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APPENDICES

Appendix A CO_2 adsorption isotherms of adsorbents at 30, 50, and 75 °C

Table A1 CO_2 adsorption isotherms of adsorbents at 30 °C

Adsorbent	P_{eq} (atm)	$N_{accumulation}$ (mmol/g)
Activated Carbon (AC)	0.1701	1.9813
	0.3701	2.1892
	0.5531	2.4165
	0.7782	2.5780
	0.9993	2.7437
	1.0585	2.8084
1.68 wt% Low Mw PEI/AC	0.2041	2.4670
	0.3912	2.5898
	0.5952	2.7376
	0.7993	2.9232
	1.0075	3.0247
	1.0627	3.0432
2.18 wt% Low Mw PEI/AC	0.2299	2.4478
	0.4041	2.5631
	0.5993	2.6862
	0.7952	2.8250
	1.0034	2.9560
	1.0755	2.9730

Table A1 CO_2 adsorption isotherms of adsorbents at 30 °C (cont.)

Adsorbent	P_{eq} (atm)	$N_{accumulation}$ (mmol/g)
2.84 wt% Low Mw PEI/AC	0.2381	2.3975
	0.4041	2.4953
	0.5993	2.6023
	0.7952	2.7248
	0.9864	2.8643
	1.0714	2.8799
0.73 wt% Med Mw PEI/AC	0.1361	2.5954
	0.3830	2.7429
	0.5993	2.8487
	0.7993	2.9701
	1.0163	3.0758
	1.0673	3.1072
1.16 wt% Med Mw PEI/AC	0.1401	2.5594
	0.3912	2.6981
	0.6082	2.8119
	0.8082	2.9140
	1.0122	3.0108
	1.0755	3.0200
1.90 wt% Med Mw PEI/AC	0.1619	2.4992
	0.3871	2.6129
	0.5993	2.7358
	0.8034	2.8509
	1.0075	2.9646
	1.0673	2.9894

Table A1 CO_2 adsorption isotherms of adsorbents at 30 °C (cont.)

Adsorbent	P_{eq} (atm)	$N_{accumulation}$ (mmol/g)
0.16 wt% High Mw PEI/AC	0.1490	2.4000
	0.3912	2.5455
	0.5952	2.6676
	0.8034	2.7742
	1.0122	2.8547
	1.0633	2.8859
0.45 wt% High Mw PEI/AC	0.1531	2.3524
	0.4041	2.4659
	0.5993	2.5715
	0.8122	2.6942
	1.0245	2.7751
	1.0633	2.8155
0.86 wt% High Mw PEI/AC	0.1531	2.2927
	0.4082	2.4070
	0.6082	2.4954
	0.8082	2.6007
	1.0122	2.6969
	1.0755	2.7151

Table A2 CO_2 adsorption isotherms of adsorbents at 50 °C

Adsorbent	P_{eq} (atm)	$N_{accumulation}$ (mmol/g)
Activated Carbon (AC)	0.2041	1.5890
	0.4041	1.6961
	0.5952	1.8494
	0.8163	1.9249
	1.0163	2.0003
	1.0755	2.0466
1.68 wt% Low Mw PEI/AC	0.1741	1.7638
	0.3830	1.8871
	0.6041	1.9487
	0.8122	2.0412
	1.0075	2.1262
	1.0755	2.1348
2.18 wt% Low Mw PEI/AC	0.1741	1.7560
	0.3912	1.8566
	0.6082	1.9253
	0.8204	1.9719
	1.0245	2.0333
	1.0639	2.1081
2.84 wt% Low Mw PEI/AC	0.1871	1.6752
	0.4082	1.7755
	0.6122	1.8526
	0.8163	1.9137
	1.0204	1.9748
	1.0714	1.9895

Table A2 CO_2 adsorption isotherms of adsorbents at 50 °C (cont.)

Adsorbent	P_{eq} (atm)	$N_{accumulation}$ (mmol/g)
0.73 wt% Med Mw PEI/AC	0.1619	1.8061
	0.3912	1.9291
	0.6082	2.0053
	0.8082	2.0668
	1.0204	2.1209
	1.0714	2.1356
1.16 wt% Med Mw PEI/AC	0.1789	1.7598
	0.3871	1.8914
	0.6122	1.9763
	0.8204	2.0304
	1.0245	2.0845
	1.0585	2.1300
1.90 wt% Med Mw PEI/AC	0.2000	1.6961
	0.4000	1.7955
	0.6082	1.8790
	0.8163	1.9563
	1.0204	2.0177
	1.0673	2.0336

Table A2 CO_2 adsorption isotherms of adsorbents at 50 °C (cont.)

Adsorbent	P_{eq} (atm)	$N_{accumulation}$ (mmol/g)
0.16 wt% High Mw PEI/AC	0.1789	1.8006
	0.3912	1.9004
	0.6041	1.9842
	0.8082	2.0605
	1.0163	2.1295
	1.0714	2.1677
0.45 wt% High Mw PEI/AC	0.1741	1.7595
	0.4000	1.8517
	0.6082	1.9353
	0.8122	2.0115
	1.0204	2.0877
	1.0673	2.1246
0.86 wt% High Mw PEI/AC	0.1701	1.7567
	0.3912	1.8560
	0.6122	1.9321
	0.8163	2.0008
	1.0245	2.0694
	1.0755	2.1001

Table A3 CO_2 adsorption isotherms of adsorbents at 75 °C

Adsorbent	P_{eq} (atm)	$N_{accumulation}$ (mmol/g)
Activated Carbon (AC)	0.2381	1.1085
	0.4041	1.1562
	0.6122	1.1994
	0.8082	1.2418
	1.0204	1.2941
	1.0755	1.3085
1.68 wt% Low Mw PEI/AC	0.2082	1.0827
	0.4082	1.1469
	0.6211	1.1894
	0.8204	1.2330
	1.0333	1.2675
	1.0714	1.3112
2.18 wt% Low Mw PEI/AC	0.2000	1.0362
	0.4000	1.1071
	0.6122	1.1643
	0.8374	1.2009
	1.0075	1.2661
	1.0673	1.2867
2.84 wt% Low Mw PEI/AC	0.2170	0.9945
	0.4122	1.0300
	0.6163	1.0724
	0.8163	1.1216
	1.0333	1.1491
	1.0755	1.1640

Table A3 CO_2 adsorption isotherms of adsorbents at 75 °C (cont.)

Adsorbent	P_{eq} (atm)	$N_{accumulation}$ (mmol/g)
0.73 wt% Med Mw PEI/AC	0.1912	1.1497
	0.4122	1.2137
	0.6211	1.2491
	0.8204	1.2994
	1.0204	1.3428
	1.0755	1.3588
1.16 wt% Med Mw PEI/AC	0.2041	1.1524
	0.4082	1.2096
	0.6163	1.2668
	0.8204	1.3103
	1.0245	1.3526
	1.0714	1.3755
1.90 wt% Med Mw PEI/AC	0.1959	1.1562
	0.4041	1.2350
	0.6122	1.2853
	0.8204	1.3276
	1.0374	1.3481
	1.0755	1.3561

Table A3 CO_2 adsorption isotherms of adsorbents at 75 °C (cont.)

Adsorbent	P_{eq} (atm)	$N_{accumulation}$ (mmol/g)
0.16 wt% High Mw PEI/AC	0.2041	1.1231
	0.4170	1.1654
	0.6122	1.2077
	0.8204	1.2512
	1.0245	1.2946
	1.0633	1.3152
0.45 wt% High Mw PEI/AC	0.2041	1.1472
	0.4082	1.1977
	0.6122	1.2470
	0.8204	1.2905
	1.0245	1.3341
	1.0633	1.3685
0.86 wt% High Mw PEI/AC	0.2041	1.0991
	0.4082	1.1616
	0.6163	1.2108
	0.8204	1.2450
	1.0204	1.2858
	1.0673	1.3342

Appendix B CO_2 adsorption isotherms in three times of the adsorption-desorption cycles over adsorbents at 30, 75 °C

Table B1 CO_2 adsorption isotherms at 30 °C of the AC and the regenerated AC

Adsorbent	P_{eq} (atm)	$N_{accumulation}$ (mmol/g)
Activated Carbon (AC)	0.1701	1.9813
	0.3701	2.1892
	0.5531	2.4165
	0.7782	2.5780
	0.9993	2.7437
	1.0585	2.8084
1st regenerated AC	0.1531	1.9241
	0.4082	2.2087
	0.6082	2.3650
	0.8082	2.5295
	1.0122	2.7102
	1.0755	2.7284
2nd regenerated AC	0.2082	2.0316
	0.3912	2.2109
	0.5653	2.4395
	0.7912	2.5850
	0.9952	2.7461
	1.0374	2.8063

Table B2 CO_2 adsorption isotherms at 30 °C of the 0.73 wt% Med Mw PEI and the regenerated sample

Adsorbent	P_{eq} (atm)	$N_{accumulation}$ (mmol/g)
0.73 wt% Med Mw PEI/AC	0.1361	2.5954
	0.3830	2.7429
	0.5993	2.8487
	0.7993	2.9701
	1.0163	3.0758
	1.0673	3.1072
1st regenerated 0.73 wt% Med Mw PEI/AC	0.1401	2.6091
	0.3912	2.7578
	0.6082	2.8543
	0.8082	2.9509
	1.0122	3.0657
	1.0755	3.0970
2nd regenerated 0.73 wt% Med Mw PEI/AC	0.2299	2.4670
	0.4041	2.5898
	0.5993	2.7376
	0.7952	2.9232
	1.0034	3.0247
	1.0755	3.0432

Table B3 CO_2 adsorption isotherms at 75 °C of the AC and the regenerated AC

Adsorbent	P_{eq} (atm)	$N_{accumulation}$ (mmol/g)
Activated Carbon (AC)	0.2381	1.1085
	0.4041	1.1562
	0.6122	1.1994
	0.8082	1.2418
	1.0204	1.2941
	1.0755	1.3085
1st regenerated AC	0.1741	1.1311
	0.3830	1.1746
	0.6041	1.2021
	0.8122	1.2456
	1.0075	1.2891
	1.0755	1.3029
2nd regenerated AC	0.1701	1.1151
	0.3701	1.1562
	0.5531	1.2133
	0.7782	1.2567
	0.9993	1.3001
	1.0585	1.3276

Table B4 CO_2 adsorption isotherms at 75 °C of the 1.16 wt% Med Mw PEI and the regenerated sample

Adsorbent	P_{eq} (atm)	$N_{accumulation}$ (mmol/g)
1.16 wt% Med Mw PEI/AC	0.2041	1.1524
	0.4082	1.2096
	0.6163	1.2668
	0.8204	1.3103
	1.0245	1.3526
	1.0714	1.3755
1st regenerated 1.16 wt% Med Mw PEI/AC	0.1741	1.1595
	0.3912	1.2168
	0.6082	1.2741
	0.8204	1.3153
	1.0245	1.3428
	1.0639	1.3428
2nd regenerated 1.16 wt% Med Mw PEI/AC	0.1959	1.1610
	0.4041	1.2045
	0.6122	1.2457
	0.8204	1.2892
	1.0374	1.3327
	1.0755	1.3602

Appendix C Calculation for CO_2 adsorption capacity in unit of mmol/g of adsorbent

From; $$n_i = \frac{P_1(V_1+V_2)}{ZRT} - \frac{P_2(V_1+V_2)}{ZRT}$$

where,

n_i= mole of adsorbed CO_2, mol

P_1 = pressure of the system before equilibrium, atm

P_2= pressure of the system after equilibrium, atm

V_1= volume of a manifold, cm^3

V_2= volume of a cylinder with adsorbent, cm^3

Z = compressibility factor

R = 82.05 cm^3atm/mol K

T = temperature of the sample, K

Properties of CO_2 (Daubert *et al.*, 1982)

Critical Temperature (T_r) = 31.04 °C (304.2 K)

Critical Pressure (P_r) = 72.8 atm (7382 kPa)

Acentric Factor (ω) = 0.2276

Step 1: To find pressure reduced (Pr)

Data:

Initial Pressure (P_1) = 11.81 psi (0.8034 atm)

Equilibrium Pressure (P_2) = 2.19 psi (0.1490 atm)

Solution;

$$P_r = \frac{P}{P_C}$$

$$P_{r1} = \frac{P}{P_C} = \frac{P_1}{P_c} = \frac{0.8034\ atm}{72.8\ atm} = 0.0110$$

P_{r2}=0.0020

Step 2: To find temperature reduced (T_r)

Data: Temperature adsorption = 30 °C (303 K)

Solution;

$$T_r = \frac{T}{T_c}$$

$$T_r = \frac{T}{T_c} = \frac{303\ K}{304.2\ K} \sim 1$$

Step 3: To find compressibility factor (Z)

Data: $P_{r1} = 0.0110$, $P_{r2} = 0.0020$

$T_r = 1$

From Figure D1, Compressibility factor (Z_1) = 0.98

Compressibility factor (Z_2) = 0.99

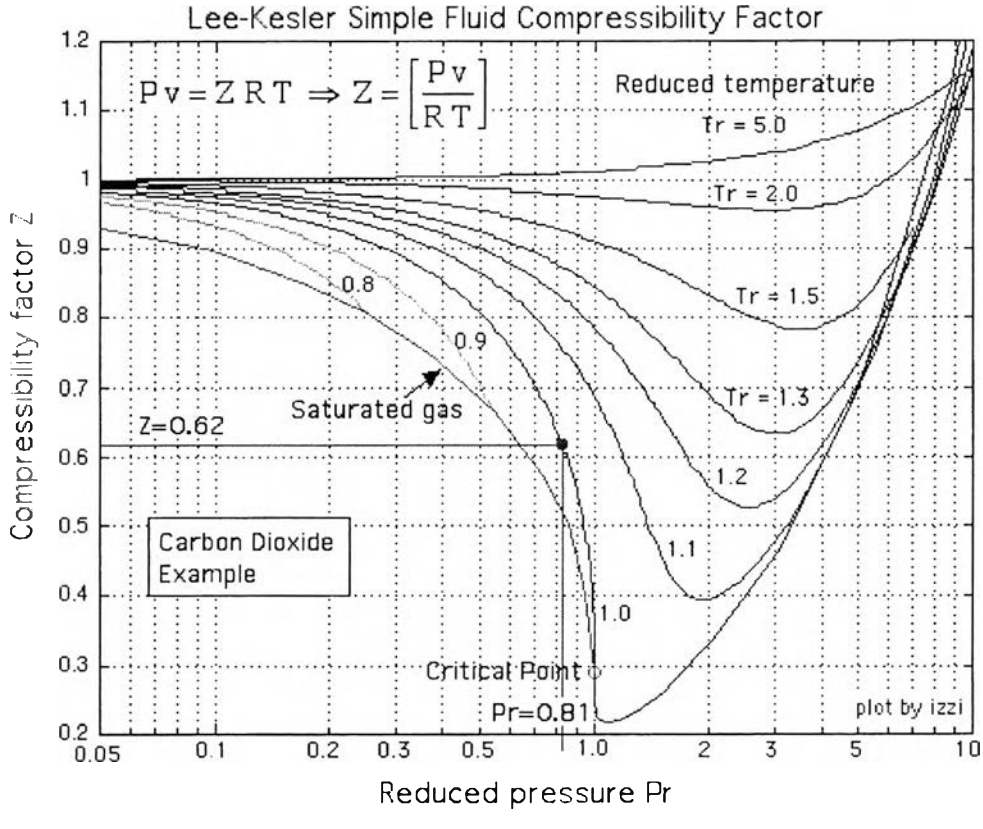

Figure C1 Relationship between the reduced pressure and reduced temperature related on compressibility factor (Lee and Kesler, 1975).

Step 4: To find CO_2 adsorption capacity (mmol/g)

Data:

Temperature adsorption = 30 °C (303 K)

Volume of reactor and manifold (V_1+V_2) = 94.82845 cm^3

R = 82.05 cm^3*atm/mol/K

Solution;

$$n_i = \frac{P_1(V_1 + V_2)}{ZRT} - \frac{P_2(V_1 + V_2)}{ZRT}$$

$$n_i = \frac{0.8034(94.82845)}{(0.98)(82.05)(303)} - \frac{0.8034(94.82845)}{(0.98)(82.05)(303)} = 2.5041 \times 10^{-3} \text{ mol/g}$$

n_i= 2.5041 mmol/g

Appendix D CO_2 Adsorption measurement

From the CO_2 adsorption experiment

The plot of the data between CO_2 pressure and time is shown as below.

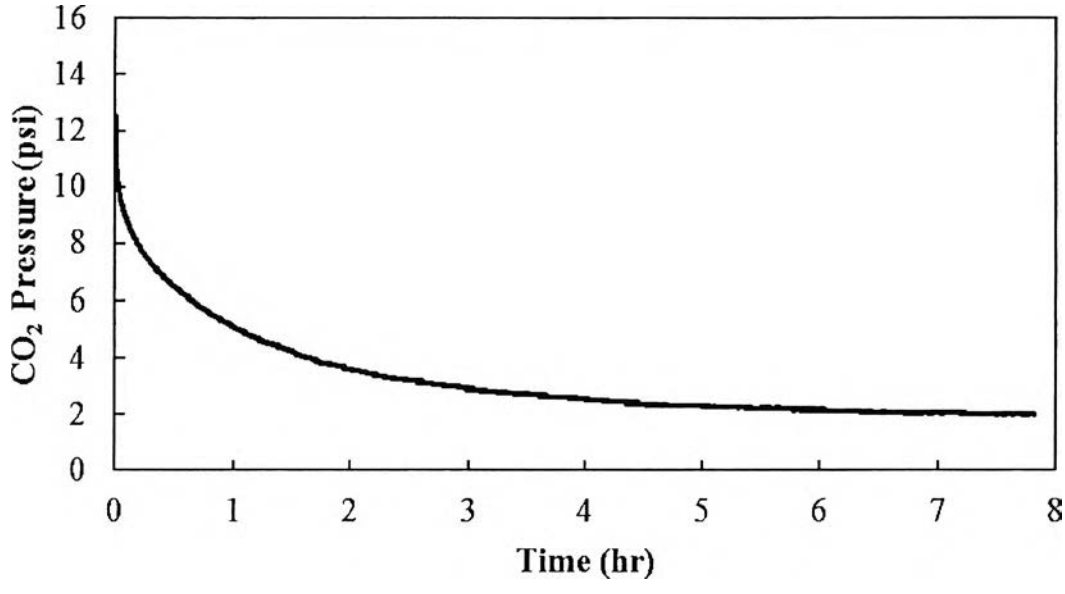

Figure D1 CO_2 pressure of CO_2 adsorption measurement as a function of time.

Appendix E Calculation the PEI-impregnated on the AC

From; $$q_e=(C_0-C_e)\frac{V_{PEI\ solution}}{m_{adsorbent}}$$

Step 1: Measure concentration via UV-visible spectrometer

The absorbance at 203 nm

Concentration of Low Mw PEI solution before impregnation → 1.0000 g/L

Concentration of Low Mw PEI solution after impregnation → 0.1623 g/L

Step 2: Calculate Low Mw PEI- impregnated sample

$$q_e=(1.0000-0.1623)\text{g/L}\frac{20\text{ mL}}{1\text{ g}}\text{x}\frac{1\text{ L}}{1000\text{ mL}}$$

q_e=0.01675 gPEI/gAC

q_e=1.68 wt% PEI/AC

So; Low Mw PEI-impregnated on AC = 1.68 wt% Low Mw PEI/AC

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Presentations and Proceedings:

1. Ritmongkolpun, P., Rangsunvigit, P., and Kulprathipanja, S. (2013, April 23) Enhancement of CO_2 Adsorption on Activated Carbon via Surface Functionalization. Proceedings of The 4th Research Symposium on Petroleum, Petrochemicals and Advanced Materials and The 19th PPC Symposium on Petroleum, Petrochemicals, and Polymers, Bangkok, Thailand.
2. Ritmongkolpun, P., Rangsunvigit, P., and Kulprathipanja, S. (2013, May 12-16) CO_2 Adsorption on Polyethyleneimine-Modified Activated Carbon : Effects of Different Polyethyleneimine Molecular Weights. Poster presented at the Second International Conference on Materials for Energy, Karlsruhe, Germany.