 70 °C

Atmosphere = 1 atm $N_2$

**Table D-5 Plot of $\sigma_{dc}$ *versus* T for the DBSA-doped polypyrrole with various DBSA concentrations (Figure 3.12)**

| Temp. (°C) | $\sigma_{dc}$ (S/cm) | | | | | | |
|---|---|---|---|---|---|---|---|
| | **0.14 M DBSA** | **0.15 M DBSA** | **0.20 M DBSA** | **0.25 M DBSA** | **0.30 M DBSA** | **0.35 M DBSA** | **0.40 M DBSA** |
| 18 | 0.6325 | 0.6124 | 0.8492 | 1.4145 | 1.6683 | 1.9029 | 2.0043 |
| 19 | 0.6528 | 0.6226 | 0.8492 | 1.4125 | 1.7011 | 1.9137 | 1.9615 |
| 20 | 0.6389 | 0.6230 | 0.8626 | 1.4189 | 1.6565 | 1.9131 | 1.9100 |
| 20 | 0.6752 | 0.6614 | 0.7802 | 1.3733 | 1.7272 | 1.8556 | 1.9808 |
| Mean | 0.6570 | 0.6422 | 0.8214 | 1.3961 | 1.6918 | 1.8843 | 1.9454 |
| S.D. | 0.0256 | 0.0271 | 0.0583 | 0.0322 | 0.0500 | 0.0406 | 0.0501 |
| 21 | 0.6423 | 0.6594 | 0.8688 | 1.4233 | 1.6603 | 1.9363 | 1.9484 |
| 22 | 0.6408 | 0.6652 | 0.8688 | 1.4277 | 1.6775 | 1.9325 | 1.9533 |
| 23 | 0.6349 | 0.6528 | 0.8752 | 1.4321 | 1.7033 | 1.9674 | 1.9597 |
| 24 | 0.6295 | 0.6491 | 0.8821 | 1.4409 | 1.7247 | 2.0121 | 1.9726 |
| 25 | 0.6054 | 0.6331 | 0.8893 | 1.4454 | 1.7478 | 2.0068 | 1.9842 |
| 25 | 0.6517 | 0.5991 | | | | | |
| Mean | 0.6285 | 0.6161 | | | | | |
| S.D. | 0.0327 | 0.0240 | | | | | |
| 26 | 0.6370 | 0.6288 | 0.8854 | 1.4518 | 1.7324 | 1.9873 | 1.9921 |
| 27 | 0.6328 | 0.6134 | 0.9009 | 1.4583 | 1.7704 | 2.0671 | 2.0017 |
| 28 | 0.6248 | 0.6075 | 0.9051 | 1.4648 | 1.7778 | 2.0296 | 2.0348 |
| 29 | 0.6265 | 0.5932 | 0.9175 | 1.4739 | 1.8156 | 2.0121 | 2.0365 |

| Temp. (°C) | $\sigma_{dc}$ (S/cm) | | | | | | |
|---|---|---|---|---|---|---|---|
| | **0.14 M DBSA** | **0.15 M DBSA** | **0.20 M DBSA** | **0.25 M DBSA** | **0.30 M DBSA** | **0.35 M DBSA** | **0.40 M DBSA** |
| 30 | 0.6368 | 0.5697 | 0.9356 | 1.5046 | 1.7895 | 1.9960 | 2.0312 |
| 30 | 0.6108 | 0.5278 | 1.0122 | 1.4474 | 1.9037 | 2.1015 | 1.9354 |
| Mean | 0.6238 | 0.5487 | 1.0189 | 1.4760 | 1.8466 | 2.0487 | 1.9833 |
| S.D. | 0.0184 | 0.0296 | 0.1178 | 0.0404 | 0.0807 | 0.0746 | 0.0677 |
| 31 | 0.6116 | 0.5548 | 0.9366 | 1.4988 | 1.8219 | 2.0224 | 2.0212 |
| 32 | 0.6134 | 0.5385 | 0.9377 | 1.5067 | 1.8640 | 2.0171 | 2.0305 |
| 33 | 0.6053 | 0.5356 | 0.9618 | 1.5199 | 1.8589 | 2.0516 | 2.0394 |
| 34 | 0.6098 | 0.5375 | 0.9790 | 1.5222 | 1.8940 | 2.0607 | 2.0406 |
| 35 | 0.6325 | 0.5338 | 0.9896 | 1.5247 | 1.9000 | 2.0210 | 2.0755 |
| 35 | 0.6156 | 0.5705 | | | | | |
| Mean | 0.6240 | 0.5521 | | | | | |
| S.D. | 0.0119 | 0.0259 | | | | | |
| 36 | 0.6277 | 0.5676 | 1.0171 | 1.5445 | 1.9177 | 2.0866 | 2.1136 |
| 37 | 0.6391 | 0.5725 | 1.0285 | 1.5532 | 1.9347 | 2.0665 | 2.1222 |
| 38 | 0.6313 | 0.5855 | 1.0344 | 1.5688 | 1.9457 | 2.1349 | 2.1222 |
| 39 | 0.6362 | 0.6037 | 1.0344 | 1.5732 | 1.9677 | 2.1429 | 2.1066 |
| 40 | 0.6349 | 0.5637 | 1.0462 | 1.6137 | 1.9454 | 2.1091 | 1.9848 |
| 40 | 0.6569 | 0.6146 | 1.1614 | 1.5246 | 2.1253 | 2.2031 | 2.1513 |
| Mean | 0.6459 | 0.5891 | 1.1038 | 1.5691 | 2.0353 | 2.1561 | 2.0680 |
| S.D. | 0.0156 | 0.0360 | 0.0815 | 0.0630 | 0.1272 | 0.0665 | 0.1177 |
| 41 | 0.6408 | 0.6208 | 1.0583 | 1.6128 | 1.9020 | 2.0792 | 2.1645 |
| 42 | 0.6479 | 0.6362 | 1.0583 | 1.6369 | 2.0045 | 2.1757 | 2.1807 |
| 43 | 0.6566 | 0.6453 | 1.0891 | 1.6409 | 2.0143 | 2.1757 | 2.1615 |
| 44 | 0.6611 | 0.6513 | 1.0958 | 1.6574 | 2.0255 | 2.1837 | 2.1671 |
| 45 | 0.6679 | 0.6561 | 1.0953 | 1.6638 | 2.0599 | 2.1645 | 2.2233 |
| 46 | 0.6791 | 0.6697 | 1.1164 | 1.6870 | 2.0645 | 2.1462 | 2.2486 |
| 47 | 0.6778 | 0.6688 | 1.1164 | 1.6713 | 2.0762 | 2.1669 | 2.2647 |
| 48 | 0.6713 | 0.6939 | 1.1164 | 1.6824 | 2.0853 | 2.2059 | 2.2612 |

| Temp. (°C) | $\sigma_{dc}$ (S/cm) | | | | | | |
|---|---|---|---|---|---|---|---|
| | **0.14 M DBSA** | **0.15 M DBSA** | **0.20 M DBSA** | **0.25 M DBSA** | **0.30 M DBSA** | **0.35 M DBSA** | **0.40 M DBSA** |
| 49 | 0.6645 | 0.6875 | 1.1330 | 1.7023 | 2.1089 | 2.2457 | 2.3107 |
| 50 | 0.6538 | 0.6395 | 1.1164 | 1.6758 | 2.0787 | 2.2736 | 2.2072 |
| 50 | 0.6938 | 0.6997 | 1.2343 | 1.7577 | 2.2468 | 2.3847 | 2.3107 |
| Mean | 0.6738 | 0.6696 | 1.1753 | 1.7167 | 2.1627 | 2.3291 | 2.2589 |
| S.D. | 0.0283 | 0.0426 | 0.0834 | 0.0579 | 0.1189 | 0.0786 | 0.0517 |
| 51 | 0.6756 | 0.7072 | 1.1257 | 1.7520 | 2.2179 | 2.2781 | 2.3446 |
| 52 | 0.6835 | 0.7023 | 1.1359 | 1.7777 | 2.1702 | 2.2848 | 2.3807 |
| 53 | 0.6801 | 0.7032 | 1.1482 | 1.8061 | 2.2352 | 2.2848 | 2.4317 |
| 54 | 0.6926 | 0.7164 | 1.1482 | 1.7885 | 2.1970 | 2.3102 | 2.3628 |
| 55 | 0.7003 | 0.7219 | 1.1751 | 1.7761 | 2.2343 | 2.3494 | 2.3769 |
| 56 | 0.7062 | 0.7168 | 1.1777 | 1.7862 | 2.2776 | 2.3698 | 2.3961 |
| 57 | 0.7199 | 0.7165 | 1.1942 | 1.8091 | 2.2695 | 2.3511 | 2.3721 |
| 58 | 0.7010 | 0.7123 | 1.1937 | 1.8297 | 2.2763 | 2.3928 | 2.3970 |
| 59 | 0.7003 | 0.7138 | 1.2318 | 1.8369 | 2.3076 | 2.4294 | 2.3686 |
| 60 | 0.6977 | 0.7608 | 1.2120 | 1.8403 | 2.2128 | 2.4389 | 2.2430 |
| 60 | 0.7319 | 0.7205 | 1.4044 | 1.7040 | 2.6199 | 2.5141 | 2.3966 |
| Mean | 0.7148 | 0.7406 | 1.3082 | 1.7721 | 2.4163 | 2.4765 | 2.3198 |
| S.D. | 0.0242 | 0.0285 | 0.1360 | 0.0964 | 0.2879 | 0.0532 | 0.1086 |
| 61 | 0.7203 | 0.7211 | 1.2758 | 1.8566 | 2.3487 | | 2.4502 |
| 62 | 0.7218 | 0.7331 | 1.2318 | 1.8565 | 2.3641 | | 2.4563 |
| 63 | 0.7218 | 0.7350 | 1.2758 | 1.8674 | 2.3842 | | 2.3961 |
| 64 | 0.7245 | 0.7368 | 1.3024 | 1.8259 | 2.3877 | | 2.4133 |
| 65 | 0.7273 | 0.7387 | 1.3396 | 1.8316 | 2.3850 | | 2.4647 |
| 66 | 0.7186 | 0.7289 | 1.4034 | 1.8642 | 2.4222 | | 2.4876 |
| 67 | 0.7214 | 0.7351 | 1.4353 | 1.8854 | 2.4520 | | 2.4920 |
| 68 | 0.7242 | 0.7236 | | | 2.5033 | | 2.4839 |
| 69 | 0.7153 | 0.7174 | | | | | 2.5089 |
| 70 | 0.7153 | 0.7174 | | | | | 2.3180 |

## D-6 Effect of Exposure Time to $SO_2$

Sample : 0.15 M - 0.35 M DBSA-doped polypyrrole films

Testing conditions : Applied current = 2.7 μA

Testing temperature = 18 $^{o}C$

Atmosphere = 2500ppm $SO_2$

**Table D-6 Effect of exposure time to 2500 ppm $SO_2$ at 18 $^{o}C$ for DBSA-doped polypyrrole films with various DBSA concentrations (Figure 3.17)**

| Time. (min) | $\sigma_{dc}$ (S/cm) | | | | |
|---|---|---|---|---|---|
| | **0.15 M DBSA** | **0.20 M DBSA** | **0.25 M DBSA** | **0.30 M DBSA** | **0.35 M DBSA** |
| -3 | 0.6617 | 0.8492 | 1.6293 | 1.9337 | 1.9653 |
| -2 | 0.6650 | 0.8492 | 1.6305 | 1.9157 | 1.9674 |
| -1 | 0.6650 | 0.8489 | 1.6318 | 1.9114 | 1.9759 |
| 0 | 0.6659 | 0.8489 | 1.6338 | 1.9198 | 1.9759 |
| 0.5 | 0.7684 | 1.0149 | 2.1978 | 2.2787 | 2.5892 |
| 1 | 0.8030 | 1.1053 | 2.2224 | 2.3240 | 2.7810 |
| 2 | 0.8699 | 1.1456 | 2.3457 | 2.4484 | 2.8444 |
| 3 | 0.8913 | 1.2042 | 2.3913 | 2.4917 | 2.9445 |
| 4 | 0.9120 | 1.2202 | 2.4426 | 2.6286 | 3.0707 |
| 5 | 0.9201 | 1.2525 | 2.4965 | 2.6869 | 3.2717 |
| 6 | 0.9354 | 1.3083 | 2.5528 | 2.7341 | 3.3182 |
| 7 | 0.9550 | 1.3396 | 2.5828 | 2.7806 | 3.4324 |
| 8 | 0.9757 | 1.4052 | 2.6278 | 2.8258 | 3.4993 |
| 9 | 0.9812 | 1.4554 | 2.7750 | 2.9161 | 3.7239 |
| 10 | 0.9967 | 1.5086 | 2.8531 | 2.9388 | 3.9809 |

| Time. (min) | $\sigma_{dc}$ (S/cm) | | | | |
|---|---|---|---|---|---|
| | **0.15 M DBSA** | **0.20 M DBSA** | **0.25 M DBSA** | **0.30 M DBSA** | **0.35 M DBSA** |
| 11 | 1.0230 | 1.5739 | 2.8871 | 2.9840 | 3.9836 |
| 12 | 1.0506 | 1.5629 | 2.8785 | 3.0759 | 4.0042 |
| 13 | 1.0605 | 1.6030 | 2.8731 | 3.1215 | 4.0437 |
| 14 | 1.0628 | 1.6494 | 2.8871 | 3.1442 | 4.0053 |
| 15 | 1.0926 | 1.6796 | 2.9132 | 3.1670 | 3.9889 |
| 16 | 1.1117 | 1.7110 | 2.9108 | 3.2126 | 4.0063 |
| 17 | 1.1363 | 1.7272 | 2.9432 | 3.2749 | 4.0242 |
| 18 | 1.1747 | 1.7604 | 2.9755 | 3.2974 | 3.9371 |
| 19 | 1.1916 | 1.7775 | 3.0079 | 3.3086 | 3.9618 |
| 20 | 1.2141 | 1.7949 | 3.0483 | 3.3198 | 3.9923 |
| 21 | 1.2191 | 1.7862 | 3.0833 | 3.3165 | 3.9367 |
| 22 | 1.2233 | 1.7949 | 3.0726 | 3.3165 | 4.0569 |
| 23 | 1.2641 | 1.8042 | 3.0726 | 3.3833 | 4.0091 |
| 24 | 1.3034 | 1.8226 | 3.0887 | 3.4056 | 4.0091 |
| 25 | 1.3261 | 1.8414 | 3.0984 | 3.4017 | 3.9957 |
| 26 | 1.3616 | 1.8332 | 3.1049 | 3.4237 | 3.9683 |
| 27 | 1.3864 | 1.8444 | 3.1049 | 3.4458 | 3.9421 |
| 28 | 1.4252 | 1.8478 | 3.0920 | 3.4679 | 3.9437 |
| 29 | 1.4312 | 1.9060 | 3.1049 | 3.4679 | 3.9312 |
| 30 | 1.4323 | 1.9218 | 3.1049 | 3.4900 | 3.9190 |
| 35 | 1.4453 | 1.9310 | 3.1114 | 3.5121 | 3.9453 |
| 40 | 1.4574 | 1.9438 | 3.1178 | 3.5342 | 3.9994 |

## D-7 Effect of $SO_2$ Concentration

Sample : 0.15 M - 0.35 M DBSA-doped polypyrrole films

Testing conditions : Applied current = 2.7 μA

Testing temperature = 18 °C

Atmosphere = 500 - 2500 ppm $SO_2$

**Table D-7 Effect of $SO_2$ concentration at 18 °C for DBSA-doped polypyrrole films with various DBSA concentrations (Figure 3.18)**

| $[SO_2]$ (ppm) | $\sigma_{dc}$ (S/cm) | | | | |
|---|---|---|---|---|---|
| | **0.15 M DBSA** | **0.20 M DBSA** | **0.25 M DBSA** | **0.30 M DBSA** | **0.35 M DBSA** |
| 0 | 0.6607 | 0.8659 | 1.6218 | 1.8894 | 1.9396 |
| 0 | 0.6735 | 0.8589 | 1.6338 | 1.8920 | 1.9577 |
| Mean | 0.6671 | 0.8624 | 1.6278 | 1.8907 | 1.943 |
| S.D. | 0.956 | 0.622 | 0.4886 | 0.6577 | 0.7579 |
| 500 | 1.2222 | 1.4101 | 2.4262 | 2.5216 | 2.4193 |
| 500 | | | 2.2030 | | 2.5193 |
| Mean | | | 2.3146 | | 2.4693 |
| S.D. | | | 0.1578 | | 0.0707 |
| 700 | 1.2829 | 1.4885 | 2.4278 | 2.6634 | 2.5329 |
| 1000 | 1.3780 | 1.5792 | 2.7536 | 2.7788 | 2.7307 |
| 1000 | 1.3206 | 1.6576 | 2.5268 | 2.9385 | 2.9809 |
| Mean | 1.3493 | 1.6184 | 2.6402 | 2.8586 | 2.007 |
| S.D. | 0.0406 | 0.533 | 0.582 | 0.6997 | 0.7673 |
| 1500 | 1.3971 | 1.6745 | 2.8462 | 2.8477 | 3.1911 |
| 1500 | | | | 3.1196 | |
| Mean | | | | 2.6536 | |
| S.D. | | | | 0.1922 | |

| $[SO_2]$ (ppm) | $\sigma_{dc}$ (S/cm) | | | | |
|---|---|---|---|---|---|
| | **0.15 M DBSA** | **0.20 M DBSA** | **0.25 M DBSA** | **0.30 M DBSA** | **0.35 M DBSA** |
| 2000 | 1.5466 | 1.7862 | 2.8831 | 3.2611 | 3.4735 |
| 2000 | 1.6918 | 1.9182 | 3.0887 | 3.4826 | 3.2577 |
| Mean | 1.6192 | 1.8522 | 2.9859 | 1.9433 | 2.0809 |
| S.D. | 0.642 | 0.5177 | 0.6868 | 0.7855 | 0.8724 |
| 2500 | 1.7338 | 1.9218 | 3.1049 | 3.4900 | 3.9190 |
| 2500 | | | 3.2274 | | 3.6559 |
| Mean | | | 3.1661 | | 3.7874 |
| S.D. | | | 0.0866 | | 0.1860 |

## D-7 Effect of Temperature in $SO_2$ Atmosphere

Sample : 0.15 M, 0.25 M and 0.35 M of DBSA-doped polypyrrole films

Testing conditions : Applied current = 2.7 μA

Testing temperature = 18 - 70 $^{o}C$

Atmosphere = 1000 ppm $SO_2$

**Table D-8 Effect of temperature in $SO_2$ atmosphere at 18 - 70 $^{o}C$ for DBSA-doped polypyrrole films with various DBSA concentrations (Figure 3.18)**

| T (°C) | $\sigma_{dc}$ (S/cm) | | |
|---|---|---|---|
| | **0.15 M DBSA** | **0.25 M DBSA** | **0.35 M DBSA** |
| 18 | 1.3480 | 2.5353 | 2.8307 |
| 20 | 1.4198 | 2.6536 | 2.8928 |
| 25 | 1.4715 | 2.7567 | 2.9862 |
| 30 | 1.4904 | 2.8585 | 3.0996 |
| 35 | 1.6041 | 2.9656 | 3.2561 |
| 40 | 1.7098 | 3.0030 | 3.3009 |
| 45 | 1.8381 | 3.1086 | 3.3743 |
| 50 | 1.9273 | 3.1803 | 3.4267 |
| 55 | 2.0070 | 3.1242 | 3.3223 |
| 60 | 2.0134 | 3.0094 | 3.2506 |
| 65 | 1.9300 | 2.9162 | 3.2303 |
| 70 | 1.8919 | 2.8386 | 3.1975 |

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