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# APPENDICES

## Appendix A  The calculation of gas permeation rate

The permeance or pressure normalized flux of component 'i' is expressed as a thickness normalized permeation rate, $\left(\dfrac{P}{\delta}\right)_i$. Permeances are expressed in gas permeation units, GPU, where GPU = $1*10^{-6}$ cm$^3$(STP)/cm$^2$.sec.cmHg.

$$\left(\frac{P}{\delta}\right)_i = \frac{Q_i \times 14.7 \times 10^6}{(A) \times (\Delta P) \times 76}$$

Where

$\left(\dfrac{P}{\delta}\right)_i$    =    permeance of gas 'i' (GPU)

$P$    =    permeability of gas 'i' (cm$^3$(STP).cm/cm$^2$.sec.cmHg)

$\delta$    =    thickness of membrane (cm)

$Q_i$    =    volumetric flow rate of gas 'i' (cm$^3$/sec)

$A$    =    area of membrane (cm$^2$)

$\Delta P$    =    pressure different across membrane (psi)

**Appendix B** The Experimental flow rate of methane (CH₄), and carbon dioxide (CO₂) of mixed matrix membranes in performance at pressure 50 psia and 100 psia for CH₄ and CO₂.

**Table B1** Pure CA

| Gas | P (psia) | vol. (ml) | time (sec) | Flow rate (ml/sec) | Permeance (GPU) | Average of Permeance (GPU) | STDEV of Permeance |
|---|---|---|---|---|---|---|---|
| CO₂ | 50 | 0.25 | 2.72 | 0.0919 | 8.048 | 8.040 | 0.30 |
| | | 0.25 | 2.60 | 0.0962 | 8.420 | | |
| | | 0.25 | 2.69 | 0.0929 | 8.138 | | |
| | | 0.25 | 2.73 | 0.0916 | 8.019 | | |
| | | 0.25 | 2.89 | 0.0865 | 7.575 | | |
| CO₂ | 100 | 0.25 | 1.36 | 0.1838 | 8.048 | 8.256 | 0.62 |
| | | 0.25 | 1.49 | 0.1678 | 7.346 | | |
| | | 0.25 | 1.33 | 0.1880 | 8.230 | | |
| | | 0.25 | 1.25 | 0.2000 | 8.756 | | |
| | | 0.25 | 1.23 | 0.2033 | 8.899 | | |
| CH₄ | 50 | 0.25 | 31.25 | 0.0080 | 0.701 | 0.712 | 0.02 |
| | | 0.25 | 30.43 | 0.0082 | 0.719 | | |
| | | 0.25 | 29.42 | 0.0085 | 0.744 | | |
| | | 0.25 | 31.39 | 0.0080 | 0.697 | | |
| | | 0.25 | 31.30 | 0.0080 | 0.699 | | |
| CH₄ | 100 | 0.25 | 15.18 | 0.0165 | 0.721 | 0.718 | 0.02 |
| | | 0.25 | 15.39 | 0.0162 | 0.711 | | |
| | | 0.25 | 15.78 | 0.0158 | 0.694 | | |
| | | 0.25 | 15.47 | 0.0162 | 0.708 | | |
| | | 0.25 | 14.51 | 0.0172 | 0.754 | | |

**Table B2** CO₂/CH₄ selectivity at 50 psia and 100 psia for CA membrane

| Feed Pressure (psia) | CO₂/CH₄ selectivity |
|---|---|
| 50 | 11.30 |
| 100 | 11.50 |

**Table B3** 10% NaY-CA MMMs

| Gas | P (psia) | vol. (ml) | time (sec) | Flow rate (ml/sec) | Permeance (GPU) | Average of Permeance (GPU) | STDEV of Permeance |
|---|---|---|---|---|---|---|---|
| $CO_2$ | 50 | 0.25 | 3.56 | 0.0702 | 6.149 | 6.01 | 0.36 |
| | | 0.25 | 4.08 | 0.0613 | 5.365 | | |
| | | 0.25 | 3.54 | 0.0706 | 6.184 | | |
| | | 0.25 | 3.54 | 0.0706 | 6.184 | | |
| | | 0.25 | 3.55 | 0.0704 | 6.166 | | |
| $CO_2$ | 100 | 0.25 | 1.51 | 0.1656 | 7.249 | 6.09 | 1.20 |
| | | 0.25 | 2.34 | 0.1068 | 4.678 | | |
| | | 0.25 | 1.88 | 0.1330 | 5.822 | | |
| | | 0.25 | 2.06 | 0.1214 | 5.313 | | |
| | | 0.25 | 1.48 | 0.1689 | 7.396 | | |
| $CH_4$ | 50 | 0.25 | 40.75 | 0.0061 | 0.537 | 0.52 | 0.06 |
| | | 0.25 | 39.90 | 0.0063 | 0.549 | | |
| | | 0.25 | 44.45 | 0.0056 | 0.492 | | |
| | | 0.25 | 36.98 | 0.0068 | 0.592 | | |
| | | 0.25 | 48.96 | 0.0051 | 0.447 | | |
| $CH_4$ | 100 | 0.25 | 21.25 | 0.0118 | 0.515 | 0.53 | 0.04 |
| | | 0.25 | 23.43 | 0.0107 | 0.467 | | |
| | | 0.25 | 19.43 | 0.0129 | 0.563 | | |
| | | 0.25 | 20.56 | 0.0122 | 0.532 | | |
| | | 0.25 | 19.28 | 0.0130 | 0.568 | | |

**Table B4** 20% NaY-CA MMMs

| Gas | P (psia) | vol. (ml) | time (sec) | Flow rate (ml/sec) | Permeance (GPU) | Average of Permeance (GPU) | STDEV of Permeance |
|---|---|---|---|---|---|---|---|
| $CO_2$ | 50 | 0.25 | 4.05 | 0.0617 | 5.405 | 5.95 | 0.97 |
| | | 0.25 | 3.49 | 0.0716 | 6.272 | | |
| | | 0.25 | 4.82 | 0.0519 | 4.542 | | |
| | | 0.25 | 3.26 | 0.0767 | 6.715 | | |
| | | 0.25 | 3.21 | 0.0779 | 6.820 | | |
| $CO_2$ | 100 | 0.25 | 2.42 | 0.1033 | 4.523 | 6.04 | 1.63 |
| | | 0.25 | 1.92 | 0.1302 | 5.701 | | |
| | | 0.25 | 1.34 | 0.1866 | 8.168 | | |
| | | 0.25 | 1.51 | 0.1656 | 7.249 | | |
| | | 0.25 | 2.40 | 0.1042 | 4.561 | | |
| $CH_4$ | 50 | 0.25 | 41.56 | 0.0060 | 0.527 | 0.51 | 0.01 |
| | | 0.25 | 42.56 | 0.0059 | 0.514 | | |
| | | 0.25 | 43.90 | 0.0057 | 0.499 | | |
| | | 0.25 | 43.04 | 0.0058 | 0.509 | | |
| | | 0.25 | 44.56 | 0.0056 | 0.491 | | |
| $CH_4$ | 100 | 0.25 | 19.35 | 0.0129 | 0.566 | 0.51 | 0.08 |
| | | 0.25 | 24.14 | 0.0104 | 0.453 | | |
| | | 0.25 | 18.36 | 0.0136 | 0.596 | | |
| | | 0.25 | 20.30 | 0.0123 | 0.539 | | |
| | | 0.25 | 26.32 | 0.0095 | 0.416 | | |

**Table B5** 30% NaY-CA MMMs

| Gas | P (psia) | vol. (ml) | time (sec) | Flow rate (ml/sec) | Permeance (GPU) | Average of Permeance (GPU) | STDEV of Permeance |
|---|---|---|---|---|---|---|---|
| $CO_2$ | 50 | 0.25 | 4.37 | 0.0572 | 5.009 | 5.93 | 0.61 |
| | | 0.25 | 3.34 | 0.0749 | 6.554 | | |
| | | 0.25 | 3.43 | 0.0729 | 6.382 | | |
| | | 0.25 | 3.82 | 0.0654 | 5.731 | | |
| | | 0.25 | 3.67 | 0.0681 | 5.965 | | |
| $CO_2$ | 100 | 0.25 | 2.25 | 0.1111 | 4.865 | 6.01 | 1.42 |
| | | 0.25 | 1.44 | 0.1736 | 7.601 | | |
| | | 0.25 | 1.57 | 0.1592 | 6.972 | | |
| | | 0.25 | 1.72 | 0.1453 | 6.364 | | |
| | | 0.25 | 2.58 | 0.0969 | 4.242 | | |
| $CH_4$ | 50 | 0.25 | 44.54 | 0.0056 | 0.491 | 0.51 | 0.05 |
| | | 0.25 | 47.37 | 0.0053 | 0.462 | | |
| | | 0.25 | 45.03 | 0.0056 | 0.486 | | |
| | | 0.25 | 44.03 | 0.0057 | 0.497 | | |
| | | 0.25 | 37.02 | 0.0068 | 0.591 | | |
| $CH_4$ | 100 | 0.25 | 22.75 | 0.0110 | 0.481 | 0.51 | 0.03 |
| | | 0.25 | 20.34 | 0.0123 | 0.538 | | |
| | | 0.25 | 20.42 | 0.0122 | 0.536 | | |
| | | 0.25 | 23.59 | 0.0106 | 0.464 | | |
| | | 0.25 | 20.68 | 0.0121 | 0.529 | | |

**Table B6** 40% NaY-CA MMMs

| Gas | P (psia) | vol. (ml) | time (sec) | Flow rate (ml/sec) | Permeance (GPU) | Average of Permeance (GPU) | STDEV of Permeance |
|---|---|---|---|---|---|---|---|
| $CO_2$ | 50 | 0.25 | 4.35 | 0.0575 | 5.032 | 5.94 | 0.81 |
| | | 0.25 | 3.24 | 0.0772 | 6.756 | | |
| | | 0.25 | 4.28 | 0.0584 | 5.115 | | |
| | | 0.25 | 3.34 | 0.0749 | 6.554 | | |
| | | 0.25 | 3.51 | 0.0712 | 6.237 | | |
| $CO_2$ | 100 | 0.25 | 1.89 | 0.1323 | 5.791 | 5.97 | 0.48 |
| | | 0.25 | 1.93 | 0.1295 | 5.671 | | |
| | | 0.25 | 1.78 | 0.1404 | 6.149 | | |
| | | 0.25 | 1.63 | 0.1534 | 6.715 | | |
| | | 0.25 | 1.98 | 0.1263 | 5.528 | | |
| $CH_4$ | 50 | 0.25 | 44.03 | 0.0057 | 0.497 | 0.51 | 0.05 |
| | | 0.25 | 47.32 | 0.0053 | 0.463 | | |
| | | 0.25 | 44.37 | 0.0056 | 0.493 | | |
| | | 0.25 | 44.01 | 0.0057 | 0.497 | | |
| | | 0.25 | 37.05 | 0.0067 | 0.591 | | |
| $CH_4$ | 100 | 0.25 | 22.79 | 0.0110 | 0.480 | 0.51 | 0.04 |
| | | 0.25 | 20.36 | 0.0123 | 0.538 | | |
| | | 0.25 | 20.12 | 0.0124 | 0.544 | | |
| | | 0.25 | 24.32 | 0.0103 | 0.450 | | |
| | | 0.25 | 20.47 | 0.0122 | 0.535 | | |

**Table B7** Selectivity at 50 psia of NaY-CA MMMs

| Membrane | $CO_2/CH_4$ selectivity |
|---|---|
| CA membrane | 11.30 |
| 10%NaY | 11.48 |
| 20%NaY | 11.70 |
| 30%NaY | 11.71 |
| 40%NaY | 11.69 |

**Table B8** Selectivity at 100 psia of NaY-CA MMMs

| Membrane | $CO_2/CH_4$ selectivity |
|---|---|
| CA membrane | 11.50 |
| 10%NaY | 11.51 |
| 20%NaY | 11.75 |
| 30%NaY | 11.78 |
| 40%NaY | 11.74 |

**Table B9** 10% NaX-CA MMMs

| Gas | P (psia) | vol. (ml) | time (sec) | Flow rate (ml/sec) | Permeance (GPU) | Average of Permeance (GPU) | STDEV of Permeance |
|---|---|---|---|---|---|---|---|
| $CO_2$ | 50 | 0.25 | 3.34 | 0.0749 | 6.554 | 6.12 | 0.61 |
| | | 0.25 | 4.13 | 0.0605 | 5.300 | | |
| | | 0.25 | 3.23 | 0.0774 | 6.777 | | |
| | | 0.25 | 3.84 | 0.0651 | 5.701 | | |
| | | 0.25 | 3.49 | 0.0716 | 6.272 | | |
| $CO_2$ | 100 | 0.25 | 1.51 | 0.1656 | 7.249 | 6.16 | 1.53 |
| | | 0.25 | 1.34 | 0.1866 | 8.168 | | |
| | | 0.25 | 1.88 | 0.1330 | 5.822 | | |
| | | 0.25 | 2.13 | 0.1174 | 5.139 | | |
| | | 0.25 | 2.47 | 0.1012 | 4.431 | | |
| $CH_4$ | 50 | 0.25 | 37.95 | 0.0066 | 0.577 | 0.53 | 0.06 |
| | | 0.25 | 38.70 | 0.0065 | 0.566 | | |
| | | 0.25 | 44.47 | 0.0056 | 0.492 | | |
| | | 0.25 | 38.18 | 0.0065 | 0.573 | | |
| | | 0.25 | 47.96 | 0.0052 | 0.456 | | |
| $CH_4$ | 100 | 0.25 | 21.23 | 0.0118 | 0.516 | 0.54 | 0.02 |
| | | 0.25 | 19.89 | 0.0126 | 0.550 | | |
| | | 0.25 | 19.73 | 0.0127 | 0.555 | | |
| | | 0.25 | 20.47 | 0.0122 | 0.535 | | |
| | | 0.25 | 20.79 | 0.0120 | 0.526 | | |

**Table B10** 20% NaX-CA MMMs

| Gas | P (psia) | vol. (ml) | time (sec) | Flow rate (ml/sec) | Permeance (GPU) | Average of Permeance (GPU) | STDEV of Permeance |
|---|---|---|---|---|---|---|---|
| CO$_2$ | 50 | 0.25 | 3.30 | 0.0758 | 6.634 | 6.13 | 0.59 |
| | | 0.25 | 4.11 | 0.0608 | 5.326 | | |
| | | 0.25 | 3.24 | 0.0772 | 6.756 | | |
| | | 0.25 | 3.74 | 0.0668 | 5.853 | | |
| | | 0.25 | 3.60 | 0.0694 | 6.081 | | |
| CO$_2$ | 100 | 0.25 | 1.20 | 0.2083 | 9.121 | 6.19 | 1.70 |
| | | 0.25 | 2.15 | 0.1163 | 5.091 | | |
| | | 0.25 | 1.76 | 0.1420 | 6.219 | | |
| | | 0.25 | 2.09 | 0.1196 | 5.237 | | |
| | | 0.25 | 2.08 | 0.1202 | 5.262 | | |
| CH$_4$ | 50 | 0.25 | 67.56 | 0.0037 | 0.324 | 0.30 | 0.02 |
| | | 0.25 | 68.76 | 0.0036 | 0.318 | | |
| | | 0.25 | 74.42 | 0.0034 | 0.294 | | |
| | | 0.25 | 78.57 | 0.0032 | 0.279 | | |
| | | 0.25 | 72.16 | 0.0035 | 0.303 | | |
| CH$_4$ | 100 | 0.25 | 37.51 | 0.0067 | 0.292 | 0.03 | 0.03 |
| | | 0.25 | 38.76 | 0.0064 | 0.282 | | |
| | | 0.25 | 34.42 | 0.0073 | 0.318 | | |
| | | 0.25 | 38.52 | 0.0065 | 0.284 | | |
| | | 0.25 | 32.06 | 0.0078 | 0.341 | | |

**Table B11** 30% NaX-CA MMMs

| Gas | P (psia) | vol. (ml) | time (sec) | Flow rate (ml/sec) | Permeance (GPU) | Average of Permeance (GPU) | STDEV of Permeance |
|---|---|---|---|---|---|---|---|
| CO$_2$ | 50 | 0.25 | 3.32 | 0.0753 | 6.594 | 6.14 | 0.58 |
| | | 0.25 | 4.10 | 0.0610 | 5.339 | | |
| | | 0.25 | 3.22 | 0.0776 | 6.798 | | |
| | | 0.25 | 3.72 | 0.0672 | 5.885 | | |
| | | 0.25 | 3.60 | 0.0694 | 6.081 | | |
| CO$_2$ | 100 | 0.25 | 1.29 | 0.1938 | 8.485 | 6.23 | 1.33 |
| | | 0.25 | 2.20 | 0.1136 | 4.975 | | |
| | | 0.25 | 1.81 | 0.1381 | 6.047 | | |
| | | 0.25 | 1.87 | 0.1337 | 5.853 | | |
| | | 0.25 | 1.89 | 0.1323 | 5.791 | | |
| CH$_4$ | 50 | 0.25 | 63.32 | 0.0039 | 0.346 | 0.32 | 0.03 |
| | | 0.25 | 78.72 | 0.0032 | 0.278 | | |
| | | 0.25 | 73.32 | 0.0034 | 0.299 | | |
| | | 0.25 | 68.51 | 0.0036 | 0.320 | | |
| | | 0.25 | 62.19 | 0.0040 | 0.352 | | |
| CH$_4$ | 100 | 0.25 | 37.43 | 0.0067 | 0.292 | 0.31 | 0.03 |
| | | 0.25 | 38.65 | 0.0065 | 0.283 | | |
| | | 0.25 | 32.34 | 0.0077 | 0.338 | | |
| | | 0.25 | 38.19 | 0.0065 | 0.287 | | |
| | | 0.25 | 32.01 | 0.0078 | 0.342 | | |

**Table B12** 40% NaX-CA MMMs

| Gas | P (psia) | vol. (ml) | time (sec) | Flow rate (ml/sec) | Permeance (GPU) | Average of Permeance (GPU) | STDEV of Permeance |
|---|---|---|---|---|---|---|---|
| $CO_2$ | 50 | 0.25 | 3.31 | 0.0755 | 6.614 | 6.14 | 0.52 |
| | | 0.25 | 4.09 | 0.0611 | 5.352 | | |
| | | 0.25 | 3.32 | 0.0753 | 6.594 | | |
| | | 0.25 | 3.58 | 0.0698 | 6.115 | | |
| | | 0.25 | 3.63 | 0.0689 | 6.031 | | |
| $CO_2$ | 100 | 0.25 | 1.32 | 0.1894 | 8.292 | 0.13 | 1.20 |
| | | 0.25 | 2.12 | 0.1179 | 5.163 | | |
| | | 0.25 | 1.75 | 0.1429 | 6.255 | | |
| | | 0.25 | 1.88 | 0.1330 | 5.822 | | |
| | | 0.25 | 1.91 | 0.1309 | 5.731 | | |
| $CH_4$ | 50 | 0.25 | 62.09 | 0.0040 | 0.353 | 0.33 | 0.03 |
| | | 0.25 | 77.54 | 0.0032 | 0.282 | | |
| | | 0.25 | 71.32 | 0.0035 | 0.307 | | |
| | | 0.25 | 66.51 | 0.0038 | 0.329 | | |
| | | 0.25 | 62.19 | 0.0040 | 0.352 | | |
| $CH_4$ | 100 | 0.25 | 36.43 | 0.0069 | 0.300 | 0.31 | 0.03 |
| | | 0.25 | 38.34 | 0.0065 | 0.285 | | |
| | | 0.25 | 32.32 | 0.0077 | 0.339 | | |
| | | 0.25 | 38.11 | 0.0066 | 0.287 | | |
| | | 0.25 | 32.01 | 0.0078 | 0.342 | | |

**Table B13** Selectivity at 50 psia of NaX-CA MMMs

| Membrane | $CO_2/CH_4$ selectivity |
|---|---|
| CA membrane | 11.30 |
| 10%NaX | 11.45 |
| 20%NaX | 20.21 |
| 30%NaX | 19.21 |
| 40%NaX | 18.85 |

**Table B14** Selectivity at 100 psia of NaX-CA MMMs

| Membrane | $CO_2/CH_4$ selectivity |
|---|---|
| CA membrane | 11.50 |
| 10%NaX | 11.49 |
| 20%NaX | 20.28 |
| 30%NaX | 20.14 |
| 40%NaX | 20.04 |

**Table B15** 10% Silicalite-CA MMMs

| Gas | P (psia) | vol. (ml) | time (sec) | Flow rate (ml/sec) | Permeance (GPU) | Average of Permeance (GPU) | STDEV of Permeance |
|---|---|---|---|---|---|---|---|
| $CO_2$ | 50 | 1.00 | 20.57 | 0.0486 | 4.257 | 4.45 | 0.31 |
| | | 1.00 | 18.58 | 0.0538 | 4.713 | | |
| | | 1.00 | 20.34 | 0.0492 | 4.305 | | |
| | | 1.00 | 21.18 | 0.0472 | 4.134 | | |
| | | 1.00 | 18.08 | 0.0553 | 4.843 | | |
| $CO_2$ | 100 | 1.00 | 9.82 | 0.1018 | 4.458 | 4.48 | 0.03 |
| | | 1.00 | 9.79 | 0.1021 | 4.472 | | |
| | | 1.00 | 9.72 | 0.1029 | 4.504 | | |
| | | 1.00 | 9.69 | 0.1032 | 4.518 | | |
| | | 1.00 | 9.85 | 0.1015 | 4.445 | | |
| $CH_4$ | 50 | 0.25 | 58.89 | 0.0042 | 0.372 | 0.40 | 0.02 |
| | | 0.25 | 57.35 | 0.0044 | 0.382 | | |
| | | 0.25 | 54.76 | 0.0046 | 0.400 | | |
| | | 0.25 | 53.87 | 0.0046 | 0.406 | | |
| | | 0.25 | 51.06 | 0.0049 | 0.429 | | |
| $CH_4$ | 100 | 0.25 | 26.65 | 0.0094 | 0.411 | 0.40 | 0.01 |
| | | 0.25 | 28.36 | 0.0088 | 0.386 | | |
| | | 0.25 | 27.71 | 0.0090 | 0.395 | | |
| | | 0.25 | 28.01 | 0.0089 | 0.391 | | |
| | | 0.25 | 27.01 | 0.0093 | 0.405 | | |

**Table B16** 20% Silicalite-CA MMMs

| Gas | P (psia) | vol. (ml) | time (sec) | Flow rate (ml/sec) | Permeance (GPU) | Average of Permeance (GPU) | STDEV of Permeance |
|---|---|---|---|---|---|---|---|
| $CO_2$ | 50 | 0.25 | 4.81 | 0.0520 | 4.551 | 4.48 | 0.17 |
| | | 0.25 | 4.75 | 0.0526 | 4.609 | | |
| | | 0.25 | 4.73 | 0.0529 | 4.628 | | |
| | | 0.25 | 5.19 | 0.0482 | 4.218 | | |
| | | 0.25 | 4.98 | 0.0502 | 4.396 | | |
| $CO_2$ | 100 | 0.25 | 2.35 | 0.1064 | 4.658 | 4.55 | 0.15 |
| | | 0.25 | 2.55 | 0.0980 | 4.292 | | |
| | | 0.25 | 2.38 | 0.1050 | 4.599 | | |
| | | 0.25 | 2.39 | 0.1046 | 4.580 | | |
| | | 0.25 | 2.37 | 0.1055 | 4.618 | | |
| $CH_4$ | 50 | 0.25 | 53.69 | 0.0047 | 0.408 | 0.40 | 0.03 |
| | | 0.25 | 55.89 | 0.0045 | 0.392 | | |
| | | 0.25 | 56.24 | 0.0044 | 0.389 | | |
| | | 0.25 | 48.43 | 0.0052 | 0.452 | | |
| | | 0.25 | 58.45 | 0.0043 | 0.375 | | |
| $CH_4$ | 100 | 0.25 | 26.59 | 0.0094 | 0.412 | 0.41 | 0.03 |
| | | 0.25 | 24.26 | 0.0103 | 0.451 | | |
| | | 0.25 | 29.80 | 0.0084 | 0.367 | | |
| | | 0.25 | 26.92 | 0.0093 | 0.407 | | |
| | | 0.25 | 27.21 | 0.0092 | 0.402 | | |

**Table B17** 30% Silicalite-CA MMMs

| Gas | P (psia) | vol. (ml) | time (sec) | Flow rate (ml/sec) | Permeance (GPU) | Average of Permeance (GPU) | STDEV of Permeance |
|---|---|---|---|---|---|---|---|
| $CO_2$ | 50 | 0.25 | 4.54 | 0.0551 | 4.822 | 4.52 | 0.38 |
| | | 0.25 | 5.29 | 0.0473 | 4.138 | | |
| | | 0.25 | 5.36 | 0.0466 | 4.084 | | |
| | | 0.25 | 4.69 | 0.0533 | 4.668 | | |
| | | 0.25 | 4.48 | 0.0558 | 4.886 | | |
| $CO_2$ | 100 | 0.25 | 2.50 | 0.1000 | 4.378 | 4.58 | 0.66 |
| | | 0.25 | 2.07 | 0.1208 | 5.288 | | |
| | | 0.25 | 3.09 | 0.0809 | 3.542 | | |
| | | 0.25 | 2.28 | 0.1096 | 4.801 | | |
| | | 0.25 | 2.24 | 0.1116 | 4.886 | | |
| $CH_4$ | 50 | 0.25 | 58.79 | 0.0043 | 0.372 | 0.41 | 0.03 |
| | | 0.25 | 55.04 | 0.0045 | 0.398 | | |
| | | 0.25 | 51.36 | 0.0049 | 0.426 | | |
| | | 0.25 | 54.10 | 0.0046 | 0.405 | | |
| | | 0.25 | 50.02 | 0.0050 | 0.438 | | |
| $CH_4$ | 100 | 0.25 | 29.57 | 0.0085 | 0.370 | 0.41 | 0.05 |
| | | 0.25 | 24.87 | 0.0101 | 0.440 | | |
| | | 0.25 | 27.13 | 0.0092 | 0.403 | | |
| | | 0.25 | 22.75 | 0.0110 | 0.481 | | |
| | | 0.25 | 29.59 | 0.0084 | 0.370 | | |

**Table B18** 40% Silicalite-CA MMMs

| Gas | P (psia) | vol. (ml) | time (sec) | Flow rate (ml/sec) | Permeance (GPU) | Average of Permeance (GPU) | STDEV of Permeance |
|---|---|---|---|---|---|---|---|
| $CO_2$ | 50 | 0.25 | 4.32 | 0.0579 | 5.067 | 4.58 | 0.31 |
| | | 0.25 | 4.69 | 0.0533 | 4.668 | | |
| | | 0.25 | 5.08 | 0.0492 | 4.309 | | |
| | | 0.25 | 4.85 | 0.0515 | 4.514 | | |
| | | 0.25 | 5.04 | 0.0496 | 4.343 | | |
| $CO_2$ | 100 | 0.25 | 2.35 | 0.1064 | 4.658 | 4.62 | 0.13 |
| | | 0.25 | 2.36 | 0.1059 | 4.638 | | |
| | | 0.25 | 2.32 | 0.1078 | 4.718 | | |
| | | 0.25 | 2.49 | 0.1004 | 4.396 | | |
| | | 0.25 | 2.33 | 0.1073 | 4.698 | | |
| $CH_4$ | 50 | 0.25 | 49.45 | 0.0051 | 0.443 | 0.42 | 0.03 |
| | | 0.25 | 48.57 | 0.0051 | 0.451 | | |
| | | 0.25 | 58.58 | 0.0043 | 0.374 | | |
| | | 0.25 | 52.50 | 0.0048 | 0.417 | | |
| | | 0.25 | 53.79 | 0.0046 | 0.407 | | |
| $CH_4$ | 100 | 0.25 | 28.04 | 0.0089 | 0.390 | 0.42 | 0.02 |
| | | 0.25 | 25.01 | 0.0100 | 0.438 | | |
| | | 0.25 | 26.04 | 0.0096 | 0.420 | | |
| | | 0.25 | 25.74 | 0.0097 | 0.425 | | |
| | | 0.25 | 26.11 | 0.0096 | 0.419 | | |

**Table B19**  Selectivity at 50 psia of Silicalite-CA MMMs

| Membrane | $CO_2/CH_4$ selectivity |
|---|---|
| CA membrane | 11.30 |
| 10% Silicalite | 11.17 |
| 20% Silicalite | 11.11 |
| 30% Silicalite | 11.07 |
| 40% Silicalite | 10.95 |

**Table B20**  Selectivity at 100 psia of Silicalite-CA MMMs

| Membrane | $CO_2/CH_4$ selectivity |
|---|---|
| CA membrane | 11.50 |
| 10% Silicalite | 11.23 |
| 20% Silicalite | 11.16 |
| 30% Silicalite | 11.08 |
| 40% Silicalite | 11.01 |

**Table B21**  10% Beta-CA MMMs

| Gas | P (psia) | vol. (ml) | time (sec) | Flow rate (ml/sec) | Permeance (GPU) | Average of Permeance (GPU) | STDEV of Permeance |
|---|---|---|---|---|---|---|---|
| $CO_2$ | 50 | 0.25 | 4.39 | 0.0569 | 4.987 | 4.86 | 0.29 |
| | | 0.25 | 4.59 | 0.0545 | 4.769 | | |
| | | 0.25 | 4.68 | 0.0534 | 4.678 | | |
| | | 0.25 | 4.80 | 0.0521 | 4.561 | | |
| | | 0.25 | 4.14 | 0.0604 | 5.288 | | |
| $CO_2$ | 100 | 0.25 | 2.38 | 0.1050 | 4.599 | 4.96 | 0.40 |
| | | 0.25 | 2.22 | 0.1126 | 4.930 | | |
| | | 0.25 | 1.95 | 0.1282 | 5.613 | | |
| | | 0.25 | 2.18 | 0.1147 | 5.021 | | |
| | | 0.25 | 2.35 | 0.1064 | 4.658 | | |
| $CH_4$ | 50 | 0.25 | 48.76 | 0.0051 | 0.449 | 0.44 | 0.01 |
| | | 0.25 | 52.50 | 0.0048 | 0.417 | | |
| | | 0.25 | 48.56 | 0.0051 | 0.451 | | |
| | | 0.25 | 49.27 | 0.0051 | 0.444 | | |
| | | 0.25 | 51.10 | 0.0049 | 0.428 | | |
| $CH_4$ | 100 | 0.25 | 25.48 | 0.0098 | 0.430 | 0.45 | 0.05 |
| | | 0.25 | 22.57 | 0.0111 | 0.485 | | |
| | | 0.25 | 21.42 | 0.0117 | 0.511 | | |
| | | 0.25 | 26.08 | 0.0096 | 0.420 | | |
| | | 0.25 | 27.76 | 0.0090 | 0.394 | | |

**Table B22** 20% Beta-CA MMMs

| Gas | P (psia) | vol. (ml) | time (sec) | Flow rate (ml/sec) | Permeance (GPU) | Average of Permeance (GPU) | STDEV of Permeance |
|---|---|---|---|---|---|---|---|
| $CO_2$ | 50 | 0.25 | 4.56 | 0.0548 | 4.801 | 4.87 | 0.23 |
| | | 0.25 | 4.16 | 0.0601 | 5.262 | | |
| | | 0.25 | 4.53 | 0.0552 | 4.832 | | |
| | | 0.25 | 4.55 | 0.0549 | 4.811 | | |
| | | 0.25 | 4.72 | 0.0530 | 4.638 | | |
| $CO_2$ | 100 | 0.25 | 2.13 | 0.1174 | 5.139 | 4.99 | 0.13 |
| | | 0.25 | 2.22 | 0.1126 | 4.930 | | |
| | | 0.25 | 2.28 | 0.1096 | 4.801 | | |
| | | 0.25 | 2.15 | 0.1163 | 5.091 | | |
| | | 0.25 | 2.19 | 0.1142 | 4.998 | | |
| $CH_4$ | 50 | 0.25 | 48.49 | 0.0052 | 0.451 | 0.44 | 0.01 |
| | | 0.25 | 48.78 | 0.0051 | 0.449 | | |
| | | 0.25 | 48.29 | 0.0052 | 0.453 | | |
| | | 0.25 | 49.56 | 0.0050 | 0.442 | | |
| | | 0.25 | 51.35 | 0.0049 | 0.426 | | |
| $CH_4$ | 100 | 0.25 | 22.37 | 0.0112 | 0.489 | 0.50 | 0.01 |
| | | 0.25 | 22.47 | 0.0111 | 0.487 | | |
| | | 0.25 | 21.53 | 0.0116 | 0.508 | | |
| | | 0.25 | 22.36 | 0.0112 | 0.490 | | |
| | | 0.25 | 21.25 | 0.0118 | 0.515 | | |

**Table B23** 30% Beta-CA MMMs

| Gas | P (psia) | vol. (ml) | time (sec) | Flow rate (ml/sec) | Permeance (GPU) | Average of Permeance (GPU) | STDEV of Permeance |
|---|---|---|---|---|---|---|---|
| $CO_2$ | 50 | 0.25 | 4.34 | 0.0576 | 5.044 | 4.92 | 0.26 |
| | | 0.25 | 4.29 | 0.0583 | 5.103 | | |
| | | 0.25 | 4.29 | 0.0583 | 5.103 | | |
| | | 0.25 | 4.53 | 0.0552 | 4.832 | | |
| | | 0.25 | 4.86 | 0.0514 | 4.504 | | |
| $CO_2$ | 100 | 0.25 | 2.15 | 0.1163 | 5.091 | 5.14 | 0.20 |
| | | 0.25 | 2.23 | 0.1121 | 4.908 | | |
| | | 0.25 | 2.10 | 0.1190 | 5.212 | | |
| | | 0.25 | 2.17 | 0.1152 | 5.044 | | |
| | | 0.25 | 2.01 | 0.1244 | 5.445 | | |
| $CH_4$ | 50 | 0.25 | 47.49 | 0.0053 | 0.461 | 0.46 | 0.01 |
| | | 0.25 | 48.13 | 0.0052 | 0.455 | | |
| | | 0.25 | 48.19 | 0.0052 | 0.454 | | |
| | | 0.25 | 46.02 | 0.0054 | 0.476 | | |
| | | 0.25 | 49.06 | 0.0051 | 0.446 | | |
| $CH_4$ | 100 | 0.25 | 25.21 | 0.0099 | 0.434 | 0.48 | 0.05 |
| | | 0.25 | 21.32 | 0.0117 | 0.513 | | |
| | | 0.25 | 20.19 | 0.0124 | 0.542 | | |
| | | 0.25 | 24.67 | 0.0101 | 0.444 | | |
| | | 0.25 | 24.22 | 0.0103 | 0.452 | | |

**Table B24** 40% Beta-CA MMMs

| Gas | P (psia) | vol. (ml) | time (sec) | Flow rate (ml/sec) | Permeance (GPU) | Average of Permeance (GPU) | STDEV of Permeance |
|---|---|---|---|---|---|---|---|
| $CO_2$ | 50 | 0.25 | 4.28 | 0.0584 | 5.115 | 4.96 | 0.15 |
| | | 0.25 | 4.46 | 0.0561 | 4.908 | | |
| | | 0.25 | 4.59 | 0.0545 | 4.769 | | |
| | | 0.25 | 4.28 | 0.0584 | 5.115 | | |
| | | 0.25 | 4.47 | 0.0559 | 4.897 | | |
| $CO_2$ | 100 | 0.25 | 2.09 | 0.1196 | 5.237 | 5.20 | 0.14 |
| | | 0.25 | 2.14 | 0.1168 | 5.115 | | |
| | | 0.25 | 2.03 | 0.1232 | 5.392 | | |
| | | 0.25 | 2.18 | 0.1147 | 5.021 | | |
| | | 0.25 | 2.09 | 0.1196 | 5.237 | | |
| $CH_4$ | 50 | 0.25 | 49.67 | 0.0050 | 0.441 | 0.47 | 0.05 |
| | | 0.25 | 48.76 | 0.0051 | 0.449 | | |
| | | 0.25 | 49.18 | 0.0051 | 0.445 | | |
| | | 0.25 | 48.81 | 0.0051 | 0.448 | | |
| | | 0.25 | 40.04 | 0.0062 | 0.547 | | |
| $CH_4$ | 100 | 0.25 | 0.25 | 24.68 | 0.0101 | 0.49 | 0.02 |
| | | 0.25 | 0.25 | 22.03 | 0.0113 | | |
| | | 0.25 | 0.25 | 22.20 | 0.0113 | | |
| | | 0.25 | 0.25 | 22.09 | 0.0113 | | |
| | | 0.25 | 0.25 | 21.95 | 0.0114 | | |

**Table B25** Selectivity at 50 psia of Beta-CA MMMs

| Membrane | $CO_2/CH_4$ selectivity |
|---|---|
| CA membrane | 11.30 |
| 10% Beta | 11.10 |
| 20% Beta | 10.98 |
| 30% Beta | 10.75 |
| 40% Beta | 10.63 |

**Table B526** Selectivity at 100 psia of Beta-CA MMMs

| Membrane | $CO_2/CH_4$ selectivity |
|---|---|
| CA membrane | 11.50 |
| 10% Beta | 11.10 |
| 20% Beta | 11.02 |
| 30% Beta | 10.78 |
| 40% Beta | 10.70 |

**Table B27** 10% NaA-CA MMM

| Gas | P (psia) | vol. (ml) | time (sec) | Flow rate (ml/sec) | Permeance (GPU) | Average of Permeance (GPU) | STDEV of Permeance |
|---|---|---|---|---|---|---|---|
| $CO_2$ | 50 | 1.00 | 10.34 | 0.0967 | 8.468 | 4.69 | 0.79 |
| | | 1.00 | 12.25 | 0.0816 | 7.148 | | |
| | | 1.00 | 11.08 | 0.0903 | 7.903 | | |
| | | 1.00 | 11.65 | 0.0858 | 7.516 | | |
| | | 1.00 | 9.58 | 0.1044 | 9.140 | | |
| $CO_2$ | 100 | 1.00 | 9.40 | 0.1064 | 4.658 | 4.96 | 0.28 |
| | | 1.00 | 9.37 | 0.1067 | 4.673 | | |
| | | 1.00 | 8.56 | 0.1168 | 5.115 | | |
| | | 1.00 | 8.38 | 0.1193 | 5.225 | | |
| | | 1.00 | 8.50 | 0.1176 | 5.151 | | |
| $CH_4$ | 50 | 0.25 | 106.08 | 0.0024 | 0.206 | 0.21 | 0.002 |
| | | 0.25 | 105.35 | 0.0024 | 0.208 | | |
| | | 0.25 | 108.02 | 0.0023 | 0.203 | | |
| | | 0.25 | 105.68 | 0.0024 | 0.207 | | |
| | | 0.25 | 105.43 | 0.0024 | 0.208 | | |
| $CH_4$ | 100 | 0.25 | 51.23 | 0.0049 | 0.214 | 0.21 | 0.01 |
| | | 0.25 | 53.11 | 0.0047 | 0.206 | | |
| | | 0.25 | 50.45 | 0.0050 | 0.217 | | |
| | | 0.25 | 53.59 | 0.0047 | 0.204 | | |
| | | 0.25 | 51.45 | 0.0049 | 0.213 | | |

**Table B28** 20% NaA-CA MMMs

| Gas | P (psia) | vol. (ml) | time (sec) | Flow rate (ml/sec) | Permeance (GPU) | Average of Permeance (GPU) | STDEV of Permeance |
|---|---|---|---|---|---|---|---|
| $CO_2$ | 50 | 0.25 | 6.31 | 0.0396 | 3.469 | 3.62 | 0.32 |
| | | 0.25 | 6.14 | 0.0407 | 3.565 | | |
| | | 0.25 | 6.88 | 0.0363 | 3.182 | | |
| | | 0.25 | 5.53 | 0.0452 | 3.959 | | |
| | | 0.25 | 5.61 | 0.0446 | 3.902 | | |
| $CO_2$ | 100 | 0.25 | 2.51 | 0.0996 | 4.361 | 4.29 | 0.32 |
| | | 0.25 | 2.34 | 0.1068 | 4.678 | | |
| | | 0.25 | 2.88 | 0.0868 | 3.800 | | |
| | | 0.25 | 2.61 | 0.0958 | 4.194 | | |
| | | 0.25 | 2.48 | 0.1008 | 4.413 | | |
| $CH_4$ | 50 | 0.25 | 164.54 | 0.0015 | 0.133 | 0.14 | 0.003 |
| | | 0.25 | 156.67 | 0.0016 | 0.140 | | |
| | | 0.25 | 161.83 | 0.0015 | 0.135 | | |
| | | 0.25 | 164.04 | 0.0015 | 0.133 | | |
| | | 0.25 | 163.32 | 0.0015 | 0.134 | | |
| $CH_4$ | 100 | 0.25 | 72.25 | 0.0035 | 0.151 | 0.16 | 0.01 |
| | | 0.25 | 68.11 | 0.0037 | 0.161 | | |
| | | 0.25 | 67.02 | 0.0037 | 0.163 | | |
| | | 0.25 | 73.09 | 0.0034 | 0.150 | | |

**Table B29** 30% NaA-CA MMMs

| Gas | P (psia) | vol. (ml) | time (sec) | Flow rate (ml/sec) | Permeance (GPU) | Average of Permeance (GPU) | STDEV of Permeance |
|---|---|---|---|---|---|---|---|
| $CO_2$ | 50 | 0.25 | 6.31 | 0.0396 | 3.468 | 3.35 | 0.08 |
|  |  | 0.25 | 6.12 | 0.0408 | 3.577 |  |  |
|  |  | 0.25 | 6.30 | 0.0397 | 3.475 |  |  |
|  |  | 0.25 | 6.02 | 0.0415 | 3.636 |  |  |
|  |  | 0.25 | 6.07 | 0.0412 | 3.606 |  |  |
| $CO_2$ | 100 | 0.25 | 3.04 | 0.0822 | 3.600 | 3.55 | 0.04 |
|  |  | 0.25 | 3.07 | 0.0814 | 3.565 |  |  |
|  |  | 0.25 | 3.12 | 0.0801 | 3.508 |  |  |
|  |  | 0.25 | 3.08 | 0.0812 | 3.554 |  |  |
| $CH_4$ | 50 | 0.25 | 194.54 | 0.0013 | 0.113 | 0.11 | 0.002 |
|  |  | 0.25 | 189.67 | 0.0013 | 0.115 |  |  |
|  |  | 0.25 | 189.83 | 0.0013 | 0.115 |  |  |
|  |  | 0.25 | 194.53 | 0.0013 | 0.113 |  |  |
|  |  | 0.25 | 187.82 | 0.0013 | 0.117 |  |  |
| $CH_4$ | 100 | 0.25 | 92.25 | 0.0027 | 0.119 | 0.12 | 0.004 |
|  |  | 0.25 | 92.34 | 0.0027 | 0.119 |  |  |
|  |  | 0.25 | 97.42 | 0.0026 | 0.112 |  |  |
|  |  | 0.25 | 93.59 | 0.0027 | 0.117 |  |  |
|  |  | 0.25 | 100.68 | 0.0025 | 0.109 |  |  |

**Table B30** 40% NaA-CA MMMs

| Gas | P (psia) | vol. (ml) | time (sec) | Flow rate (ml/sec) | Permeance (GPU) | Average of Permeance (GPU) | STDEV of Permeance |
|---|---|---|---|---|---|---|---|
| $CO_2$ | 50 | 0.25 | 7.31 | 0.0342 | 2.994 | 3.06 | 0.04 |
|  |  | 0.25 | 7.09 | 0.0353 | 3.088 |  |  |
|  |  | 0.25 | 7.12 | 0.0351 | 3.075 |  |  |
|  |  | 0.25 | 7.15 | 0.0349 | 3.060 |  |  |
|  |  | 0.25 | 7.12 | 0.0351 | 3.075 |  |  |
| $CO_2$ | 100 | 0.25 | 3.24 | 0.0772 | 3.378 | 3.35 | 0.04 |
|  |  | 0.25 | 3.26 | 0.0767 | 3.357 |  |  |
|  |  | 0.25 | 3.27 | 0.0765 | 3.347 |  |  |
|  |  | 0.25 | 3.33 | 0.0751 | 3.287 |  |  |
|  |  | 0.25 | 3.25 | 0.0769 | 3.368 |  |  |
| $CH_4$ | 50 | 0.25 | 229.16 | 0.0011 | 0.096 | 0.01 | 0.004 |
|  |  | 0.25 | 229.37 | 0.0011 | 0.095 |  |  |
|  |  | 0.25 | 229.76 | 0.0011 | 0.095 |  |  |
|  |  | 0.25 | 228.33 | 0.0011 | 0.096 |  |  |
|  |  | 0.25 | 230.90 | 0.0011 | 0.095 |  |  |
| $CH_4$ | 100 | 0.25 | 106.78 | 0.0023 | 0.103 | 0.01 | 0.003 |
|  |  | 0.25 | 109.49 | 0.0023 | 0.100 |  |  |
|  |  | 0.25 | 112.54 | 0.0022 | 0.097 |  |  |
|  |  | 0.25 | 114.67 | 0.0022 | 0.095 |  |  |
|  |  | 0.25 | 113.68 | 0.0022 | 0.096 |  |  |

**Table B31**  Selectivity at 50 psia of NaA-CA MMMs

| Membrane | $CO_2/CH_4$ selectivity |
|----------|-------------------------|
| CA membrane | 11.30 |
| 10% NaA | 22.73 |
| 20% NaA | 26.67 |
| 30% NaA | 29.34 |
| 40% NaA | 32.19 |

**Table B32**  Selectivity at 100 psia of NaA-CA MMMs

| Membrane | $CO_2/CH_4$ selectivity |
|----------|-------------------------|
| CA membrane | 11.50 |
| 10% NaA | 23.45 |
| 20% NaA | 27.82 |
| 30% NaA | 30.87 |
| 40% NaA | 34.16 |

**Table B33**  10% AgA-CA MMMs

| Gas | P (psia) | vol. (ml) | time (sec) | Flow rate (ml/sec) | Permeance (GPU) | Average of Permeance (GPU) | STDEV of Permeance |
|-----|----------|-----------|------------|--------------------|-----------------| ---------------------------|--------------------|
| $CO_2$ | 50 | 1.00 | 15.69 | 0.0637 | 5.581 | 5.58 | 0.22 |
|        |    | 1.00 | 16.34 | 0.0612 | 5.359 |      |      |
|        |    | 1.00 | 16.32 | 0.0613 | 5.365 |      |      |
|        |    | 1.00 | 15.05 | 0.0664 | 5.818 |      |      |
|        |    | 1.00 | 15.11 | 0.0662 | 5.795 |      |      |
| $CO_2$ | 100 | 1.00 | 6.78 | 0.1475 | 6.457 | 6.61 | 0.38 |
|        |     | 1.00 | 6.59 | 0.1517 | 6.644 |      |      |
|        |     | 1.00 | 6.37 | 0.1570 | 6.873 |      |      |
|        |     | 1.00 | 7.24 | 0.1381 | 6.047 |      |      |
|        |     | 1.00 | 6.23 | 0.1605 | 7.028 |      |      |
| $CH_4$ | 50 | 0.25 | 108.45 | 0.0023 | 0.202 | 0.20 | 0.001 |
|        |    | 0.25 | 108.92 | 0.0023 | 0.201 |      |       |
|        |    | 0.25 | 107.87 | 0.0023 | 0.203 |      |       |
|        |    | 0.25 | 108.87 | 0.0023 | 0.201 |      |       |
|        |    | 0.25 | 109.84 | 0.0023 | 0.199 |      |       |
| $CH_4$ | 100 | 0.25 | 53.45 | 0.0047 | 0.205 | 0.20 | 0.004 |
|        |     | 0.25 | 51.90 | 0.0048 | 0.211 |      |       |
|        |     | 0.25 | 54.60 | 0.0046 | 0.200 |      |       |
|        |     | 0.25 | 54.27 | 0.0046 | 0.202 |      |       |
|        |     | 0.25 | 52.61 | 0.0048 | 0.208 |      |       |

**Table B34**  20% AgA-CA MMMs

| Gas | P (psia) | vol. (ml) | time (sec) | Flow rate (ml/sec) | Permeance (GPU) | Average of Permeance (GPU) | STDEV of Permeance |
|---|---|---|---|---|---|---|---|
| $CO_2$ | 50 | 0.25 | 4.31 | 0.0580 | 5.079 | 4.30 | 0.59 |
| | | 0.25 | 5.97 | 0.0419 | 3.667 | | |
| | | 0.25 | 4.64 | 0.0539 | 4.718 | | |
| | | 0.25 | 5.32 | 0.0470 | 4.115 | | |
| | | 0.25 | 5.60 | 0.0446 | 3.909 | | |
| $CO_2$ | 100 | 0.25 | 2.04 | 0.1225 | 5.365 | 5.34 | 0.45 |
| | | 0.25 | 2.25 | 0.1111 | 4.865 | | |
| | | 0.25 | 2.23 | 0.1121 | 4.908 | | |
| | | 0.25 | 1.89 | 0.1323 | 5.791 | | |
| | | 0.25 | 1.90 | 0.1316 | 5.761 | | |
| $CH_4$ | 50 | 0.25 | 173.98 | 0.0014 | 0.126 | 0.13 | 0.003 |
| | | 0.25 | 171.03 | 0.0015 | 0.128 | | |
| | | 0.25 | 174.51 | 0.0014 | 0.125 | | |
| | | 0.25 | 165.79 | 0.0015 | 0.132 | | |
| | | 0.25 | 164.70 | 0.0015 | 0.133 | | |
| $CH_4$ | 100 | 0.25 | 72.57 | 0.0034 | 0.151 | 0.13 | 0.01 |
| | | 0.25 | 86.97 | 0.0029 | 0.126 | | |
| | | 0.25 | 85.64 | 0.0029 | 0.128 | | |
| | | 0.25 | 82.68 | 0.0030 | 0.132 | | |
| | | 0.25 | 86.19 | 0.0029 | 0.127 | | |

**Table B35**  30% AgA-CA MMMs

| Gas | P (psia) | vol. (ml) | time (sec) | Flow rate (ml/sec) | Permeance (GPU) | Average of Permeance (GPU) | STDEV of Permeance |
|---|---|---|---|---|---|---|---|
| $CO_2$ | 50 | 0.25 | 5.13 | 0.0487 | 4.267 | 4.28 | 0.05 |
| | | 0.25 | 5.18 | 0.0483 | 4.226 | | |
| | | 0.25 | 5.01 | 0.0499 | 4.369 | | |
| | | 0.25 | 5.13 | 0.0487 | 4.267 | | |
| | | 0.25 | 5.10 | 0.0490 | 4.292 | | |
| $CO_2$ | 100 | 0.25 | 2.04 | 0.1225 | 5.365 | 5.28 | 0.21 |
| | | 0.25 | 2.15 | 0.1163 | 5.091 | | |
| | | 0.25 | 2.06 | 0.1214 | 5.313 | | |
| | | 0.25 | 2.16 | 0.1157 | 5.067 | | |
| | | 0.25 | 1.96 | 0.1276 | 5.584 | | |
| $CH_4$ | 50 | 0.25 | 196.78 | 0.0013 | 0.111 | 0.11 | 0.002 |
| | | 0.25 | 193.68 | 0.0013 | 0.113 | | |
| | | 0.25 | 198.03 | 0.0013 | 0.111 | | |
| | | 0.25 | 200.24 | 0.0012 | 0.109 | | |
| | | 0.25 | 191.26 | 0.0013 | 0.114 | | |
| $CH_4$ | 100 | 0.25 | 96.25 | 0.0026 | 0.114 | 0.12 | 0.01 |
| | | 0.25 | 90.86 | 0.0028 | 0.120 | | |
| | | 0.25 | 93.46 | 0.0027 | 0.117 | | |
| | | 0.25 | 98.10 | 0.0025 | 0.112 | | |
| | | 0.25 | 87.80 | 0.0028 | 0.125 | | |

**Table B36** 40% AgA-CA MMMs

| Gas | P (psia) | vol. (ml) | time (sec) | Flow rate (ml/sec) | Permeance (GPU) | Average of Permeance (GPU) | STDEV of Permeance |
|---|---|---|---|---|---|---|---|
| $CO_2$ | 50 | 0.25 | 5.35 | 0.0467 | 4.092 | 4.12 | 0.06 |
| | | 0.25 | 5.20 | 0.0481 | 4.210 | | |
| | | 0.25 | 5.38 | 0.0465 | 4.069 | | |
| | | 0.25 | 5.34 | 0.0468 | 4.099 | | |
| $CO_2$ | 100 | 0.25 | 2.22 | 0.1126 | 4.930 | 5.11 | 0.59 |
| | | 0.25 | 2.35 | 0.1064 | 4.658 | | |
| | | 0.25 | 2.43 | 0.1029 | 4.504 | | |
| | | 0.25 | 1.93 | 0.1295 | 5.671 | | |
| | | 0.25 | 1.89 | 0.1323 | 5.791 | | |
| $CH_4$ | 50 | 0.25 | 231.25 | 0.0011 | 0.095 | 0.09 | 0.004 |
| | | 0.25 | 223.65 | 0.0011 | 0.098 | | |
| | | 0.25 | 232.13 | 0.0011 | 0.094 | | |
| | | 0.25 | 251.89 | 0.0010 | 0.087 | | |
| | | 0.25 | 241.64 | 0.0010 | 0.091 | | |
| $CH_4$ | 100 | 0.25 | 102.78 | 0.0024 | 0.106 | 0.11 | 0.004 |
| | | 0.25 | 100.34 | 0.0025 | 0.109 | | |
| | | 0.25 | 101.56 | 0.0025 | 0.108 | | |
| | | 0.25 | 110.43 | 0.0023 | 0.099 | | |
| | | 0.25 | 100.19 | 0.0025 | 0.109 | | |

**Table B37** Selectivity at 50 psia of AgA-CA MMMs

| Membrane | $CO_2/CH_4$ selectivity |
|---|---|
| CA membrane | 11.30 |
| 10% AgA | 27.78 |
| 20% AgA | 33.32 |
| 30% AgA | 38.25 |
| 40% AgA | 44.32 |

**Table B38** Selectivity at 100 psia of AgA-CA MMMs

| Membrane | $CO_2/CH_4$ selectivity |
|---|---|
| CA membrane | 11.50 |
| 10% AgA | 32.24 |
| 20% AgA | 40.12 |
| 30% AgA | 44.78 |
| 40% AgA | 48.23 |

**Table B39** 10% CaA-CA MMMs

| Gas | P (psia) | vol. (ml) | time (sec) | Flow rate (ml/sec) | Permeance (GPU) | Average of Permeance (GPU) | STDEV of Permeance |
|---|---|---|---|---|---|---|---|
| $CO_2$ | 50 | 1.00 | 15.57 | 0.0642 | 5.624 | 5.53 | 0.42 |
| | | 1.00 | 14.58 | 0.0686 | 6.007 | | |
| | | 1.00 | 15.78 | 0.0634 | 5.549 | | |
| | | 1.00 | 15.59 | 0.0641 | 5.617 | | |
| | | 1.00 | 18.08 | 0.0553 | 4.843 | | |
| $CO_2$ | 100 | 1.00 | 7.32 | 0.1366 | 5.981 | 5.95 | 0.17 |
| | | 1.00 | 7.39 | 0.1353 | 5.924 | | |
| | | 1.00 | 7.44 | 0.1344 | 5.885 | | |
| | | 1.00 | 7.62 | 0.1312 | 5.745 | | |
| | | 1.00 | 7.05 | 0.1418 | 6.210 | | |
| $CH_4$ | 50 | 0.25 | 98.59 | 0.0025 | 0.222 | 0.22 | 0.01 |
| | | 0.25 | 97.65 | 0.0026 | 0.224 | | |
| | | 0.25 | 99.76 | 0.0025 | 0.219 | | |
| | | 0.25 | 93.57 | 0.0027 | 0.234 | | |
| | | 0.25 | 99.58 | 0.0025 | 0.220 | | |
| $CH_4$ | 100 | 0.25 | 44.65 | 0.0056 | 0.245 | 0.24 | 0.01 |
| | | 0.25 | 48.76 | 0.0051 | 0.224 | | |
| | | 0.25 | 45.71 | 0.0055 | 0.239 | | |
| | | 0.25 | 48.81 | 0.0051 | 0.224 | | |
| | | 0.25 | 45.30 | 0.0055 | 0.242 | | |

**Table B40** 20% CaA-CA MMMs

| Gas | P (psia) | vol. (ml) | time (sec) | Flow rate (ml/sec) | Permeance (GPU) | Average of Permeance (GPU) | STDEV of Permeance |
|---|---|---|---|---|---|---|---|
| $CO_2$ | 50 | 0.25 | 5.31 | 0.0471 | 4.123 | 4.45 | 0.21 |
| | | 0.25 | 4.75 | 0.0526 | 4.609 | | |
| | | 0.25 | 4.73 | 0.0529 | 4.628 | | |
| | | 0.25 | 4.87 | 0.0513 | 4.495 | | |
| | | 0.25 | 4.98 | 0.0502 | 4.396 | | |
| $CO_2$ | 100 | 0.25 | 2.12 | 0.1179 | 5.163 | 4.75 | 0.45 |
| | | 0.25 | 2.45 | 0.1020 | 4.468 | | |
| | | 0.25 | 2.58 | 0.0969 | 4.242 | | |
| | | 0.25 | 2.39 | 0.1046 | 4.580 | | |
| | | 0.25 | 2.07 | 0.1208 | 5.288 | | |
| $CH_4$ | 50 | 0.25 | 142.69 | 0.0018 | 0.153 | 0.15 | 0.01 |
| | | 0.25 | 135.89 | 0.0018 | 0.161 | | |
| | | 0.25 | 136.24 | 0.0018 | 0.161 | | |
| | | 0.25 | 147.80 | 0.0017 | 0.148 | | |
| | | 0.25 | 148.45 | 0.0017 | 0.147 | | |
| $CH_4$ | 100 | 0.25 | 64.59 | 0.0039 | 0.169 | 0.17 | 0.01 |
| | | 0.25 | 64.26 | 0.0039 | 0.170 | | |
| | | 0.25 | 69.80 | 0.0036 | 0.157 | | |
| | | 0.25 | 60.92 | 0.0041 | 0.180 | | |
| | | 0.25 | 68.21 | 0.0037 | 0.160 | | |

**Table B41** 30% CaA-CA MMMs

| Gas | P (psia) | vol. (ml) | time (sec) | Flow rate (ml/sec) | Permeance (GPU) | Average of Permeance (GPU) | STDEV of Permeance |
|---|---|---|---|---|---|---|---|
| $CO_2$ | 50 | 0.25 | 5.54 | 0.0451 | 3.951 | 4.00 | 0.07 |
| | | 0.25 | 5.59 | 0.0447 | 3.916 | | |
| | | 0.25 | 5.39 | 0.0464 | 4.061 | | |
| | | 0.25 | 5.48 | 0.0456 | 3.995 | | |
| | | 0.25 | 5.39 | 0.0464 | 4.061 | | |
| $CO_2$ | 100 | 0.25 | 2.19 | 0.1142 | 4.998 | 4.41 | 1.00 |
| | | 0.25 | 1.98 | 0.1263 | 5.528 | | |
| | | 0.25 | 3.49 | 0.0716 | 3.136 | | |
| | | 0.25 | 2.28 | 0.1096 | 4.801 | | |
| | | 0.25 | 3.04 | 0.0822 | 3.600 | | |
| $CH_4$ | 50 | 0.25 | 181.79 | 0.0014 | 0.120 | 0.13 | 0.01 |
| | | 0.25 | 175.04 | 0.0014 | 0.125 | | |
| | | 0.25 | 171.36 | 0.0015 | 0.128 | | |
| | | 0.25 | 168.57 | 0.0015 | 0.130 | | |
| | | 0.25 | 161.52 | 0.0015 | 0.136 | | |
| $CH_4$ | 100 | 0.25 | 78.57 | 0.0032 | 0.139 | 0.14 | 0.002 |
| | | 0.25 | 80.87 | 0.0031 | 0.135 | | |
| | | 0.25 | 80.90 | 0.0031 | 0.135 | | |
| | | 0.25 | 80.75 | 0.0031 | 0.136 | | |
| | | 0.25 | 78.19 | 0.0032 | 0.140 | | |

**Table B42** 40% CaA-CA MMMs

| Gas | P (psia) | vol. (ml) | time (sec) | Flow rate (ml/sec) | Permeance (GPU) | Average of Permeance (GPU) | STDEV of Permeance |
|---|---|---|---|---|---|---|---|
| $CO_2$ | 50 | 0.25 | 6.32 | 0.0396 | 3.464 | 3.67 | 0.14 |
| | | 0.25 | 5.69 | 0.0439 | 3.847 | | |
| | | 0.25 | 5.89 | 0.0424 | 3.717 | | |
| | | 0.25 | 5.93 | 0.0422 | 3.692 | | |
| | | 0.25 | 6.05 | 0.0413 | 3.620 | | |
| $CO_2$ | 100 | 0.25 | 2.54 | 0.0984 | 4.309 | 4.34 | 0.18 |
| | | 0.25 | 2.57 | 0.0973 | 4.259 | | |
| | | 0.25 | 2.42 | 0.1033 | 4.523 | | |
| | | 0.25 | 2.67 | 0.0936 | 4.099 | | |
| | | 0.25 | 2.43 | 0.1029 | 4.504 | | |
| $CH_4$ | 50 | 0.25 | 218.45 | 0.0011 | 0.100 | 0.10 | 0.003 |
| | | 0.25 | 220.57 | 0.0011 | 0.099 | | |
| | | 0.25 | 216.58 | 0.0012 | 0.101 | | |
| | | 0.25 | 211.50 | 0.0012 | 0.104 | | |
| | | 0.25 | 200.79 | 0.0012 | 0.109 | | |
| $CH_4$ | 100 | 0.25 | 98.04 | 0.0025 | 0.112 | 0.12 | 0.005 |
| | | 0.25 | 90.23 | 0.0028 | 0.121 | | |
| | | 0.25 | 89.12 | 0.0028 | 0.123 | | |
| | | 0.25 | 95.74 | 0.0026 | 0.114 | | |
| | | 0.25 | 90.29 | 0.0028 | 0.121 | | |

**Table B43** Selectivity at 50 psia of CaA-CA MMMs

| Membrane | $CO_2/CH_4$ selectivity |
|---|---|
| CA membrane | 11.30 |
| 10% CaA | 23.67 |
| 20% CaA | 28.89 |
| 30% CaA | 31.24 |
| 40% CaA | 35.67 |

**Table B44** Selectivity at 100 psia of CaA-CA MMMs

| Membrane | $CO_2/CH_4$ selectivity |
|---|---|
| CA membrane | 11.50 |
| 10% CaA | 25.32 |
| 20% CaA | 28.43 |
| 30% CaA | 32.21 |
| 40% CaA | 36.76 |

**Table B45** 10% Mor-CA MMMs

| Gas | P (psia) | vol. (ml) | time (sec) | Flow rate (ml/sec) | Permeance (GPU) | Average of Permeance (GPU) | STDEV of Permeance |
|---|---|---|---|---|---|---|---|
| $CO_2$ | 50 | 1.00 | 18.48 | 0.0541 | 4.738 | 4.69 | 0.19 |
| | | 1.00 | 18.80 | 0.0532 | 4.658 | | |
| | | 1.00 | 19.81 | 0.0505 | 4.420 | | |
| | | 1.00 | 18.78 | 0.0532 | 4.663 | | |
| | | 1.00 | 17.66 | 0.0566 | 4.958 | | |
| $CO_2$ | 100 | 1.00 | 8.92 | 0.1121 | 4.908 | 4.96 | 0.25 |
| | | 1.00 | 9.07 | 0.1103 | 4.827 | | |
| | | 1.00 | 8.46 | 0.1182 | 5.175 | | |
| | | 1.00 | 9.44 | 0.1059 | 4.638 | | |
| | | 1.00 | 8.34 | 0.1199 | 5.250 | | |
| $CH_4$ | 50 | 0.25 | 103.45 | 0.0024 | 0.212 | 0.21 | 0.01 |
| | | 0.25 | 106.54 | 0.0023 | 0.205 | | |
| | | 0.25 | 109.03 | 0.0023 | 0.201 | | |
| | | 0.25 | 107.34 | 0.0023 | 0.204 | | |
| | | 0.25 | 105.87 | 0.0024 | 0.207 | | |
| $CH_4$ | 100 | 0.25 | 47.68 | 0.0052 | 0.230 | 0.21 | 0.03 |
| | | 0.25 | 44.95 | 0.0056 | 0.244 | | |
| | | 0.25 | 48.32 | 0.0052 | 0.227 | | |
| | | 0.25 | 46.59 | 0.0054 | 0.235 | | |
| | | 0.25 | 44.32 | 0.0056 | 0.247 | | |

**Table B46** 20% Mor-CA MMMs

| Gas | P (psia) | vol. (ml) | time (sec) | Flow rate (ml/sec) | Permeance (GPU) | Average of Permeance (GPU) | STDEV of Permeance |
|---|---|---|---|---|---|---|---|
| $CO_2$ | 50 | 0.25 | 5.89 | 0.0424 | 3.717 | 3.62 | 0.35 |
| | | 0.25 | 6.11 | 0.0409 | 3.583 | | |
| | | 0.25 | 6.84 | 0.0365 | 3.200 | | |
| | | 0.25 | 5.28 | 0.0473 | 4.146 | | |
| | | 0.25 | 6.38 | 0.0392 | 3.431 | | |
| $CO_2$ | 100 | 0.25 | 2.28 | 0.1096 | 4.801 | 4.33 | 0.57 |
| | | 0.25 | 2.98 | 0.0839 | 3.673 | | |
| | | 0.25 | 2.17 | 0.1152 | 5.044 | | |
| | | 0.25 | 2.71 | 0.0923 | 4.039 | | |
| | | 0.25 | 2.68 | 0.0933 | 4.084 | | |
| $CH_4$ | 50 | 0.25 | 160.56 | 0.0016 | 0.136 | 0.14 | 0.01 |
| | | 0.25 | 165.82 | 0.0015 | 0.132 | | |
| | | 0.25 | 164.56 | 0.0015 | 0.133 | | |
| | | 0.25 | 161.79 | 0.0015 | 0.135 | | |
| | | 0.25 | 150.56 | 0.0017 | 0.145 | | |
| $CH_4$ | 100 | 0.25 | 68.35 | 0.0037 | 0.160 | 0.16 | 0.01 |
| | | 0.25 | 64.90 | 0.0039 | 0.169 | | |
| | | 0.25 | 67.45 | 0.0037 | 0.162 | | |
| | | 0.25 | 75.46 | 0.0033 | 0.145 | | |
| | | 0.25 | 74.92 | 0.0033 | 0.146 | | |

**Table B47** 30% Mor-CA MMMs

| Gas | P (psia) | vol. (ml) | time (sec) | Flow rate (ml/sec) | Permeance (GPU) | Average of Permeance (GPU) | STDEV of Permeance |
|---|---|---|---|---|---|---|---|
| $CO_2$ | 50 | 0.25 | 6.61 | 0.0378 | 3.312 | 3.35 | 0.08 |
| | | 0.25 | 6.29 | 0.0397 | 3.480 | | |
| | | 0.25 | 6.59 | 0.0379 | 3.322 | | |
| | | 0.25 | 6.46 | 0.0387 | 3.389 | | |
| | | 0.25 | 6.71 | 0.0373 | 3.262 | | |
| $CO_2$ | 100 | 0.25 | 3.01 | 0.0831 | 3.636 | 3.55 | 0.09 |
| | | 0.25 | 3.04 | 0.0822 | 3.600 | | |
| | | 0.25 | 3.03 | 0.0825 | 3.612 | | |
| | | 0.25 | 3.16 | 0.0791 | 3.464 | | |
| | | 0.25 | 3.19 | 0.0784 | 3.431 | | |
| $CH_4$ | 50 | 0.25 | 195.23 | 0.0013 | 0.112 | 0.11 | 0.01 |
| | | 0.25 | 195.35 | 0.0013 | 0.112 | | |
| | | 0.25 | 199.78 | 0.0013 | 0.110 | | |
| | | 0.25 | 187.43 | 0.0013 | 0.117 | | |
| | | 0.25 | 179.79 | 0.0014 | 0.122 | | |
| $CH_4$ | 100 | 0.25 | 93.24 | 0.0027 | 0.117 | 0.12 | 0.01 |
| | | 0.25 | 98.26 | 0.0025 | 0.111 | | |
| | | 0.25 | 86.30 | 0.0029 | 0.127 | | |
| | | 0.25 | 92.32 | 0.0027 | 0.119 | | |
| | | 0.25 | 107.15 | 0.0023 | 0.102 | | |

**Table B48** 40% Mor-CA MMMs

| Gas | P (psia) | vol. (ml) | time (sec) | Flow rate (ml/sec) | Permeance (GPU) | Average of Permeance (GPU) | STDEV of Permeance |
|---|---|---|---|---|---|---|---|
| $CO_2$ | 50 | 0.25 | 6.15 | 0.0407 | 3.559 | 3.05 | 0.31 |
| | | 0.25 | 7.09 | 0.0353 | 3.088 | | |
| | | 0.25 | 8.02 | 0.0312 | 2.730 | | |
| | | 0.25 | 7.48 | 0.0334 | 2.927 | | |
| | | 0.25 | 7.47 | 0.0335 | 2.930 | | |
| $CO_2$ | 100 | 0.25 | 3.28 | 0.0762 | 3.337 | 3.34 | 0.06 |
| | | 0.25 | 3.26 | 0.0767 | 3.357 | | |
| | | 0.25 | 3.20 | 0.0781 | 3.420 | | |
| | | 0.25 | 3.35 | 0.0746 | 3.267 | | |
| | | 0.25 | 3.30 | 0.0758 | 3.317 | | |
| $CH_4$ | 50 | 0.25 | 236.64 | 0.0011 | 0.093 | 0.10 | 0.01 |
| | | 0.25 | 222.89 | 0.0011 | 0.098 | | |
| | | 0.25 | 236.40 | 0.0011 | 0.093 | | |
| | | 0.25 | 227.74 | 0.0011 | 0.096 | | |
| | | 0.25 | 223.58 | 0.0011 | 0.098 | | |
| $CH_4$ | 100 | 0.25 | 97.78 | 0.0026 | 0.112 | 0.10 | 0.01 |
| | | 0.25 | 113.90 | 0.0022 | 0.096 | | |
| | | 0.25 | 110.34 | 0.0023 | 0.099 | | |
| | | 0.25 | 120.61 | 0.0021 | 0.091 | | |
| | | 0.25 | 118.05 | 0.0021 | 0.093 | | |

**Table B49** Selectivity at 50 psia of Mor-CA MMMs

| Membrane | $CO_2/CH_4$ selectivity |
|---|---|
| CA membrane | 11.302 |
| 10%Mor | 15.44 |
| 20% Mor | 18.28 |
| 30% Mor | 22.75 |
| 40% Mor | 25.06 |

**Table B50** Selectivity at 100 psia of Mor-CA MMMs

| Membrane | $CO_2/CH_4$ selectivity |
|---|---|
| CA membrane | 11.45 |
| 10% Mor | 17.21 |
| 20% Mor | 19.48 |
| 30% Mor | 23.82 |
| 40% Mor | 27.38 |

## Appendix C The modified Maxwell model

**Table C1** Calculated volume fraction data of dispersed phase in different phases of NaA-CA MMMs in the new modified Maxwell model which simultaneously considers both polymer chain rigidification and partial pore blockage of zeolites.

| | | |
|---|---|---|
| Calculated volume fraction of the bulk of zeolite 4A (considered as the dispersed phase) in the third phase | | 0.980 |
| Calculated volume fraction of the third phase (considered as the dispersed phase) in the second phase | | 0.579 |
| Calculated volume fraction of the second phase(considered as the dispersed phase) in the whole mixed matrix membrane | 10 wt.% zeolite loading | 0.079 |
| | 20 wt.% zeolite loading | 0.146 |
| | 30 wt.% zeolite loading | 0.204 |
| | 40 wt.% zeolite loading | 0.255 |

**Table C2** Comparison of $O_2$ permeances of NaA-CA MMMs based on experimental and modified Maxwell model data.

| Membrane | Experimental $O_2$ permeability (Barrer) | Modified Maxwell model $O_2$ permeability (Barrer) |
|---|---|---|
| CA membrane | 3.477 | 3.477 |
| 10% NaA | 3.145 | 3.168 |
| 20% NaA | 2.921 | 2.918 |
| 30% NaA | 2.696 | 2.712 |
| 40% NaA | 2.562 | 2.539 |

**Table C3** Comparison of $N_2$ permeability of NaA-CA MMMs based on experimental and modified Maxwell model data.

| Membrane | Experimental $N_2$ permeability (Barrer) | Modified Maxwell model $N_2$ permeability (Barrer) |
|---|---|---|
| CA membrane | 1.014 | 1.014 |
| 10% NaA | 0.905 | 0.914 |
| 20% NaA | 0.838 | 0.834 |
| 30% NaA | 0.763 | 0.768 |
| 40% NaA | 0.707 | 0.713 |

**Table C4** Comparison of $O_2/N_2$ selectivity of NaA-CA MMMs based on experimental and modified Maxwell model data.

| Membrane | Experimental $N_2$ permeability (Barrer) | Modified Maxwell model $N_2$ permeability (Barrer) |
|---|---|---|
| CA membrane | 3.430 | 3.43 |
| 10% NaA | 3.475 | 3.467 |
| 20% NaA | 3.486 | 3.501 |
| 30% NaA | 3.533 | 3.533 |
| 40% NaA | 3.624 | 3.563 |

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1. Singha-in, P., Rirksomboon, T., and Kulprathipanja, S. (2008, April 23) Mixed Matrix Membranes for $CO_2/CH_4$ Separation: Effects of Various Zeolites Incorporated into Cellulose Acetate. Proceedings of The 14th PPC Symposium on Petroleum, Petrochemicals, and Polymers, Bangkok, Thailand.

2. Singha-in, P., Rirksomboon, T., and Kulprathipanja, S. (2007, November 4-9) Mixed Matrix Membranes for Gas Separation. Poster presented at AIChE Annual Meeting 2007, Salt Lake City, Utah, USA.

3. Singha-in, P., Tantirungrotechai, Y. (2006, March 14-15) Substituent Effects on Activation Energy of Cope Rearrangement : A Theoretical Study. Poster presented at DPST Meeting 2006, Bangkok, Thailand.