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# APPENDICES

## APPENDIX A Influence of concentration on fiber diameter

**Table A1** Diameter of electrospun PAN fiber (in nm) as a function of PAN concentration in DMF (Conditions for electrospinning process: applied voltage of +20 kV, collection distance of 15 cm, nozzle radius of 0.47 mm and stationary collection screen)

| No. of Fiber | Concentration of PAN solution in DMF (wt%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **4.0** | **5.9** | **7.8** | **9.5** | **11.2** | **12.9** | **14.4** | **15.9** | **17.4** |
| 1 | 56 | 81 | 102 | 151 | 339 | 297 | 273 | 382 | 773 |
| 2 | 90 | 102 | 166 | 143 | 243 | 310 | 307 | 339 | 730 |
| 3 | 79 | 100 | 88 | 285 | 270 | 254 | 328 | 386 | 680 |
| 4 | 66 | 100 | 140 | 236 | 189 | 289 | 340 | 397 | 819 |
| 5 | 66 | 134 | 130 | 186 | 242 | 301 | 336 | 419 | 832 |
| 6 | 53 | 98 | 172 | 191 | 269 | 314 | 302 | 426 | 796 |
| 7 | 72 | 107 | 145 | 151 | 265 | 408 | 320 | 394 | 738 |
| 8 | 66 | 107 | 114 | 129 | 230 | 288 | 345 | 302 | 670 |
| 9 | 63 | 100 | 107 | 158 | 203 | 352 | 260 | 461 | 676 |
| 10 | 78 | 106 | 106 | 182 | 251 | 339 | 328 | 404 | 837 |
| 11 | 51 | 112 | 134 | 180 | 229 | 306 | 395 | 316 | 745 |
| 12 | 58 | 92 | 158 | 167 | 189 | 314 | 316 | 392 | 661 |
| 13 | 61 | 88 | 139 | 205 | 219 | 351 | 334 | 392 | 732 |
| 14 | 49 | 100 | 114 | 138 | 170 | 322 | 350 | 426 | 731 |
| 15 | 66 | 86 | 136 | 191 | 237 | 317 | 313 | 432 | 771 |
| 16 | 86 | 92 | 151 | 252 | 209 | 400 | 268 | 416 | 737 |
| 17 | 19 | 72 | 204 | 176 | 221 | 352 | 313 | 462 | 657 |
| 18 | 72 | 97 | 196 | 282 | 247 | 334 | 330 | 417 | 650 |
| 19 | 47 | 95 | 170 | 151 | 216 | 355 | 326 | 396 | 789 |
| 20 | 68 | 108 | 130 | 271 | 220 | 334 | 314 | 420 | 742 |
| 21 | 55 | 122 | 122 | 267 | 226 | 346 | 334 | 439 | 733 |
| 22 | 75 | 75 | 158 | 175 | 226 | 329 | 319 | 406 | 850 |
| 23 | 106 | 103 | 151 | 179 | 216 | 288 | 340 | 426 | 733 |
| 24 | 74 | 88 | 156 | 238 | 145 | 293 | 282 | 367 | 757 |
| 25 | 70 | 88 | 132 | 143 | 195 | 292 | 305 | 425 | 694 |
| 26 | 43 | 92 | 188 | 221 | 246 | 278 | 344 | 426 | 738 |
| 27 | 37 | 97 | 137 | 168 | 230 | 311 | 381 | 378 | 814 |
| 28 | 69 | 74 | 184 | 112 | 277 | 366 | 358 | 463 | 856 |

Cont.....

Table A1 (Continued)

| No. of Fiber | Concentration of PAN solution in DMF (wt%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **4.0** | **5.9** | **7.8** | **9.5** | **11.2** | **12.9** | **14.4** | **15.9** | **17.4** |
| 29 | 44 | 50 | 295 | 156 | 160 | 378 | 284 | 444 | 811 |
| 30 | 79 | 81 | 155 | 216 | 208 | 322 | 325 | 365 | 726 |
| 31 | 64 | 56 | 139 | 188 | 315 | 215 | 370 | 389 | 647 |
| 32 | 67 | 67 | 149 | 147 | 246 | 334 | 303 | 346 | 714 |
| 33 | 83 | 81 | 127 | 186 | 178 | 341 | 370 | 394 | 662 |
| 34 | 44 | 93 | 198 | 178 | 252 | 325 | 337 | 396 | 717 |
| 35 | 71 | 100 | 149 | 223 | 232 | 286 | 320 | 442 | 776 |
| 36 | 107 | 88 | 130 | 213 | 243 | 208 | 320 | 391 | 826 |
| 37 | 112 | 106 | 119 | 150 | 177 | 271 | 315 | 393 | 676 |
| 38 | 59 | 72 | 126 | 139 | 480 | 272 | 361 | 398 | 847 |
| 39 | 71 | 101 | 140 | 57 | 346 | 282 | 329 | 420 | 691 |
| 40 | 74 | 92 | 130 | 176 | 386 | 311 | 290 | 390 | 698 |
| 41 | 78 | 113 | 114 | 139 | 368 | 272 | 298 | 417 | 626 |
| 42 | 83 | 76 | 155 | 128 | 407 | 310 | 309 | 417 | 786 |
| 43 | 71 | 71 | 166 | 184 | 385 | 285 | 374 | 432 | 664 |
| 44 | 67 | 71 | 145 | 88 | 437 | 305 | 291 | 445 | 642 |
| 45 | 72 | 108 | 144 | 273 | 349 | 261 | 294 | 428 | 766 |
| 46 | 50 | 103 | 213 | 146 | 303 | 314 | 325 | 441 | 676 |
| 47 | 53 | 83 | 161 | 151 | 168 | 364 | 193 | 372 | 876 |
| 48 | 89 | 96 | 135 | 170 | 224 | 330 | 341 | 410 | 772 |
| 49 | 69 | 83 | 124 | 176 | 108 | 302 | 323 | 410 | 713 |
| 50 | 90 | 103 | 135 | 160 | 241 | 323 | 298 | 418 | 741 |
| 51 | 69 | 113 | 158 | 175 | 235 | 294 | 299 | 397 | 722 |
| 52 | 101 | 97 | 145 | 221 | 310 | 351 | 388 | 374 | 655 |
| 53 | 75 | 63 | 182 | 194 | 245 | 300 | 482 | 389 | 713 |
| 54 | 80 | 101 | 223 | 168 | 254 | 311 | 321 | 426 | 695 |
| 55 | 67 | 107 | 92 | 204 | 200 | 372 | 340 | 418 | 778 |
| 56 | 67 | 106 | 132 | 168 | 235 | 322 | 280 | 407 | 697 |
| 57 | 80 | 107 | 126 | 135 | 247 | 336 | 365 | 372 | 709 |
| 58 | 48 | 106 | 196 | 210 | 196 | 286 | 406 | 429 | 754 |
| 59 | 71 | 94 | 115 | 179 | 257 | 267 | 336 | 477 | 631 |
| 60 | 64 | 92 | 109 | 177 | 321 | 396 | 340 | 467 | 705 |
| 61 | 84 | 98 | 128 | 169 | 240 | 331 | 332 | 373 | 639 |
| 62 | 88 | 92 | 133 | 183 | 266 | 326 | 338 | 378 | 637 |
| 63 | 67 | 88 | 186 | 232 | 273 | 378 | 309 | 432 | 752 |
| 64 | 69 | 88 | 124 | 314 | 218 | 236 | 371 | 363 | 639 |
| 65 | 80 | 72 | 135 | 124 | 212 | 321 | 356 | 468 | 758 |
| 66 | 67 | 95 | 148 | 172 | 235 | 352 | 333 | 387 | 748 |
| 67 | 64 | 108 | 321 | 271 | 211 | 300 | 354 | 416 | 837 |
| 68 | 63 | 97 | 243 | 153 | 241 | 357 | 354 | 415 | 825 |

Cont.....

Table A1 (Continued)

| No. of Fiber | Concentration of PAN solution in DMF (wt%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **4.0** | **5.9** | **7.8** | **9.5** | **11.2** | **12.9** | **14.4** | **15.9** | **17.4** |
| 69 | 76 | 102 | 146 | 202 | 209 | 348 | 322 | 413 | 692 |
| 70 | 64 | 77 | 143 | 188 | 196 | 217 | 305 | 396 | 771 |
| 71 | 88 | 80 | 133 | 155 | 271 | 308 | 332 | 395 | 764 |
| 72 | 76 | 120 | 126 | 151 | 262 | 311 | 325 | 375 | 784 |
| 73 | 59 | 100 | 107 | 230 | 208 | 283 | 317 | 393 | 735 |
| 74 | 75 | 102 | 132 | 178 | 166 | 283 | 362 | 423 | 650 |
| 75 | 59 | 92 | 142 | 98 | 126 | 385 | 329 | 438 | 709 |
| 76 | 52 | 121 | 141 | 107 | 253 | 358 | 350 | 444 | 710 |
| 77 | 64 | 108 | 158 | 177 | 219 | 362 | 400 | 398 | 679 |
| 78 | 62 | 133 | 109 | 149 | 275 | 264 | 326 | 404 | 767 |
| 79 | 83 | 97 | 134 | 157 | 211 | 342 | 345 | 385 | 720 |
| 80 | 80 | 101 | 146 | 64 | 188 | 303 | 322 | 384 | 723 |
| 81 | 52 | 148 | 145 | 159 | 171 | 404 | 280 | 415 | 788 |
| 82 | 80 | 110 | 107 | 166 | 229 | 226 | 369 | 435 | 692 |
| 83 | 64 | 106 | 151 | 275 | 200 | 329 | 360 | 404 | 733 |
| 84 | 69 | 94 | 217 | 155 | 268 | 303 | 392 | 443 | 589 |
| 85 | 71 | 92 | 93 | 237 | 208 | 373 | 295 | 396 | 684 |
| 86 | 64 | 97 | 149 | 142 | 232 | 310 | 359 | 405 | 723 |
| 87 | 79 | 137 | 117 | 173 | 230 | 266 | 295 | 439 | 597 |
| 88 | 59 | 87 | 93 | 267 | 260 | 325 | 324 | 372 | 792 |
| 89 | 56 | 127 | 161 | 115 | 241 | 375 | 253 | 406 | 886 |
| 90 | 59 | 87 | 151 | 141 | 247 | 306 | 304 | 400 | 592 |
| 91 | 57 | 122 | 151 | 155 | 228 | 309 | 342 | 388 | 739 |
| 92 | 63 | 89 | 158 | 129 | 202 | 242 | 342 | 423 | 705 |
| 93 | 71 | 94 | 144 | 145 | 349 | 388 | 376 | 376 | 771 |
| 94 | 71 | 95 | 126 | 216 | 198 | 314 | 299 | 390 | 695 |
| 95 | 56 | 100 | 188 | 320 | 193 | 373 | 315 | 417 | 651 |
| 96 | 67 | 88 | 141 | 277 | 243 | 311 | 344 | 372 | 814 |
| 97 | 80 | 102 | 158 | 179 | 305 | 302 | 411 | 406 | 737 |
| 98 | 82 | 95 | 145 | 151 | 220 | 302 | 345 | 392 | 703 |
| 99 | 82 | 87 | 144 | 196 | 203 | 297 | 482 | 401 | 779 |
| 100 | 67 | 100 | 213 | 204 | 215 | 350 | 319 | 340 | 773 |

**Table A2** Statistics of fiber diameter at various concentrations

| Statistics | Concentration of PAN solution in DMF (wt%) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | **4.0** | **5.9** | **7.8** | **9.5** | **11.2** | **12.9** | **14.4** | **15.9** | **17.4** |
| N Valid | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 | 100 |
| Missing | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 |
| Mean | 69 | 96 | 148 | 181 | 243 | 317 | 332 | 402 | 730 |
| Std.Error of Mean | 1.46 | 1.63 | 3.75 | 5.02 | 6.16 | 4.18 | 4.05 | 4.99 | 6.43 |
| Median | 68.50 | 97.00 | 143.50 | 175.50 | 232.00 | 312.50 | 328.50 | 404.50 | 730.50 |
| Mode | 67 | 92 | 158 | 151 | 208 | 311 | 340 | 426 | 676 |
| Std.Deviation | 14.60 | 16.32 | 37.54 | 50.18 | 61.58 | 41.75 | 40.51 | 49.92 | 64.29 |
| Variance | 213.2 | 266.4 | 1409.3 | 2518.5 | 3792.5 | 1743.4 | 1641.4 | 2491.9 | 4133.7 |
| Skewness | 0.062 | 0.170 | 1.864 | 0.532 | 1.317 | -0.170 | 0.656 | -5.030 | 0.157 |
| Std.Error of Skewness | 0.241 | 0.241 | 0.241 | 0.241 | 0.241 | 0.241 | 0.241 | 0.241 | 0.241 |
| Kurtosis | 1.528 | 1.264 | 5.698 | 0.559 | 2.790 | 0.167 | 3.630 | 38.749 | -0.286 |
| Std.Error of Kurtosis | 0.478 | 0.478 | 0.478 | 0.478 | 0.478 | 0.478 | 0.478 | 0.478 | 0.478 |
| Range | 93 | 98 | 233 | 263 | 372 | 200 | 289 | 468 | 297 |
| Minimum | 19 | 50 | 88 | 57 | 108 | 208 | 193 | 9 | 589 |
| Maximum | 112 | 148 | 321 | 320 | 480 | 408 | 482 | 477 | 886 |
| Sum | 6883 | 9624 | 14844 | 18079 | 24254 | 31656 | 33176 | 40210 | 72985 |
| a.Multiple modes exist. The smallest value is shown | | | | | | | | | |

## APPENDIX B Influence of applied voltage on fiber diameter

**Table B1** Diameter of electrospun PAN fiber (in nm) as a function of applied voltage.(Conditions for electrospinning process: PAN concentration of 9.5 wt%, collection distance of 15 cm, nozzle radius of 0.47 mm and stationary collection screen)

| No. of fiber | Applied voltage (kV) | | | | |
|---|---|---|---|---|---|
| | 10 | 15 | 20 | 25 | 30 |
| 1 | 120 | 163 | 203 | 195 | 170 |
| 2 | 127 | 146 | 153 | 107 | 165 |
| 3 | 126 | 151 | 186 | 203 | 213 |
| 4 | 140 | 172 | 198 | 183 | 179 |
| 5 | 174 | 163 | 158 | 241 | 152 |
| 6 | 108 | 177 | 195 | 211 | 202 |
| 7 | 115 | 146 | 217 | 196 | 269 |
| 8 | 92 | 171 | 141 | 188 | 180 |
| 9 | 125 | 140 | 181 | 237 | 238 |
| 10 | 138 | 158 | 181 | 211 | 137 |
| 11 | 115 | 146 | 203 | 323 | 234 |
| 12 | 125 | 139 | 183 | 232 | 182 |
| 13 | 155 | 160 | 155 | 211 | 258 |
| 14 | 118 | 146 | 151 | 205 | 195 |
| 15 | 151 | 172 | 130 | 192 | 214 |
| 16 | 118 | 153 | 79 | 177 | 166 |
| 17 | 150 | 163 | 162 | 199 | 147 |
| 18 | 155 | 190 | 83 | 151 | 151 |
| 19 | 151 | 151 | 192 | 173 | 213 |
| 20 | 145 | 147 | 238 | 199 | 155 |
| 21 | 135 | 169 | 202 | 181 | 202 |
| 22 | 138 | 169 | 151 | 232 | 232 |
| 23 | 150 | 182 | 221 | 219 | 153 |
| 24 | 142 | 177 | 198 | 156 | 213 |
| 25 | 133 | 175 | 127 | 251 | 239 |
| 26 | 119 | 167 | 179 | 209 | 182 |
| 27 | 115 | 167 | 153 | 184 | 239 |
| 28 | 150 | 160 | 220 | 245 | 188 |
| 29 | 139 | 199 | 170 | 225 | 178 |
| 30 | 144 | 183 | 248 | 184 | 143 |
| 31 | 103 | 161 | 214 | 290 | 138 |

Cont.....

Table B1 (Continued)

| No. of fiber | Applied voltage (kV) | | | | |
|---|---|---|---|---|---|
| | 10 | 15 | 20 | 25 | 30 |
| 32 | 107 | 139 | 195 | 208 | 186 |
| 33 | 161 | 150 | 232 | 189 | 204 |
| 34 | 144 | 192 | 133 | 217 | 202 |
| 35 | 149 | 216 | 247 | 212 | 204 |
| 36 | 151 | 246 | 213 | 203 | 148 |
| 37 | 128 | 161 | 171 | 163 | 175 |
| 38 | 143 | 237 | 188 | 183 | 230 |
| 39 | 122 | 169 | 219 | 271 | 179 |
| 40 | 165 | 153 | 184 | 186 | 191 |
| 41 | 153 | 166 | 204 | 197 | 178 |
| 42 | 160 | 159 | 198 | 203 | 182 |
| 43 | 128 | 166 | 134 | 273 | 160 |
| 44 | 134 | 175 | 220 | 219 | 266 |
| 45 | 124 | 161 | 150 | 211 | 375 |
| 46 | 130 | 153 | 219 | 173 | 255 |
| 47 | 115 | 163 | 155 | 194 | 166 |
| 48 | 169 | 139 | 179 | 198 | 218 |
| 49 | 150 | 145 | 211 | 224 | 190 |
| 50 | 124 | 158 | 230 | 192 | 230 |
| 51 | 234 | 146 | 269 | 233 | 213 |
| 52 | 114 | 158 | 213 | 256 | 194 |
| 53 | 149 | 143 | 204 | 139 | 204 |
| 54 | 144 | 151 | 194 | 194 | 336 |
| 55 | 159 | 153 | 167 | 224 | 202 |
| 56 | 103 | 189 | 226 | 263 | 221 |
| 57 | 133 | 155 | 261 | 196 | 191 |
| 58 | 127 | 183 | 213 | 213 | 178 |
| 59 | 142 | 149 | 232 | 175 | 151 |
| 60 | 144 | 151 | 257 | 193 | 206 |
| 61 | 153 | 143 | 221 | 213 | 135 |
| 62 | 140 | 141 | 191 | 188 | 169 |
| 63 | 153 | 166 | 257 | 204 | 177 |
| 64 | 103 | 180 | 288 | 238 | 195 |
| 65 | 105 | 168 | 179 | 179 | 196 |
| 66 | 155 | 166 | 189 | 244 | 179 |
| 67 | 113 | 205 | 238 | 207 | 222 |
| 68 | 127 | 117 | 84 | 271 | 214 |
| 69 | 129 | 173 | 189 | 197 | 207 |
| 70 | 148 | 183 | 179 | 237 | 171 |
| 71 | 123 | 194 | 181 | 196 | 246 |

Cont.....

Table B1 (Continued)

| No. of fiber | Applied voltage (kV) | | | | |
|---|---|---|---|---|---|
| | 10 | 15 | 20 | 25 | 30 |
| 72 | 130 | 192 | 179 | 163 | 226 |
| 73 | 130 | 196 | 180 | 246 | 321 |
| 74 | 118 | 149 | 221 | 176 | 201 |
| 75 | 122 | 158 | 198 | 186 | 227 |
| 76 | 150 | 158 | 189 | 188 | 190 |
| 77 | 149 | 130 | 186 | 217 | 143 |
| 78 | 109 | 156 | 240 | 230 | 188 |
| 79 | 132 | 173 | 114 | 131 | 230 |
| 80 | 153 | 168 | 124 | 189 | 200 |
| 81 | 106 | 176 | 208 | 182 | 209 |
| 82 | 112 | 158 | 184 | 206 | 288 |
| 83 | 126 | 268 | 161 | 234 | 205 |
| 84 | 112 | 167 | 213 | 188 | 168 |
| 85 | 161 | 167 | 211 | 163 | 194 |
| 86 | 136 | 174 | 156 | 199 | 183 |
| 87 | 130 | 133 | 158 | 169 | 211 |
| 88 | 139 | 169 | 213 | 246 | 243 |
| 89 | 144 | 145 | 196 | 204 | 185 |
| 90 | 135 | 213 | 179 | 195 | 149 |
| 91 | 133 | 195 | 163 | 182 | 211 |
| 92 | 115 | 188 | 188 | 143 | 184 |
| 93 | 115 | 151 | 185 | 196 | 149 |
| 94 | 132 | 151 | 250 | 238 | 202 |
| 95 | 145 | 159 | 213 | 202 | 199 |
| 96 | 148 | 155 | 179 | 182 | 235 |
| 97 | 125 | 153 | 214 | 242 | 228 |
| 98 | 145 | 160 | 204 | 202 | 211 |
| 99 | 124 | 145 | 207 | 158 | 157 |
| 100 | 125 | 176 | 208 | 175 | 117 |

**Table B2** Statistics of fiber diameter at various applied voltages

| Statistics | | Applied voltage (kV) | | | | |
|---|---|---|---|---|---|---|
| | | **10** | **15** | **20** | **25** | **30** |
| N | Valid | 100 | 100 | 100 | 100 | 100 |
| | Missing | 10 | 10 | 10 | 10 | 10 |
| Mean | | 134.72 | 166.08 | 191.07 | 204.18 | 199.27 |
| Std. Error of Mean | | 1.98 | 2.33 | 3.86 | 3.38 | 4.17 |
| Median | | 133.0 | 162.0 | 193.0 | 199.0 | 195.5 |
| Mode | | 115 | 151 | 179 | 188 | 202 |
| Std. Deviation | | 19.76 | 23.34 | 38.63 | 33.82 | 41.67 |
| Variance | | 390.43 | 544.92 | 1492.09 | 1143.89 | 1736.28 |
| Skewness | | 1.161 | 1.598 | -0.456 | 0.434 | 1.285 |
| Std. Error of Skewness | | 0.241 | 0.241 | 0.241 | 0.241 | 0.241 |
| Kurtosis | | 5.138 | 4.382 | 0.835 | 1.412 | 3.505 |
| Std. Error of Kurtosis | | 0.478 | 0.478 | 0.478 | 0.478 | 0.478 |
| Range | | 142 | 151 | 209 | 216 | 258 |
| Minimum | | 92 | 117 | 79 | 107 | 117 |
| Maximum | | 234 | 268 | 288 | 323 | 375 |
| Sum | | 13472 | 16608 | 19107 | 20418 | 19927 |
| a.Multiple modes exist. The smallest value is shown | | | | | | |

## APPENDIX C Influence of collection distance on fiber diameter

**Table C1** Diameter of electrospun PAN fiber (in nm) as a function of collection distance.(Conditions for electrospinning process: PAN solution concentration of 9.5 wt%, applied voltage of +30 kV, nozzle radius of 0.47 mm and stationary collection screen)

| No. of fiber | Collection distance (cm) | | | | |
|---|---|---|---|---|---|
| | 10 | 15 | 20 | 25 | 30 |
| 1 | 230 | 173 | 216 | 311 | 204 |
| 2 | 188 | 196 | 216 | 212 | 216 |
| 3 | 183 | 166 | 230 | 167 | 196 |
| 4 | 143 | 190 | 202 | 203 | 213 |
| 5 | 232 | 248 | 179 | 192 | 133 |
| 6 | 205 | 234 | 238 | 191 | 194 |
| 7 | 192 | 92 | 210 | 179 | 174 |
| 8 | 186 | 193 | 120 | 183 | 253 |
| 9 | 145 | 175 | 113 | 179 | 188 |
| 10 | 153 | 206 | 169 | 242 | 202 |
| 11 | 205 | 202 | 178 | 160 | 160 |
| 12 | 216 | 100 | 275 | 266 | 171 |
| 13 | 169 | 178 | 157 | 206 | 182 |
| 14 | 158 | 186 | 211 | 216 | 188 |
| 15 | 211 | 367 | 194 | 172 | 207 |
| 16 | 214 | 185 | 301 | 176 | 194 |
| 17 | 188 | 202 | 226 | 278 | 160 |
| 18 | 145 | 178 | 182 | 253 | 182 |
| 19 | 200 | 299 | 226 | 175 | 227 |
| 20 | 115 | 205 | 373 | 213 | 182 |
| 21 | 157 | 186 | 206 | 198 | 199 |
| 22 | 179 | 275 | 265 | 219 | 202 |
| 23 | 175 | 181 | 182 | 179 | 194 |
| 24 | 261 | 266 | 218 | 157 | 193 |
| 25 | 151 | 222 | 178 | 270 | 164 |
| 26 | 179 | 146 | 178 | 188 | 205 |
| 27 | 195 | 195 | 143 | 163 | 188 |
| 28 | 177 | 227 | 195 | 216 | 163 |
| 29 | 216 | 186 | 252 | 198 | 158 |
| 30 | 230 | 198 | 226 | 342 | 251 |
| 31 | 206 | 214 | 199 | 326 | 265 |

Cont.....

Table C1 (Continued)

| No. of fiber | Collection distance (cm) | | | | |
|---|---|---|---|---|---|
| | 10 | 15 | 20 | 25 | 30 |
| 32 | 232 | 125 | 188 | 146 | 134 |
| 33 | 168 | 263 | 211 | 168 | 161 |
| 34 | 142 | 221 | 167 | 213 | 208 |
| 35 | 174 | 168 | 210 | 178 | 193 |
| 36 | 165 | 190 | 199 | 177 | 161 |
| 37 | 188 | 185 | 184 | 197 | 181 |
| 38 | 234 | 221 | 157 | 180 | 170 |
| 39 | 211 | 99 | 247 | 179 | 175 |
| 40 | 191 | 204 | 153 | 134 | 140 |
| 41 | 249 | 151 | 166 | 266 | 169 |
| 42 | 188 | 224 | 204 | 198 | 237 |
| 43 | 188 | 224 | 221 | 195 | 202 |
| 44 | 168 | 160 | 143 | 188 | 279 |
| 45 | 195 | 159 | 189 | 211 | 114 |
| 46 | 177 | 230 | 194 | 200 | 156 |
| 47 | 202 | 198 | 160 | 172 | 170 |
| 48 | 221 | 194 | 214 | 161 | 185 |
| 49 | 207 | 153 | 255 | 136 | 233 |
| 50 | 207 | 177 | 143 | 173 | 199 |
| 51 | 238 | 269 | 253 | 214 | 188 |
| 52 | 189 | 261 | 212 | 183 | 172 |
| 53 | 140 | 207 | 228 | 230 | 204 |
| 54 | 115 | 181 | 193 | 181 | 165 |
| 55 | 227 | 200 | 178 | 203 | 202 |
| 56 | 204 | 253 | 203 | 181 | 150 |
| 57 | 286 | 169 | 299 | 169 | 148 |
| 58 | 194 | 186 | 181 | 213 | 172 |
| 59 | 240 | 202 | 205 | 202 | 150 |
| 60 | 177 | 212 | 136 | 232 | 188 |
| 61 | 199 | 206 | 180 | 197 | 134 |
| 62 | 216 | 169 | 173 | 238 | 189 |
| 63 | 188 | 181 | 200 | 173 | 270 |
| 64 | 186 | 192 | 190 | 184 | 188 |
| 65 | 202 | 261 | 219 | 223 | 206 |
| 66 | 212 | 197 | 200 | 188 | 205 |
| 67 | 197 | 213 | 221 | 228 | 185 |
| 68 | 177 | 207 | 199 | 201 | 152 |
| 69 | 269 | 181 | 181 | 279 | 202 |
| 70 | 261 | 179 | 185 | 169 | 188 |
| 71 | 261 | 205 | 153 | 192 | 151 |

Cont.....

Table C1 (Continued)

| No. of fiber | Collection distance (cm) | | | | |
|---|---|---|---|---|---|
| | 10 | 15 | 20 | 25 | 30 |
| 72 | 207 | 162 | 230 | 198 | 194 |
| 73 | 181 | 211 | 195 | 161 | 140 |
| 74 | 192 | 216 | 191 | 172 | 314 |
| 75 | 169 | 187 | 209 | 171 | 178 |
| 76 | 181 | 208 | 296 | 182 | 179 |
| 77 | 206 | 358 | 179 | 188 | 188 |
| 78 | 205 | 313 | 251 | 226 | 154 |
| 79 | 169 | 196 | 222 | 170 | 161 |
| 80 | 255 | 202 | 136 | 184 | 189 |
| 81 | 109 | 208 | 219 | 165 | 216 |
| 82 | 173 | 254 | 218 | 234 | 114 |
| 83 | 375 | 261 | 130 | 68 | 246 |
| 84 | 208 | 228 | 169 | 184 | 171 |
| 85 | 190 | 221 | 222 | 82 | 189 |
| 86 | 143 | 210 | 204 | 220 | 188 |
| 87 | 325 | 163 | 205 | 214 | 241 |
| 88 | 154 | 194 | 247 | 169 | 179 |
| 89 | 170 | 163 | 210 | 155 | 153 |
| 90 | 279 | 204 | 229 | 194 | 133 |
| 91 | 164 | 152 | 149 | 224 | 156 |
| 92 | 182 | 202 | 238 | 245 | 268 |
| 93 | 268 | 215 | 172 | 156 | 161 |
| 94 | 338 | 124 | 237 | 179 | 198 |
| 95 | 184 | 179 | 152 | 244 | 179 |
| 96 | 131 | 200 | 179 | 171 | 179 |
| 97 | 213 | 311 | 160 | 209 | 217 |
| 98 | 156 | 242 | 170 | 192 | 297 |
| 99 | 243 | 190 | 155 | 229 | 208 |
| 100 | 189 | 185 | 194 | 174 | 196 |

**Table C2** Statistics of diameter of electrospun PAN fiber at various collection distances

| Statistics | | Collection distance (cm) | | | | |
|---|---|---|---|---|---|---|
| | | **10** | **15** | **20** | **25** | **30** |
| N | Valid | 100 | 100 | 100 | 100 | 100 |
| | Missing | 7 | 7 | 7 | 7 | 7 |
| Mean | | 198.48 | 203.07 | 200.2 | 197.42 | 188.7 |
| Std. Error of Mean | | 4.42 | 4.56 | 4.11 | 4.13 | 3.65 |
| Median | | 191.3 | 199.0 | 199.2 | 191.3 | 187.2 |
| Mode | | 188 | 202 | 178 | 179 | 188 |
| Std. Deviation | | 44.24 | 45.69 | 41.06 | 41.27 | 36.49 |
| Variance | | 1957.5 | 2087.2 | 1685.7 | 1703.6 | 1331.4 |
| Skewness | | 1.136 | 0.856 | 0.910 | 0.646 | 0.900 |
| Std. Error of Skewness | | 0.241 | 0.241 | 0.241 | 0.241 | 0.241 |
| Kurtosis | | 2.804 | 2.601 | 2.618 | 2.793 | 1.546 |
| Std. Error of Kurtosis | | 0.478 | 0.478 | 0.478 | 0.478 | 0.478 |
| Range | | 266 | 275 | 260 | 274 | 200 |
| Minimum | | 109 | 92 | 113 | 68 | 114 |
| Maximum | | 375 | 367 | 373 | 342 | 314 |
| Sum | | 19848 | 20307 | 20020 | 19742 | 18870 |
| a.Calculated from grouped data. | | | | | | |

## APPENDIX D Influence of electrode polarity on fiber diameter

**Table D1** Diameter of electrospun PAN fiber (in nm) as a function of concentration when the positive electrode was attached to the nozzle tip.(Conditions for electrospinning process: applied voltage of 20 kV, collection distance of 15 cm, nozzle radius of 0.47 mm and stationary collection screen)

| No. of Fiber | Concentration of PAN solution in DMF (wt%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 5.9 | 7.8 | 9.5 | 11.2 | 12.9 | 14.4 | 15.9 | 17.4 |
| 1 | 95 | 125 | 206 | 293 | 333 | 620 | 455 | 605 |
| 2 | 92 | 142 | 221 | 317 | 366 | 660 | 513 | 603 |
| 3 | 96 | 248 | 207 | 333 | 389 | 522 | 474 | 656 |
| 4 | 78 | 172 | 225 | 356 | 371 | 456 | 440 | 660 |
| 5 | 123 | 258 | 198 | 263 | 333 | 620 | 413 | 579 |
| 6 | 94 | 176 | 189 | 370 | 390 | 496 | 904 | 598 |
| 7 | 111 | 139 | 199 | 336 | 317 | 410 | 548 | 627 |
| 8 | 98 | 184 | 213 | 301 | 358 | 411 | 421 | 598 |
| 9 | 71 | 139 | 228 | 288 | 331 | 472 | 558 | 627 |
| 10 | 94 | 138 | 239 | 166 | 395 | 647 | 440 | 601 |
| 11 | 95 | 143 | 209 | 325 | 388 | 359 | 510 | 720 |
| 12 | 125 | 122 | 175 | 357 | 343 | 382 | 433 | 627 |
| 13 | 79 | 162 | 215 | 299 | 459 | 415 | 536 | 652 |
| 14 | 107 | 130 | 228 | 401 | 369 | 491 | 471 | 660 |
| 15 | 92 | 128 | 217 | 329 | 375 | 505 | 591 | 571 |
| 16 | 76 | 145 | 208 | 412 | 385 | 467 | 509 | 869 |
| 17 | 102 | 150 | 204 | 301 | 184 | 564 | 526 | 604 |
| 18 | 83 | 149 | 215 | 375 | 423 | 503 | 616 | 574 |
| 19 | 60 | 147 | 216 | 288 | 356 | 490 | 711 | 643 |
| 20 | 124 | 168 | 182 | 270 | 412 | 429 | 424 | 625 |
| 21 | 92 | 142 | 223 | 240 | 364 | 500 | 608 | 797 |
| 22 | 102 | 149 | 213 | 321 | 452 | 518 | 536 | 643 |
| 23 | 83 | 124 | 161 | 297 | 385 | 631 | 492 | 608 |
| 24 | 75 | 161 | 231 | 350 | 340 | 561 | 526 | 647 |
| 25 | 79 | 159 | 197 | 295 | 311 | 388 | 448 | 608 |
| 26 | 95 | 155 | 176 | 326 | 370 | 474 | 604 | 647 |
| 27 | 92 | 143 | 208 | 415 | 404 | 434 | 480 | 608 |
| 28 | 96 | 160 | 227 | 267 | 354 | 668 | 424 | 854 |
| 29 | 107 | 157 | 246 | 287 | 313 | 404 | 450 | 630 |
| 30 | 123 | 155 | 190 | 312 | 334 | 461 | 594 | 672 |
| 31 | 78 | 151 | 206 | 421 | 334 | 567 | 459 | 571 |

Cont.....

Table D1 (Continued)

| No. of Fiber | Concentration of PAN solution in DMF (wt%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | **5.9** | **7.8** | **9.5** | **11.2** | **12.9** | **14.4** | **15.9** | **17.4** |
| 32 | 94 | 140 | 229 | 292 | 358 | 509 | 398 | 751 |
| 33 | 111 | 157 | 198 | 277 | 441 | 479 | 408 | 536 |
| 34 | 98 | 168 | 188 | 328 | 363 | 581 | 540 | 607 |
| 35 | 71 | 166 | 232 | 300 | 359 | 432 | 425 | 607 |
| 36 | 92 | 180 | 187 | 279 | 355 | 436 | 464 | 630 |
| 37 | 95 | 168 | 238 | 366 | 372 | 597 | 544 | 634 |
| 38 | 94 | 163 | 210 | 378 | 345 | 526 | 810 | 627 |
| 39 | 78 | 170 | 218 | 318 | 503 | 448 | 487 | 684 |
| 40 | 89 | 182 | 216 | 342 | 483 | 451 | 442 | 757 |
| 41 | 89 | 155 | 153 | 305 | 310 | 386 | 411 | 643 |
| 42 | 59 | 142 | 214 | 328 | 333 | 475 | 455 | 624 |
| 43 | 95 | 162 | 196 | 421 | 372 | 439 | 487 | 717 |
| 44 | 86 | 181 | 231 | 385 | 328 | 581 | 500 | 709 |
| 45 | 95 | 161 | 228 | 280 | 328 | 401 | 521 | 716 |
| 46 | 66 | 178 | 247 | 391 | 325 | 356 | 483 | 650 |
| 47 | 78 | 204 | 177 | 660 | 367 | 420 | 500 | 498 |
| 48 | 82 | 130 | 329 | 377 | 358 | 452 | 536 | 628 |
| 49 | 66 | 147 | 204 | 292 | 374 | 196 | 482 | 605 |
| 50 | 86 | 255 | 260 | 424 | 513 | 455 | 543 | 603 |

**Table D2** Statistics of fiber diameter at various concentrations when positive electrode was used

| Statistics | | Concentration of PAN solution in DMF (wt%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **5.9** | **7.8** | **9.5** | **11.2** | **12.9** | **14.4** | **15.9** | **17.4** |
| N | Valid | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |
| | Missing | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Mean | | 90.82 | 160.6 | 212.54 | 333.08 | 368.5 | 482.9 | 511 | 644.2 |
| Std. Error of Mean | | 2.2018 | 4.1624 | 3.889 | 9.9557 | 7.6538 | 12.824 | 13.641 | 9.942 |
| Median | | 92 | 156 | 213 | 323 | 363.5 | 473 | 489.5 | 627.5 |
| Mode | | 95 | 142 | 228 | 288 | 333 | 581 | 536 | 627 |
| Std. Deviation | | 15.569 | 29.433 | 27.499 | 70.398 | 54.121 | 90.679 | 96.459 | 70.3 |
| Variance | | 242.4 | 866.29 | 756.21 | 4955.8 | 2929 | 8222.7 | 9304.4 | 4942.1 |
| Skewness | | 0.2475 | 1.8649 | 1.272 | 1.9193 | 0.1974 | -0.101 | 2.1249 | 1.3265 |
| Std. Error of Skewness | | 0.3366 | 0.3366 | 0.3366 | 0.3366 | 0.3366 | 0.3366 | 0.3366 | 0.3366 |
| Kurtosis | | 0.1436 | 4.2593 | 5.7135 | 8.7532 | 3.0226 | 1.0095 | 6.0568 | 2.6307 |
| Std. Error of Kurtosis | | 0.6619 | 0.6619 | 0.6619 | 0.6619 | 0.6619 | 0.6619 | 0.6619 | 0.6619 |
| Range | | 66 | 136 | 176 | 494 | 329 | 472 | 506 | 371 |
| Minimum | | 59 | 122 | 153 | 166 | 184 | 196 | 398 | 498 |
| Maximum | | 125 | 258 | 329 | 660 | 513 | 668 | 904 | 869 |
| Sum | | 4541 | 8030 | 10627 | 16654 | 18425 | 24145 | 25550 | 32210 |
| a. Multiple modes exist. The smallest value is shown | | | | | | | | | |

**Table D3** Diameter of electrospun PAN fiber (in nm) as a function of concentration when the negative electrode was attached to the nozzle tip.(Conditions for electrospinning process: applied voltage of -20 kV, collection distance of 15 cm, nozzle radius of 0.47 mm and stationary collection screen)

| No. of fiber | Concentration of PAN solution in DMF (wt%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 5.9 | 7.8 | 9.5 | 11.2 | 12.9 | 14.4 | 15.9 | 17.4 |
| 1 | 138 | 144 | 191 | 244 | 305 | 469 | 436 | 605 |
| 2 | 72 | 125 | 168 | 259 | 317 | 441 | 574 | 603 |
| 3 | 114 | 146 | 255 | 275 | 309 | 487 | 486 | 656 |
| 4 | 98 | 120 | 198 | 292 | 316 | 490 | 444 | 660 |
| 5 | 104 | 175 | 219 | 239 | 312 | 536 | 494 | 579 |
| 6 | 105 | 199 | 284 | 269 | 328 | 362 | 445 | 598 |
| 7 | 105 | 157 | 219 | 254 | 282 | 452 | 550 | 627 |
| 8 | 98 | 146 | 287 | 248 | 409 | 531 | 522 | 598 |
| 9 | 96 | 288 | 401 | 277 | 310 | 448 | 509 | 627 |
| 10 | 96 | 155 | 243 | 254 | 323 | 480 | 500 | 601 |
| 11 | 134 | 172 | 308 | 494 | 386 | 474 | 451 | 720 |
| 12 | 64 | 205 | 202 | 268 | 347 | 442 | 488 | 627 |
| 13 | 128 | 125 | 204 | 275 | 319 | 483 | 565 | 652 |
| 14 | 111 | 139 | 238 | 264 | 370 | 589 | 481 | 660 |
| 15 | 91 | 142 | 194 | 254 | 197 | 905 | 547 | 571 |
| 16 | 127 | 248 | 280 | 272 | 231 | 539 | 452 | 869 |
| 17 | 91 | 172 | 206 | 297 | 240 | 498 | 441 | 604 |
| 18 | 78 | 258 | 271 | 327 | 254 | 415 | 519 | 574 |
| 19 | 76 | 139 | 215 | 267 | 235 | 802 | 466 | 643 |
| 20 | 106 | 138 | 197 | 280 | 259 | 501 | 453 | 625 |
| 21 | 127 | 143 | 231 | 309 | 208 | 431 | 397 | 797 |
| 22 | 83 | 184 | 240 | 288 | 197 | 494 | 479 | 643 |
| 23 | 92 | 176 | 254 | 311 | 182 | 508 | 440 | 608 |
| 24 | 90 | 132 | 235 | 333 | 221 | 426 | 610 | 647 |
| 25 | 131 | 137 | 259 | 247 | 205 | 451 | 503 | 608 |
| 26 | 83 | 206 | 208 | 214 | 141 | 572 | 460 | 647 |
| 27 | 79 | 205 | 141 | 248 | 197 | 393 | 474 | 608 |
| 28 | 59 | 151 | 197 | 294 | 245 | 594 | 401 | 854 |
| 29 | 81 | 167 | 182 | 275 | 264 | 715 | 491 | 630 |
| 30 | 65 | 268 | 197 | 310 | 251 | 457 | 499 | 672 |
| 31 | 90 | 200 | 245 | 297 | 283 | 377 | 441 | 571 |
| 32 | 110 | 169 | 264 | 311 | 276 | 448 | 469 | 751 |
| 33 | 151 | 155 | 257 | 293 | 336 | 879 | 444 | 536 |
| 34 | 81 | 173 | 221 | 328 | 196 | 439 | 489 | 607 |

Cont.....

Table D3 (Continued)

| No. of fiber | Concentration of PAN solution in DMF (wt%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | 5.9 | 7.8 | 9.5 | 11.2 | 12.9 | 14.4 | 15.9 | 17.4 |
| 36 | 110 | 186 | 283 | 322 | 295 | 526 | 488 | 630 |
| 37 | 115 | 158 | 276 | 248 | 274 | 368 | 518 | 634 |
| 38 | 110 | 134 | 196 | 294 | 293 | 499 | 580 | 627 |
| 39 | 96 | 159 | 336 | 269 | 250 | 477 | 501 | 684 |
| 40 | 115 | 115 | 297 | 306 | 255 | 555 | 479 | 757 |
| 41 | 106 | 122 | 232 | 242 | 236 | 483 | 530 | 643 |
| 42 | 88 | 186 | 255 | 255 | 216 | 433 | 663 | 624 |
| 43 | 104 | 153 | 236 | 253 | 232 | 461 | 528 | 717 |
| 44 | 101 | 181 | 274 | 249 | 297 | 472 | 524 | 709 |
| 45 | 131 | 153 | 258 | 253 | 314 | 491 | 463 | 716 |
| 46 | 90 | 184 | 295 | 296 | 289 | 350 | 453 | 650 |
| 47 | 106 | 169 | 216 | 276 | 227 | 427 | 524 | 498 |
| 48 | 84 | 140 | 293 | 289 | 278 | 511 | 457 | 628 |
| 49 | 107 | 183 | 250 | 275 | 288 | 455 | 560 | 605 |
| 50 | 116 | 164 | 314 | 323 | 232 | 472 | 536 | 603 |

**Table D4** Statistics of fiber diameter at various concentrations when negative electrode was used

| Statistics | | Concentration of PAN solution in DMF (wt%) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | **5.9** | **7.8** | **9.5** | **11.2** | **12.9** | **14.4** | **15.9** | **17.4** |
| N | Valid | 50 | 50 | 50 | 50 | 50 | 50 | 50 | 50 |
| | Missing | 5 | 5 | 5 | 5 | 5 | 5 | 5 | 5 |
| Mean | | 100.26 | 167.42 | 242.54 | 282.04 | 269.7 | 499.28 | 492.94 | 631.18 |
| Std. Error of Mean | | 2.8638 | 5.367 | 6.6464 | 5.786 | 7.7707 | 15.916 | 7.4223 | 19.436 |
| Median | | 99.5 | 158.5 | 239 | 275 | 269 | 475.5 | 488 | 596 |
| Mode | | 90 | 125 | 197 | 275 | 197 | 448 | 441 | 554 |
| Std. Deviation | | 20.25 | 37.951 | 46.997 | 40.914 | 54.947 | 112.54 | 52.484 | 137.43 |
| Variance | | 410.07 | 1440.2 | 2208.7 | 1673.9 | 3019.2 | 12666 | 2754.5 | 18888 |
| Skewness | | 0.2423 | 1.3382 | 0.7206 | 2.8611 | 0.2037 | 2.1911 | 0.8301 | 2.5753 |
| Std. Error of Skewness | | 0.3366 | 0.3366 | 0.3366 | 0.3366 | 0.3366 | 0.3366 | 0.3366 | 0.3366 |
| Kurtosis | | -0.18 | 1.9965 | 1.4682 | 13.954 | 0.0279 | 5.487 | 1.2063 | 8.5026 |
| Std. Error of Kurtosis | | 0.6619 | 0.6619 | 0.6619 | 0.6619 | 0.6619 | 0.6619 | 0.6619 | 0.6619 |
| Range | | 92 | 173 | 260 | 280 | 268 | 555 | 266 | 835 |
| Minimum | | 59 | 115 | 141 | 214 | 141 | 350 | 397 | 415 |
| Maximum | | 151 | 288 | 401 | 494 | 409 | 905 | 663 | 1250 |
| Sum | | 5013 | 8371 | 12127 | 14102 | 13485 | 24964 | 24647 | 31559 |
| a. Multiple modes exist. The smallest value is shown | | | | | | | | | |

## APPENDIX E Influence of take-up speed on fiber diameter

**Table E1** Diameter of electrospun PAN fiber (in nm) as a function of take-up speed when the positive electrode was attached to the nozzle tip.(Conditions for electrospinning process: of 14.4 wt% PAN solution, appied voltage of +20 kV, collection distance of 10 cm, nozzle radius of 0.47 mm and adjustable speed rotationally collection screen)

| No. of fiber | Take-up speed (rpm) | | | | |
|---|---|---|---|---|---|
| | 1500 | 1750 | 2000 | 2250 | 2500 |
| 1 | 338 | 299 | 317 | 281 | 317 |
| 2 | 328 | 354 | 294 | 305 | 342 |
| 3 | 390 | 303 | 313 | 315 | 367 |
| 4 | 401 | 390 | 291 | 312 | 379 |
| 5 | 339 | 388 | 380 | 276 | 321 |
| 6 | 350 | 274 | 316 | 324 | 243 |
| 7 | 299 | 328 | 294 | 308 | 333 |
| 8 | 373 | 391 | 291 | 377 | 363 |
| 9 | 438 | 420 | 325 | 321 | 241 |
| 10 | 346 | 417 | 305 | 324 | 285 |
| 11 | 364 | 300 | 281 | 274 | 212 |
| 12 | 310 | 377 | 337 | 260 | 292 |
| 13 | 318 | 267 | 244 | 331 | 321 |
| 14 | 358 | 327 | 310 | 258 | 328 |
| 15 | 392 | 306 | 364 | 281 | 270 |
| 16 | 337 | 363 | 247 | 263 | 264 |
| 17 | 288 | 291 | 296 | 305 | 370 |
| 18 | 339 | 345 | 277 | 296 | 322 |
| 19 | 327 | 463 | 346 | 276 | 313 |
| 20 | 390 | 356 | 399 | 295 | 298 |
| 21 | 409 | 359 | 297 | 310 | 414 |
| 22 | 413 | 242 | 439 | 224 | 299 |
| 23 | 399 | 462 | 207 | 356 | 322 |
| 24 | 338 | 367 | 283 | 292 | 339 |
| 25 | 345 | 300 | 385 | 327 | 236 |
| 26 | 361 | 221 | 218 | 280 | 357 |
| 27 | 317 | 369 | 370 | 317 | 327 |
| 28 | 331 | 303 | 347 | 334 | 354 |
| 29 | 361 | 274 | 284 | 302 | 387 |
| 30 | 306 | 328 | 218 | 322 | 333 |

Cont.....

Table E1 (Continued)

| No. of fiber | Take-up speed (rpm) | | | | |
|---|---|---|---|---|---|
| | 1500 | 1750 | 2000 | 2250 | 2500 |
| 31 | 41 | 344 | 270 | 211 | 328 |
| 32 | 361 | 299 | 375 | 386 | 399 |
| 33 | 260 | 303 | 334 | 302 | 253 |
| 34 | 288 | 361 | 358 | 309 | 317 |
| 35 | 345 | 363 | 370 | 349 | 231 |
| 36 | 314 | 274 | 280 | 320 | 395 |
| 37 | 349 | 334 | 308 | 221 | 264 |
| 38 | 409 | 391 | 261 | 313 | 299 |
| 39 | 324 | 385 | 246 | 344 | 317 |
| 40 | 405 | 339 | 356 | 294 | 282 |
| 41 | 377 | 342 | 341 | 313 | 312 |
| 42 | 357 | 339 | 313 | 263 | 299 |
| 43 | 370 | 336 | 289 | 250 | 280 |
| 44 | 345 | 350 | 348 | 302 | 292 |
| 45 | 390 | 339 | 370 | 306 | 293 |
| 46 | 370 | 381 | 292 | 341 | 247 |
| 47 | 345 | 370 | 370 | 296 | 227 |
| 48 | 391 | 309 | 319 | 256 | 263 |
| 49 | 236 | 337 | 346 | 332 | 352 |
| 50 | 347 | 349 | 364 | 341 | 337 |
| 51 | 373 | 540 | 301 | 269 | 313 |
| 52 | 408 | 445 | 288 | 239 | 405 |
| 53 | 345 | 360 | 313 | 346 | 352 |
| 54 | 317 | 281 | 228 | 320 | 281 |
| 55 | 270 | 288 | 238 | 269 | 213 |
| 56 | 327 | 431 | 300 | 306 | 310 |
| 57 | 413 | 334 | 346 | 300 | 249 |
| 58 | 455 | 317 | 261 | 306 | 327 |
| 59 | 318 | 228 | 273 | 313 | 277 |
| 60 | 356 | 347 | 277 | 264 | 281 |
| 61 | 392 | 386 | 354 | 287 | 346 |
| 62 | 345 | 401 | 349 | 314 | 381 |
| 63 | 417 | 333 | 277 | 229 | 304 |
| 64 | 377 | 395 | 354 | 354 | 306 |
| 65 | 307 | 345 | 356 | 300 | 327 |
| 66 | 377 | 363 | 388 | 295 | 324 |
| 67 | 405 | 350 | 340 | 367 | 358 |
| 68 | 370 | 308 | 238 | 315 | 369 |
| 69 | 410 | 263 | 352 | 341 | 226 |
| 70 | 357 | 296 | 256 | 357 | 374 |

Cont.....

Table E1 (Continued)

| No. of fiber | Take-up speed (rpm) | | | | |
|---|---|---|---|---|---|
| | 1500 | 1750 | 2000 | 2250 | 2500 |
| 71 | 385 | 227 | 408 | 291 | 249 |
| 72 | 444 | 384 | 374 | 274 | 289 |
| 73 | 325 | 398 | 402 | 356 | 261 |
| 74 | 346 | 327 | 341 | 328 | 243 |
| 75 | 381 | 402 | 352 | 247 | 278 |
| 76 | 344 | 430 | 316 | 345 | 238 |
| 77 | 300 | 417 | 267 | 338 | 238 |
| 78 | 361 | 356 | 283 | 317 | 294 |
| 79 | 431 | 345 | 357 | 362 | 278 |
| 80 | 435 | 326 | 372 | 285 | 323 |
| 81 | 373 | 245 | 258 | 299 | 341 |
| 82 | 409 | 363 | 301 | 292 | 273 |
| 83 | 327 | 372 | 254 | 342 | 211 |
| 84 | 345 | 337 | 296 | 373 | 218 |
| 85 | 282 | 382 | 329 | 305 | 279 |
| 86 | 333 | 291 | 344 | 231 | 291 |
| 87 | 295 | 354 | 348 | 414 | 280 |
| 88 | 293 | 324 | 291 | 398 | 306 |
| 89 | 391 | 272 | 367 | 346 | 313 |
| 90 | 392 | 360 | 317 | 321 | 267 |
| 91 | 379 | 313 | 281 | 282 | 329 |
| 92 | 402 | 402 | 336 | 321 | 386 |
| 93 | 339 | 243 | 361 | 321 | 286 |
| 94 | 374 | 311 | 322 | 292 | 342 |
| 95 | 345 | 355 | 306 | 315 | 305 |
| 96 | 347 | 313 | 346 | 367 | 260 |
| 97 | 427 | 284 | 372 | 337 | 264 |
| 98 | 312 | 334 | 317 | 359 | 285 |
| 99 | 338 | 341 | 345 | 299 | 261 |
| 100 | 306 | 381 | 277 | 338 | 310 |

**Table E2** Statistics of fiber diameter at various take-up speeds when positive electrode was used

| Statistics | | Take-up speed (rpm) | | | | | |
|---|---|---|---|---|---|---|---|
| | | **0** | **1500** | **1750** | **2000** | **2250** | **2500** |
| N | Valid | 100 | 100 | 100 | 100 | 100 | 100 |
| | Missing | 8 | 8 | 8 | 8 | 8 | 8 |
| Mean | | 403.95 | 353.29 | 342.29 | 317.14 | 308.81 | 303.57 |
| Std. Error of Mean | | 4.77 | 5.31 | 5.46 | 4.71 | 3.89 | 4.76 |
| Median | | 396 | 349.5 | 343 | 316.5 | 309.5 | 304.51 |
| Mode | | 381 | 345 | 363 | 277 | 321 | 264 |
| Std. Deviation | | 47.66 | 53.08 | 54.56 | 47.12 | 38.93 | 47.63 |
| Variance | | 2271.1 | 2817.8 | 2977 | 2220.1 | 1515.6 | 2268.9 |
| Skewness | | 0.383 | -2.028 | 0.337 | -0.103 | -0.095 | 0.137 |
| Std. Error of Skewness | | 0.241 | 0.241 | 0.241 | 0.241 | 0.241 | 0.241 |
| Kurtosis | | 0.892 | 11.016 | 1.107 | -0.426 | 0.223 | -0.513 |
| Std. Error of Kurtosis | | 0.478 | 0.478 | 0.478 | 0.478 | 0.478 | 0.478 |
| Range | | 269 | 414 | 319 | 232 | 203 | 203 |
| Minimum | | 283 | 41 | 221 | 207 | 211 | 211 |
| Maximum | | 552 | 455 | 540 | 439 | 414 | 414 |
| Sum | | 40395 | 35329 | 34229 | 31714 | 30881 | 30357 |
| a. Multiple modes exist. The smallest value is shown | | | | | | | |

## APPENDIX F Influence of nozzle radius on fiber diameter

**Table F1** Diameter of electrospun PAN fiber (in nm) as a function of nozzle radius when the positive electrode was attached to the nozzle tip.(Conditions for electrospinning process: 14.4 wt% PAN solution, applied voltage of +15 kV, collection distance of 15 cm and stationary collection screen)

| No. of fiber | Nozzle radius (mm) | | | | | |
|---|---|---|---|---|---|---|
| | 0.81 | 0.71 | 0.64 | 0.56 | 0.51 | 0.47 |
| 1 | 448 | 390 | 318 | 398 | 282 | 321 |
| 2 | 442 | 391 | 370 | 339 | 308 | 372 |
| 3 | 388 | 345 | 345 | 282 | 337 | 363 |
| 4 | 455 | 274 | 310 | 267 | 344 | 349 |
| 5 | 365 | 334 | 291 | 285 | 338 | 303 |
| 6 | 264 | 338 | 310 | 288 | 273 | 372 |
| 7 | 405 | 392 | 281 | 327 | 308 | 284 |
| 8 | 385 | 277 | 346 | 334 | 341 | 263 |
| 9 | 463 | 336 | 277 | 293 | 385 | 308 |
| 10 | 381 | 381 | 275 | 283 | 381 | 270 |
| 11 | 444 | 472 | 281 | 296 | 317 | 327 |
| 12 | 363 | 417 | 282 | 310 | 292 | 327 |
| 13 | 390 | 391 | 363 | 299 | 347 | 272 |
| 14 | 350 | 363 | 358 | 303 | 317 | 317 |
| 15 | 337 | 476 | 325 | 321 | 330 | 272 |
| 16 | 420 | 324 | 246 | 305 | 337 | 304 |
| 17 | 453 | 401 | 363 | 256 | 367 | 317 |
| 18 | 465 | 361 | 359 | 318 | 382 | 263 |
| 19 | 442 | 321 | 374 | 302 | 369 | 329 |
| 20 | 345 | 442 | 305 | 270 | 417 | 302 |
| 21 | 449 | 408 | 305 | 338 | 298 | 321 |
| 22 | 391 | 462 | 410 | 260 | 327 | 317 |
| 23 | 398 | 367 | 363 | 299 | 436 | 302 |
| 24 | 329 | 333 | 331 | 331 | 399 | 315 |
| 25 | 382 | 354 | 321 | 344 | 322 | 312 |
| 26 | 385 | 384 | 282 | 282 | 329 | 357 |
| 27 | 402 | 314 | 285 | 263 | 426 | 333 |
| 28 | 385 | 432 | 380 | 343 | 285 | 338 |
| 29 | 538 | 321 | 308 | 320 | 299 | 282 |
| 30 | 534 | 381 | 329 | 314 | 281 | 276 |
| 31 | 462 | 410 | 300 | 261 | 312 | 312 |

Cont.....

Table F1 (Continued)

| No. of fiber | Nozzle radius (mm) | | | | | |
|---|---|---|---|---|---|---|
| | **0.81** | **0.71** | **0.64** | **0.56** | **0.51** | **0.47** |
| 32 | 438 | 352 | 281 | 267 | 308 | 308 |
| 33 | 370 | 293 | 328 | 304 | 285 | 314 |
| 34 | 388 | 388 | 310 | 289 | 285 | 339 |
| 35 | 479 | 423 | 313 | 271 | 310 | 328 |
| 36 | 580 | 362 | 338 | 236 | 292 | 295 |
| 37 | 499 | 333 | 361 | 296 | 321 | 315 |
| 38 | 409 | 331 | 308 | 306 | 361 | 322 |
| 39 | 500 | 398 | 374 | 278 | 426 | 285 |
| 40 | 407 | 313 | 367 | 358 | 388 | 321 |
| 41 | 350 | 373 | 321 | 299 | 345 | 309 |
| 42 | 430 | 336 | 288 | 287 | 346 | 341 |
| 43 | 391 | 310 | 292 | 355 | 282 | 317 |
| 44 | 487 | 425 | 326 | 302 | 281 | 377 |
| 45 | 333 | 328 | 337 | 304 | 352 | 270 |
| 46 | 385 | 317 | 310 | 329 | 180 | 292 |
| 47 | 485 | 283 | 309 | 329 | 275 | 285 |
| 48 | 451 | 313 | 312 | 311 | 333 | 310 |
| 49 | 565 | 392 | 389 | 284 | 272 | 374 |
| 50 | 418 | 317 | 272 | 273 | 291 | 312 |
| 51 | 426 | 345 | 361 | 317 | 244 | 336 |
| 52 | 355 | 425 | 367 | 299 | 365 | 260 |
| 53 | 244 | 364 | 374 | 287 | 248 | 297 |
| 54 | 462 | 398 | 280 | 305 | 345 | 338 |
| 55 | 356 | 360 | 337 | 328 | 315 | 324 |
| 56 | 445 | 438 | 300 | 382 | 409 | 308 |
| 57 | 313 | 292 | 317 | 334 | 310 | 322 |
| 58 | 308 | 417 | 300 | 277 | 281 | 372 |
| 59 | 377 | 334 | 297 | 308 | 305 | 333 |
| 60 | 426 | 339 | 379 | 334 | 327 | 357 |
| 61 | 463 | 317 | 295 | 345 | 306 | 304 |
| 62 | 349 | 365 | 409 | 393 | 349 | 334 |
| 63 | 353 | 350 | 338 | 350 | 367 | 287 |
| 64 | 514 | 367 | 345 | 281 | 399 | 308 |
| 65 | 398 | 455 | 326 | 293 | 407 | 264 |
| 66 | 345 | 337 | 339 | 321 | 388 | 333 |
| 67 | 462 | 377 | 272 | 276 | 321 | 337 |
| 68 | 359 | 444 | 322 | 336 | 405 | 264 |
| 69 | 356 | 401 | 327 | 390 | 339 | 356 |
| 70 | 321 | 346 | 321 | 310 | 321 | 310 |
| 71 | 414 | 448 | 325 | 327 | 372 | 293 |

Cont.....

Table F1 (Continued)

| No. of fiber | Nozzle radius (mm) | | | | | |
|---|---|---|---|---|---|---|
| | **0.81** | **0.71** | **0.64** | **0.56** | **0.51** | **0.47** |
| 72 | 345 | 337 | 336 | 299 | 270 | 306 |
| 73 | 416 | 349 | 341 | 313 | 354 | 333 |
| 74 | 628 | 327 | 382 | 324 | 349 | 356 |
| 75 | 459 | 327 | 321 | 282 | 358 | 331 |
| 76 | 385 | 401 | 299 | 309 | 270 | 317 |
| 77 | 374 | 282 | 329 | 325 | 299 | 299 |
| 78 | 346 | 297 | 356 | 275 | 338 | 295 |
| 79 | 363 | 297 | 447 | 345 | 314 | 367 |
| 80 | 506 | 434 | 349 | 348 | 309 | 305 |
| 81 | 579 | 345 | 356 | 363 | 328 | 306 |
| 82 | 331 | 363 | 375 | 321 | 270 | 252 |
| 83 | 374 | 328 | 393 | 270 | 324 | 317 |
| 84 | 455 | 333 | 334 | 291 | 390 | 292 |
| 85 | 384 | 358 | 317 | 322 | 245 | 337 |
| 86 | 427 | 322 | 310 | 333 | 267 | 313 |
| 87 | 365 | 306 | 318 | 308 | 313 | 338 |
| 88 | 420 | 374 | 333 | 341 | 396 | 345 |
| 89 | 361 | 390 | 293 | 312 | 322 | 395 |
| 90 | 410 | 379 | 391 | 305 | 306 | 321 |
| 91 | 363 | 373 | 299 | 340 | 340 | 269 |
| 92 | 405 | 321 | 215 | 309 | 333 | 240 |
| 93 | 384 | 350 | 345 | 327 | 331 | 382 |
| 94 | 462 | 345 | 367 | 323 | 340 | 357 |
| 95 | 317 | 359 | 337 | 289 | 301 | 308 |
| 96 | 399 | 500 | 277 | 298 | 369 | 310 |
| 97 | 586 | 361 | 356 | 314 | 354 | 304 |
| 98 | 372 | 350 | 358 | 292 | 359 | 310 |
| 99 | 407 | 367 | 248 | 296 | 255 | 272 |
| 100 | 455 | 402 | 356 | 285 | 321 | 305 |

**Table F2** Statistics of fiber diameter at various nozzle radiuses when positive eletrode was used

| Statistics | | Nozzle radius (mm) | | | | | |
|---|---|---|---|---|---|---|---|
| | | **0.81** | **0.71** | **0.64** | **0.56** | **0.51** | **0.47** |
| N | Valid | 100 | 100 | 100 | 100 | 100 | 100 |
| | Missing | 2 | 2 | 2 | 2 | 2 | 2 |
| Mean | | 411.49 | 363.75 | 327.98 | 309.61 | 328.67 | 315.33 |
| Std. Error of Mean | | 6.86 | 4.78 | 3.87 | 3.05 | 4.60 | 3.12 |
| Median | | 400.50 | 359.50 | 326.00 | 307.00 | 327.00 | 313.50 |
| Mode | | 385 | 345 | 310 | 299 | 321 | 317 |
| Std. Deviation | | 68.56 | 47.80 | 38.73 | 30.52 | 45.98 | 31.22 |
| Variance | | 4700.03 | 2285.12 | 1500.00 | 931.45 | 2114.28 | 974.43 |
| Skewness | | 0.674 | 0.519 | 0.102 | 0.508 | 0.000 | 0.121 |
| Std. Error of Skewness | | 0.241 | 0.241 | 0.241 | 0.241 | 0.241 | 0.241 |
| Kurtosis | | 0.899 | -0.064 | 0.423 | 0.536 | 0.329 | -0.068 |
| Std. Error of Kurtosis | | 0.478 | 0.478 | 0.478 | 0.478 | 0.478 | 0.478 |
| Range | | 384 | 226 | 232 | 162 | 256 | 155 |
| Minimum | | 244 | 274 | 215 | 236 | 180 | 240 |
| Maximum | | 628 | 500 | 447 | 398 | 436 | 395 |
| Sum | | 41149 | 36375 | 32798 | 30961 | 32867 | 31533 |

## APPENDIX G Definitions of electronically terms used in electrospinning

### G1 Electrical Charge

The electrical charges referred to in electrospinning are the excess charges, whose electrical fields at long distances are not cancelled by nearby counterions (Reneker, 2000). The common assumption that charge moves instantaneously through a metal is not appropriate for ionic conductivity in a moving fluid. In an uncharged ionic solution, there are the same number of positive and negative ions in each volume element of the solution and no external field is applied to the solution, the positive and negative electrode. The difference in the number of positive and negative ions in a particular region is often called the excess charge or, simply, the charge. For example, a volume element of the fluid near the negative electrode will then contain more positive ions than negative ions. The excess charge establishes an electrical field that extends for large distance. Adding a soluble salt, which dissociates into equal numbers of positive and negative ions, increases the excess charge. The higher conductivity may, however, shorten the time required for the excess charge, in the form of ions, to the electrical field, or in the shape of a segment of the jet.

### G2 Ion Mobility

The mobility of ions through the polymer solution around 10-6 m2/Vs.was reported by Bailey (1998) and Chang (1995)(Reneker, 2000). The value of the electric field, determined by dividing the applied potential by the distance between the surface of the pendent drop and the collector plate, was typically 100 000 V/m. The drift velocity of ions inside the jet is then estimated to be 0.1 m/s. The velocity of the segment at the end of the straight segment of the jet was observed to be about 1 m/s in the experiment of Reneker *et al.* (2000) and about 5 m/s in the work of Waner *et al.* (1998). In many cases it is useful to simplify this by assuming that the ionic charge is fixed in the fluid and moves with the jet.

## G3 Formation of Bending Instability

During the electrospinning of an aqueous solution of high molecular weight polyethylene oxide, a straight jet was formed, as a consequence of electrical forces, from a conical protrusion, often called a Taylor cone, on the surface of a pendent drop of solution. The electrically charged jet travels for a few centimeters in a straight line. At the end of this straight segment, a diaphanous shape, also conical, with its vertex at the end of the straight segment, was seen when proper illumination was provided. This cone is the envelope, in space, of the complicated set of paths taken by jet during the observation time. Images obtained with short expose times by Baumgarten and by Wanner *et al.* indicated that the jet was continuously bending for as far as it could be followed after it entered the envelope cone.

# CURRICULUM VITAE

**Name:** Ms. Jutawan Sutasinpromprae

**Date of Birth:** February 25, 1979

**Nationality:** Thai

**University Education:**

1997-2001 Bachelor Degree of Science in Chemistry, Faculty of Science, Chiangmai University, Chiang Mai, Thailand

**Plublication:**

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