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APPENDICES

APPENDIX A Preparation Of Piperazine Solution

$$M = \frac{g}{M_w} * \frac{1000}{V}$$

M_w= molecular weight of piperazine (86.14g/mol), V= volume of solvent (5mL)

Piperazine was loaded into activated carbon by adding the activated carbon into the piperazine solution for 2 hours stirring at 500rpm.

Piperazine			Activated carbon
Molar (M)	Wt%	Weight (g)	Weight (g)
0.3483	22.82	0.1532	0.5180
0.4644	29.48	0.2164	0.5177
0.5805	33.71	0.2571	0.5055

Note: Wt%= weight percent

$$\text{Weight \%} = \frac{\text{Weight of piperazine}}{\text{Weight of piperazine} + \text{Activated Carbon}} * 100$$

APPENDIX B Piperazine Calibration Curve

Preparation of 0.35M piperazine stock solution required

Piperazine of 3.0167g in 100 mL aqueous solution

Preparation of piperazine concentration for calibration curve

$C_1V_1=C_2V_2$; C_1 = the concentration of piperazine ($0.5M \times 10^{-3}$)

V_1 = volume needed to prepare (10 mL), C_2 = concentration of stock solution (0.3502M)

V_2 = volume required to pipette ($x=0.0143$)

$C_1 \times 10^{-3}$ (M)	V_1 (mL)	C_2 (M)	V_2 (mL)
0.5	10	0.3502	0.0143
2.5	10	0.3502	0.0714
4.5	10	0.3502	0.1286
6.5	10	0.3502	0.1857

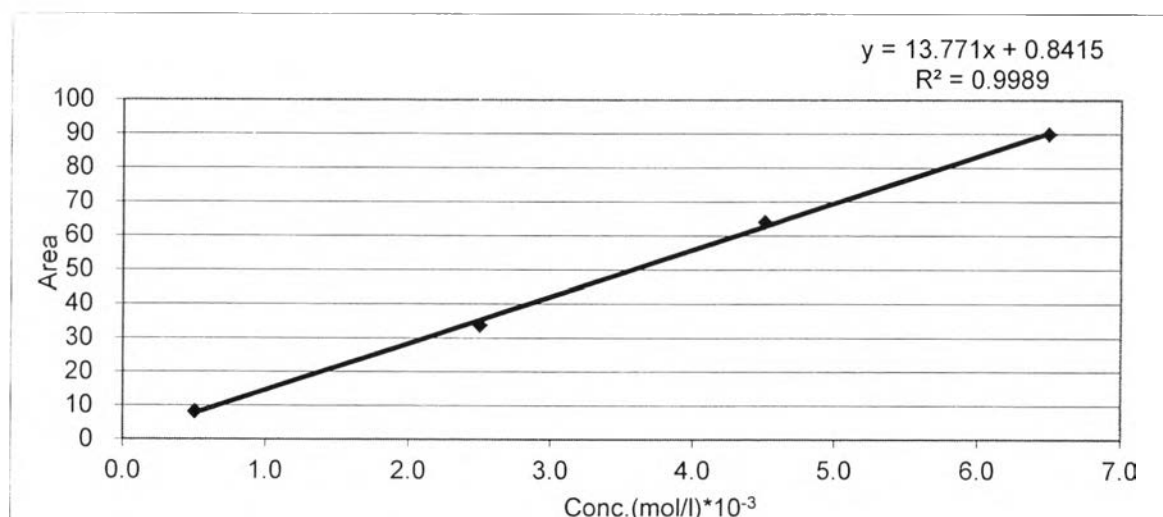


Figure B1 Calibration curve of piperazine standard.

Analysis of Piperazine by GC

After oven dry of the impregnated activated carbon, it was grinded and weighed (sample1 (0.0607g) and sample2 (0.0810g)) to dissolve the piperazine in 5 mL ethanol and in the final ethanol solution of 10 mL. Next, 5 injections of samples were injected into the GC-FID to find the unknown concentration of piperazine using the calibration curve from the equation $y = 13.771x + 0.8415$; $y =$ peak area of piperazine, $13.771 =$ sensitivity, $0.8415 =$ interception, $x =$ unknown piperazine concentration.

$$M = g/M_w * 1000/V$$

$$M = x = \text{unknown piperazine concentration } (2.7753 \text{ M} \times 10^{-3})$$

$$M_w = \text{molecular weight of piperazine } (86.14 \text{ g/mol}),$$

$$V = \text{volume of solvent } (10 \text{ mL}), \quad g = \text{weight of piperazine loading } (0.2391 \text{ gram} \times 10^{-2})$$

$$\text{Weight of Act. C} = \text{Total weight} - \text{weight of piperazine}$$

$$\text{Piperazine loading (wt\%)} = \frac{\text{Weight of piperazine}}{\text{Weight of activated carbon} + \text{piperazine}} * 100$$

Table B1 Sample 1 and 2; 28.57 wt % piperazine loading on activated carbon

	Sample weight (g)	Peak area*	Pz (g)*	Pz loading (wt %)
Sample 1	0.0607	30.84 ± 7.738	0.001876 ± 0.00048	3.0913 ± 0.7974
Sample 2	0.0810	41.61 ± 5.575	0.002550 ± 0.00035	3.1480 ± 0.4306
			Actual Piperazine loading (wt %)	3.1197

Pz* = 5 average piperazine injections ± SD, Peak area* = 5 average peak area ± SD

$$\text{Actual Piperazine loading (wt\%)} \bar{x} = \frac{1}{2}(x_1 + x_2)$$

; \bar{x} = actual piperazine loading (3.1197 wt%), x_1 = average piperazine loading of sample 1 (3.0913 wt%), x_2 = average piperazine loading of sample 2 (3.1480 wt%)

2nd Alternative Analysis of Piperazine by CHN

Table B2 Pure activated carbon and 28.57 wt % piperazine loading on activated carbon

	Weight (g) (Aver. 2runs)	Carbon (%) (Aver. 2 runs)	Hydrogen (%) (Aver. 2runs)	Nitrogen % (Aver. 2 runs)
Pure Act.C (Aver. 2runs)	0.15065 ± 0.0001	65.22 ± 0.8140	0.3804 ± 0.0098	0.49072 ± 0.0120
28.57wt%Pz-Act.C (Aver. 2runs)	0.15170 ± 0.0008	68.26 ± 1.4000	2.6800 ± 0.0120	1.6572 ± 0.0754

Table B3 Normalized data of Table B2

	Weight (g) (Aver. 2runs)	Carbon (%) (Aver. 2 runs)	Hydrogen (%) (Aver. 2runs)	Nitrogen (%) (Aver. 2 runs)
Pure Act.C (Aver. 2runs)	0.1500 ± 0.0001	64.9386 ± 0.8140	0.3788 ± 0.0098	0.4886 ± 0.0120
28.57wt % Pz-Act.C (Aver. 2runs)	0.1500 ± 0.0008	67.4951 ± 1.4000	2.6500 ± 0.0120	1.6386 ± 0.0754
			Actual Piperazine loading (wt %)	3.5379

$$Total\ N\ \%_{PZ} = N\ \%_{Pz-Act.C} - N\ \%_{Act.C}$$

$$Total\ weight\ of\ Nitrogen\ (g) = \frac{Total\ N\ \%_{PZ}}{100} * weight\ of\ adsorbent$$

$$Total\ weight\ of\ Piperazine\ (g) = \frac{Total\ weight\ of\ Nitrogen}{Mw\ of\ Nitrogen\ in\ Piperazine} * Mw\ of\ Piperazine$$

$$Actual\ Piperazine\ loading\ (wt\%) = \frac{Total\ weight\ of\ Piperazine}{weight\ of\ adsorbent} * 100$$

; Total N %_{PZ} = 1.15%, N %_{Pz-Act.C} = 1.6386%, N %_{Act.C} = 0.4886%, total weight of nitrogen = 1.7250*10⁻³g, total weight of piperazine = 5.3068*10⁻³g, weight of adsorbent = 0.15g, Mw = molecular weight, Mw of Nitrogen in Piperazine = 28 g mol⁻¹, Mw of Piperazine = 86.14 g mol⁻¹, actual piperazine loading = 3.5379 wt%

APPENDIX C Specification Of Activated Carbon And Equipment

Table C1 Specification of palm shell activated carbon

TECHNICAL SPECIFICATION	
Product:	Granular activated palm shell based carbon
Grade:	PH5 12 X 40 P
Test Method:	ASTM, Unless otherwise stated
Application:	Water purification, deodorization, decolourization, dechlorination and removal of organic compound in water
PHYSICAL PROPERTIES	SPECIFICATION
Apparent density (g/cc)	min. 0.48
Moisture (%w/w) (as packed)	max. 8
Ash (%w/w) (as packed)	max. 5
pH	9-11
Surface area (m ² /g)	min. 1150
Iodine Number (mg/g) (AWWA B604)	min. 1100
Hardness Number (%) (ASTM 3802-79)	min. 98

Mass flow controller specifications:

- a. Model: GFC 17
- b. Flow range: 0-100 %
- c. Accuracy: ± 1.5 %
- d. Repeatability: ± 0.25 %
- e. Max. Gas Pressure: 1000 psig
- f. Brand: AALBORG

Rotameter specifications:

- a. Model: PMR1-010266
- b. Accuracy: ± 2 % full-scale
- c. Repeatability: ± 0.25 %
- d. Max Pressure: 200 psig
- e. Brand: Cole-Parmer

APPENDIX D Preparation For Standard Carbon Dioxide Concentration

Preparation of 1%CO₂ concentration from 15% premixed CO₂

$$\%CO_2 = \left(\frac{\text{flow of } CO_2}{\text{flow of } CO_2 + N_2} \right) * \text{Concentration of } \frac{CO_2}{N_2} * 100$$

Example of calculation of CO₂= 1%,

Flow of N₂= 70 mL/min (fixed), CO₂ premixed concentration, $\frac{CO_2}{N_2} = 0.15$

Flow of CO₂= required flow (5.0001mL/min)

TABLE D1 Required flow rate and actual flow rate for different carbon dioxide concentration

1% CO ₂	Peak Area	Flow of N ₂ (mL/min)	Flow of CO ₂ (mL/min)	Actual N ₂ flow (mL/min)	Actual CO ₂ flow (mL/min)		
Trial(1)	10.83	70	5.0001	70	5		
Trial(2)	11.02			AVG	10.9467		
Trial(3)	10.99			STDEV	0.1021	%SD	0.9331

2% CO ₂	Peak Area	Flow of N ₂ (mL/min)	Flow of CO ₂ (mL/min)	Actual N ₂ flow (mL/min)	Actual CO ₂ flow (mL/min)		
Trial(1)	15.00	70	10.7687	70	11		
Trial(2)	15.11			AVG	15.0900		
Trial(3)	15.16			STDEV	0.0800	%SD	0.5424

3% CO ₂	Peak Area	Flow of N ₂ (mL/min)	Flow of CO ₂ (mL/min)	Actual N ₂ flow (mL/min)	Actual CO ₂ flow (mL/min)		
Trial(1)	19.47	70	17.5000	70	18		
Trial(2)	19.67			AVG	19.49		
Trial(3)	19.33			STDEV	0.1709	%SD	0.8768

4% CO ₂	Peak Area	Flow of N ₂ (mL/min)	Flow of CO ₂ (mL/min)	Actual N ₂ flow (mL/min)	Actual CO ₂ flow (mL/min)		
Trial(1)	24.81	70	25.4556	70	26		
Trial(2)	24.83			AVG	24.7467		
Trial(3)	24.60			STDEV	0.1274	%SD	0.5149

5% CO ₂	Area	Flow of N ₂ (mL/min)	Flow of CO ₂ (mL/min)	Actual N ₂ flow (mL/min)	Actual CO ₂ flow (mL/min)		
Trial(1)	30.02	70	34.9983	70	35		
Trial(2)	30.26			AVG	30.0333		
Trial(3)	29.82			STDEV	0.2203	%SD	0.7335

TABLE D2 Actual flow (mL/min) from mass flow controllers by bubble flowmeter

Flow of CO ₂ (mL/min)	Actual Flow ^a (mL/min)			Average Actual Flow (mL/min)	Actual Flow	Actual (%) CO ₂ concentration
	Trial 1	Trial 2	Trial 3			
5	18	18	18	18		2.0558
11	26.2	26.2	26.3	26.23		2.8192
18	36.2	36.1	36.2	36.17		3.6291
26	47.2	47	47.3	47.17		4.4084
35	59.1	59.2	59.1	59.13		5.1429
Flow of N ₂ (mL/min)	Actual Flow ^a (mL/min)			Average Actual Flow (mL/min)	Actual Flow	Actual (%) CO ₂ concentration
	Trial 1	Trial 2	Trial 3			
70	113	113	114	113.33		

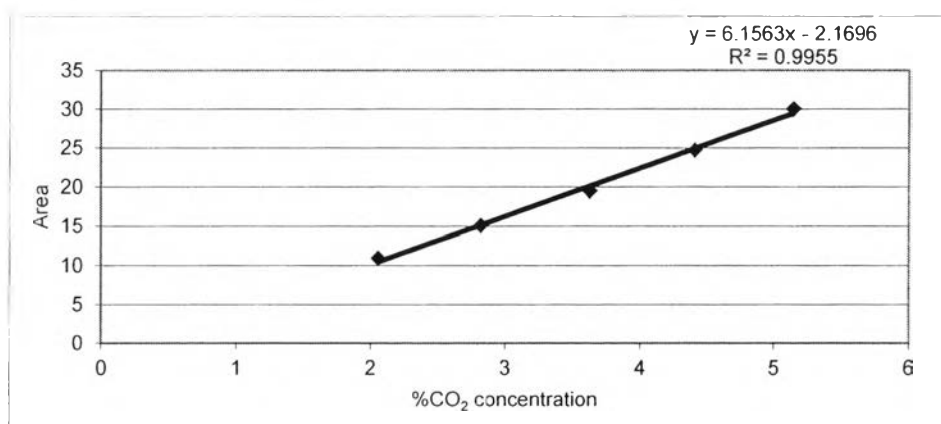
Actual Flow^a= measured by bubble flow meter

$$\text{Actual \%CO}_2 = \left(\frac{\text{average actual flow of CO}_2}{\text{average actual flow of CO}_2 + \text{N}_2} \right) * \text{Concentration of } \frac{\text{CO}_2}{\text{N}_2} * 100$$

Example of calculation of CO₂=2.0558%

Average actual flow of N₂= 1133.33 mL/min, CO₂ premixed concentration, $\frac{\text{CO}_2}{\text{N}_2} = 0.15$

Average actual flow of CO₂= 18 mL/min

**Figure D1** Calibration curve of standard CO₂ concentration for 5 mL /min.

Preparation for CO₂ adsorption at 4.4084 %CO₂ concentration and adsorbent

After line cleaning-up, 0.5 g of adsorbent in the column was pre-dry at 60 °C for 1h while purging with N₂ gas at 113 mL/min. Then, 4.4084 % premixed CO₂ of dry gas at 5 mL/min was allowed to flow into the packed bed adsorber to carry out the experiment at 25, 45 and 55 °C at atmospheric pressure until the CO₂ concentrations of feed gas at the outlet of adsorber reaches equilibrium.

TABLE D3 Adsorption data from Gas Chromatogram of pure Act. C at 25 °C

Time (min)	Peak area of CO ₂	Retention Time	C _A	C _A /C ₀
0	0	-	0.3524	0.08018
3	0	-	0.3524	0.08018
6	0	-	0.3524	0.08018
9	0	-	0.3524	0.08018
12	0	-	0.3524	0.08018
15	0	-	0.3524	0.08018
18	0	-	0.3524	0.08018
21	4.60	1.45	1.0996	0.25017
24	19.52	1.45	3.5232	0.80155
27	22.63	1.43	4.0283	0.91648
30	23.01	1.45	4.0901	0.93052
33	23.65	1.45	4.1940	0.95418
36	23.88	1.45	4.2314	0.96267
39	24.05	1.45	4.2590	0.96896
42	24.33	1.43	4.3045	0.97930
45	24.54	1.42	4.3386	0.98707
48	24.66	1.45	4.3581	0.99150
51	24.65	1.45	4.3564	0.99113
54	24.89	1.45	4.3954	1
57	24.83	1.47	4.3857	0.99778
60	24.83	1.47	4.3857	0.99778

Retention Time= time carbon dioxide appear, C₀ = CO₂ concentrations of the influent, C_A = CO₂ concentration of effluent stream of the column

From the calibration curve obtaining an equation $y = 6.1563x - 2.1696$; y = peak area of CO₂, 6.1563 =sensitivity, -2.1696= interception, $x = C_A$.

TABLE D4 Adsorption data from Gas Chromatogram of pure Act. C at 45 °C

Time (min)	Peak area of CO ₂	Retention Time	C _A	C _A /C ₀
0	0	-	0.3524	0.0806
3	0	-	0.3524	0.0806
6	0	-	0.3524	0.0806
9	0	-	0.3524	0.0806
12	18.08	1.43	3.2892	0.7519
15	20.63	1.43	3.7035	0.8466
18	21.37	1.43	3.8237	0.8741
21	23.08	1.42	4.1014	0.9376
24	23.62	1.43	4.1891	0.9577
27	23.72	1.45	4.2054	0.9614
30	24.13	1.43	4.2720	0.9766
33	24.09	1.43	4.2655	0.9751
36	24.15	1.43	4.2752	0.9773
39	24.28	1.40	4.2963	0.9822
42	24.76	1.43	4.3743	1
45	24.74	1.42	4.3711	0.9993

TABLE D5 Adsorption data from Gas Chromatogram of pure Act. C at 55 °C

Time (min)	Peak area of CO ₂	Retention Time	C _A	C _A /C ₀
0	0	-	0.3524	0.0805
3	0	-	0.3524	0.0805
6	0	-	0.3524	0.0805
9	4.53	1.45	1.0883	0.2486
12	22.97	1.43	4.0836	0.9328
15	23.45	1.43	4.1615	0.9506
18	24.04	1.43	4.2574	0.9725
21	24.59	1.40	4.3467	0.9929
24	24.49	1.42	4.3305	0.9892
27	24.53	1.43	4.3370	0.9907
30	24.48	1.45	4.3288	0.9889
33	24.78	1.45	4.3776	1

TABLE D6 Adsorption data from Gas Chromatogram of 3.12wt% Piperazine-Activated carbon at 25 °C

Time (min)	Peak area of CO ₂	Retention Time	C _A	C _A /C ₀
0	0	-	0.3524	0.0799
3	0	-	0.3524	0.0799
6	0	-	0.3524	0.0799
9	0	-	0.3524	0.0799
12	0	-	0.3524	0.0799
15	0	-	0.3524	0.0799
18	0	-	0.3524	0.0799
21	0	-	0.3524	0.0799
24	0	-	0.3524	0.0799
27	0	-	0.3524	0.0799
30	18.10	1.43	3.2925	0.7469
33	19.97	1.45	3.5963	0.8158
36	21.00	1.43	3.7636	0.8537
39	22.75	1.45	4.0478	0.9182
42	23.04	1.45	4.0949	0.9289
45	23.84	1.45	4.2249	0.9584
48	23.72	1.42	4.2054	0.9539
51	23.86	1.45	4.2281	0.9591
54	24.10	1.45	4.2671	0.9679
57	24.08	1.45	4.2639	0.9672
60	24.89	1.45	4.3954	0.9971
63	24.08	1.45	4.2639	0.9672
66	24.95	1.45	4.4052	0.9993
69	24.97	1.43	4.4084	1

TABLE D7 Adsorption data from Gas Chromatogram of 3.12wt% Piperazine-Activated carbon at 45 °C

Time (min)	Peak area of CO ₂	Retention Time	C _A	C _A /C ₀
0	0	-	0.3524	0.0810
3	0	-	0.3524	0.0810
6	0	-	0.3524	0.0810
9	0	-	0.3524	0.0810
12	0	-	0.3524	0.0810
15	0	-	0.3524	0.0810
18	21.21	1.40	3.7977	0.8727
21	22.86	1.43	4.0657	0.9343
24	23.69	1.43	4.2005	0.9653
27	23.97	1.45	4.2460	0.9757
30	24.62	1.43	4.3516	1
33	24.53	1.43	4.3370	0.9966
36	24.55	1.40	4.3402	0.9974
39	24.37	1.43	4.3110	0.9907
42	24.62	1.42	4.3516	1

TABLE D8 Adsorption data from Gas Chromatogram of 3.12wt% Piperazine-Activated carbon at 55 °C

Time (min)	Peak area of CO ₂	Retention Time	C _A	C _A /C ₀
0	0	-	0.3524	0.0811
3	0	-	0.3524	0.0811
6	0	-	0.3524	0.0811
9	0	-	0.3524	0.0811
12	16.59	1.45	3.0472	0.7010
15	22.41	1.45	3.9926	0.9185
18	23.93	1.45	4.2395	0.9753
21	24.49	1.43	4.3305	0.9963
24	24.59	1.42	4.3467	1
27	24.14	1.43	4.2736	0.9832
30	24.50	1.43	4.3321	0.9966

TABLE D8 Adsorption data from Gas Chromatogram of moisturized Act.C at 25 °C

Time (min)	Peak area of CO ₂	Retention Time	C _A	C _A /C ₀
0	0	-	0.3524	0.0798
3	0	-	0.3524	0.0798
6	0	-	0.3524	0.0798
9	19.49	1.45	3.5182	0.7966
12	22.47	1.42	4.0023	0.9062
15	23.97	1.43	4.2460	0.9614
18	23.85	1.45	4.2265	0.9570
21	24.15	1.43	4.2752	0.9680
24	24.54	1.43	4.3386	0.9823
27	25.02	1.45	4.4165	1
30	24.69	1.40	4.3629	0.9879
33	24.54	1.45	4.3386	0.9823
36	24.78	1.43	4.3776	0.9911
39	24.67	1.45	4.3597	0.9871

TABLE D9 Adsorption data from Gas Chromatogram of moisturized Act.C at 45 °C

Time (min)	Peak area of CO ₂	Retention Time	C _A	C _A /C ₀
0	0	-	0.3524	0.0823
3	0	-	0.3524	0.0823
6	22.37	1.45	3.9861	0.9306
9	23.16	1.45	4.1144	0.9606
12	23.57	1.45	4.1810	0.9761
15	23.85	1.45	4.2265	0.9867
18	23.95	1.40	4.2427	0.9905
21	24.20	1.45	4.2834	1
24	24.20	1.45	4.2834	1

TABLE D10 Adsorption data from Gas Chromatogram of moisturized Act.C at 55 °C

Time (min)	Peak area of CO ₂	Retention Time	C _A	C _A /C ₀
0	0	-	0.3524	0.0794
3	6.36	1.45	1.3855	0.3122
6	24.12	1.45	4.2704	0.9623
9	24.81	1.43	4.3824	0.9876
12	24.61	1.42	4.3500	0.9802
15	25.01	1.43	4.4149	0.9949
18	25.15	1.40	4.4377	1

TABLE D11 Required flow rate and actual flow rate for different carbon dioxide concentration (2nd Calibration curve)

1% CO ₂	Peak Area	Flow of N ₂ (mL/min)	Flow of CO ₂ (mL/min)	Actual N ₂ flow (mL/min)	Actual CO ₂ flow (mL/min)		
Trial(1)	12.69	70	5.0001	70	5		
Trial(2)	12.57			AVG	12.65		
Trial(3)	12.69			STDEV	0.069282	%SD	0.547684

2% CO ₂	Peak Area	Flow of N ₂ (mL/min)	Flow of CO ₂ (mL/min)	Actual N ₂ flow (mL/min)	Actual CO ₂ flow (mL/min)		
Trial(1)	17.61	70	10.7687	70	11		
Trial(2)	17.86			AVG	17.72		
Trial(3)	17.69			STDEV	0.127671	%SD	0.720494

3% CO ₂	Peak Area	Flow of N ₂ (mL/min)	Flow of CO ₂ (mL/min)	Actual N ₂ flow (mL/min)	Actual CO ₂ flow (mL/min)		
Trial(1)	22.64	70	17.5000	70	18		
Trial(2)	22.63			AVG	19.49		
Trial(3)	22.54			STDEV	0.055076	%SD	0.243662

4% CO ₂	Peak Area	Flow of N ₂ (mL/min)	Flow of CO ₂ (mL/min)	Actual N ₂ flow (mL/min)	Actual CO ₂ flow (mL/min)		
Trial(1)	27.82	70	25.4556	70	26		
Trial(2)	28.04			AVG	29.03333		
Trial(3)	28.24			STDEV	0.210079	%SD	0.749391

5% CO ₂	Area	Flow of N ₂ (mL/min)	Flow of CO ₂ (mL/min)	Actual N ₂ flow (mL/min)	Actual CO ₂ flow (mL/min)		
Trial(1)	32.91	70	34.9983	70	35		
Trial(2)	33.17			AVG	33.02667		
Trial(3)	23.00			STDEV	0.132035	%SD	0.399784

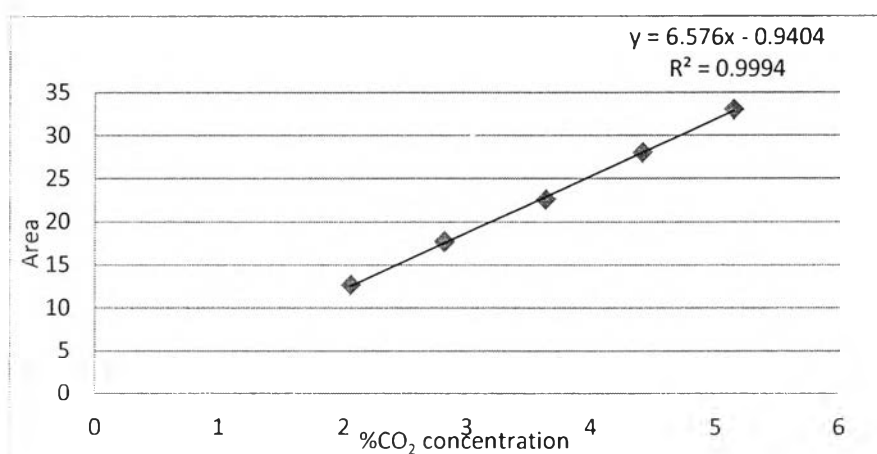


Figure D2 2nd Calibration curve of standard CO₂ concentration for 5mL /min.

The 2nd calibration curve was done to improve the accuracy of the measurement as time passed.

From the calibration curve obtaining an equation $y = 6.576x - 0.9404$; y = peak area of CO₂, 6.576 = sensitivity, -0.9494 = interception, $x = C_A$.

TABLE D12 Adsorption data from Gas Chromatogram of moisturized 3.12 wt % Act.C-piperazine at 25 °C

Time (min)	Peak area of CO ₂	Retention Time	C _A	C _A /C ₀
0	0	-	0.14300	0.03256
3	0	-	0.14300	0.03256
6	0	-	0.14300	0.03256
9	0	-	0.14300	0.03256
12	0	-	0.14300	0.03256
15	16.49	1.33	2.65061	0.60354
18	23.79	1.30	3.76076	0.85630
21	25.32	1.33	3.99337	0.90928
24	26.28	1.33	4.13936	0.94252
27	26.39	1.28	4.15608	0.94633
30	26.99	1.33	4.24732	0.96711
33	26.89	1.33	4.23117	0.96364
36	26.49	1.28	4.17129	0.94979
39	27.29	1.33	4.29294	0.97749
42	27.10	1.33	4.26405	0.97091
45	27.94	1.30	4.39179	1

TABLE D13 Adsorption data from Gas Chromatogram of moisturized 3.12 wt % Act.C-piperazine at 45 °C

Time (min)	Peak area of CO ₂	Retention Time	C _A	C _A /C ₀
0	0	-	0.14300	0.03256
3	2.40	1.35	0.50797	0.11749
6	2.56	1.35	0.53230	0.12312
9	19.04	1.28	3.03838	0.70278
12	24.53	1.32	3.87324	0.89589
15	25.99	1.32	4.09526	0.94724
18	26.95	1.28	4.24124	0.98101
21	26.79	1.33	4.21691	0.97538
24	26.81	1.32	4.21995	0.97608
27	26.75	1.28	4.20931	0.97362
30	27.49	1.32	4.32336	1
33	27.35	1.33	4.30207	0.99508

TABLE D14 Adsorption data from Gas Chromatogram of moisturized 3.12 wt % Act.C-piperazine at 55 °C

Time (min)	Peak area of CO ₂	Retention Time	C _A	C _A /C ₀
0	0	-	0.14300	0.03256
3	6.42	1.33	1.11928	0.25592
6	14.69	1.32	2.37689	0.54335
9	22.60	1.30	3.57974	0.81850
12	24.71	1.33	3.90061	0.89187
15	25.46	1.33	4.01466	0.91794
18	27.82	1.30	4.37354	1

TABLE D15 Required flow rate and actual flow rate for different carbon dioxide concentration (3rd Calibration curve)

1% CO ₂	Peak Area	Flow of N ₂ (mL/min)	Flow of CO ₂ (mL/min)	Actual N ₂ flow (mL/min)	Actual CO ₂ flow (mL/min)		
Trial(1)	12.73	70	5.0001	70	5		
Trial(2)	12.60			AVG	12.63667		
Trial(3)	12.58			STDEV	0.081445	%SD	0.64452

2% CO ₂	Peak Area	Flow of N ₂ (mL/min)	Flow of CO ₂ (mL/min)	Actual N ₂ flow (mL/min)	Actual CO ₂ flow (mL/min)		
Trial(1)	17.77	70	10.7687	70	11		
Trial(2)	17.90			AVG	17.84		
Trial(3)	17.85			STDEV	0.06557	%SD	0.36757

3% CO ₂	Peak Area	Flow of N ₂ (mL/min)	Flow of CO ₂ (mL/min)	Actual N ₂ flow (mL/min)	Actual CO ₂ flow (mL/min)		
Trial(1)	22.78	70	17.5000	70	18		
Trial(2)	22.85			AVG	22.8767		
Trial(3)	23.00			STDEV	0.1124	%SD	0.49132

4% CO ₂	Peak Area	Flow of N ₂ (mL/min)	Flow of CO ₂ (mL/min)	Actual N ₂ flow (mL/min)	Actual CO ₂ flow (mL/min)		
Trial(1)	28.58	70	25.4556	70	26		
Trial(2)	28.53			AVG	28.63		
Trial(3)	28.78			STDEV	0.13229	%SD	0.46206

5% CO ₂	Area	Flow of N ₂ (mL/min)	Flow of CO ₂ (mL/min)	Actual N ₂ flow (mL/min)	Actual CO ₂ flow (mL/min)		
Trial(1)	33.05	70	34.9983	70	35		
Trial(2)	32.89			AVG	32.9533		
Trial(3)	32.92			STDEV	0.08505	%SD	0.25809

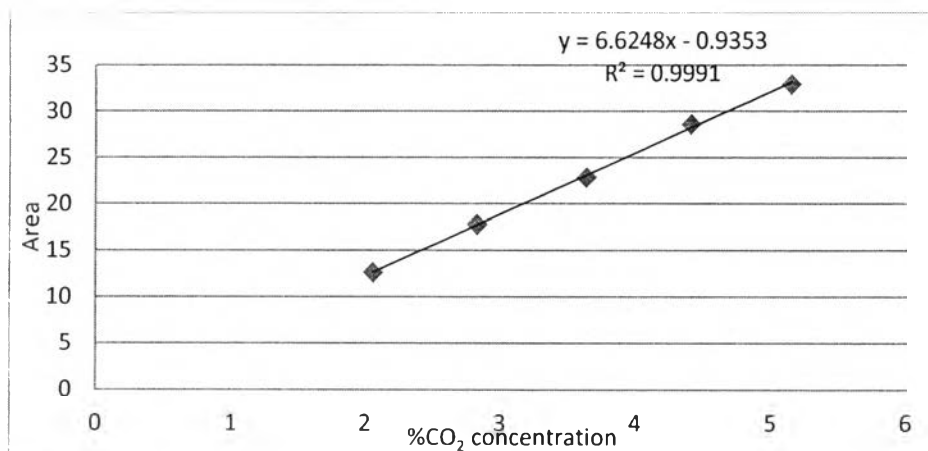


Figure D3 3rd Calibration curve of standard CO₂ concentration for 5mL /min.

From the calibration curve obtaining an equation $y = 6.6248x - 0.9353$; y = peak area of CO₂, 6.6248=sensitivity, -0.9353= interception, $x = C_A$.

TABLE D16-1 Adsorption data from Gas Chromatogram of pure Act. C at 25 °C for regeneration

Time (min)	Peak area of CO ₂	Retention Time	C_A	C_A / C_0
0	0	-	0.1412	0.0317
3	0	-	0.1412	0.0317
6	0	-	0.1412	0.0317
9	0	-	0.1412	0.0317
12	0	-	0.1412	0.0317
15	0	-	0.1412	0.0317
18	0	-	0.1412	0.0317
21	13.82	1.43	2.2273	0.4994
24	25.82	1.45	4.0462	0.9073
27	26.63	1.45	4.1609	0.9330
30	27.48	1.47	4.2892	0.9618
33	27.76	1.45	4.3315	0.9712
36	28.08	1.47	4.3798	0.9821
39	28.12	1.42	4.3858	0.9834
42	28.13	1.45	4.3873	0.9838
45	28.16	1.45	4.3919	0.9848
48	28.50	1.45	4.4432	0.9963
51	28.33	1.45	4.4175	0.9905
54	28.61	1.42	4.4598	1

TABLE D16-2 Adsorption data from Gas Chromatogram of regenerated Act. C at 25 °C

Time (min)	Peak area of CO ₂	Retention Time	C _A	C _A /C ₀
0	0	-	0.1412	0.0317
3	0	-	0.1412	0.0317
6	0	-	0.1412	0.0317
9	0	-	0.1412	0.0317
12	0	-	0.1412	0.0317
15	0	-	0.1412	0.0317
18	3.14	1.47	0.6152	0.1377
21	24.39	1.45	3.8228	0.8554
24	26.95	1.47	4.2092	0.9519
27	27.72	1.45	4.3255	0.9679
30	27.98	1.42	4.3647	0.9767
33	27.73	1.45	4.3270	0.9683
36	28.12	1.45	4.3858	0.9814
39	28.38	1.48	4.4251	0.9902
42	28.52	1.47	4.4462	0.9949
45	28.52	1.47	4.4462	0.9949
48	28.67	1.43	4.4689	1

TABLE D17-1 Adsorption data from Gas Chromatogram of 3.12wt% Piperazine-Activated carbon at 25 °C for regeneration

Time (min)	Peak area of CO ₂	Retention Time	C _A	C _A /C ₀
0	0	-	0.1412	0.0315
3	0	-	0.1412	0.0315
6	0	-	0.1412	0.0315
9	0	-	0.1412	0.0315
12	0	-	0.1412	0.0315
15	0	-	0.1412	0.0315
18	0	-	0.1412	0.0315
21	0	-	0.1412	0.0315
24	0	-	0.1412	0.0315
27	4.30	1.45	0.7903	0.1761
30	21.02	1.38	3.3141	0.7384
33	24.37	1.45	3.8198	0.8510
36	25.19	1.43	3.9436	0.8786
39	26.08	1.43	4.0779	0.9085
42	26.80	1.43	4.1866	0.9327
45	26.85	1.43	4.1941	0.9344
48	27.26	1.40	4.2560	0.9482
51	27.50	1.45	4.2923	0.9563
54	27.81	1.43	4.3390	0.9667
57	27.95	1.43	4.3602	0.9714
60	28.53	1.45	4.4477	0.9909
63	28.80	1.45	4.4885	1

TABLE D17-2 Adsorption data from Gas Chromatogram of regenerated 3.12wt% Piperazine-Activated carbon at 25 °C

Time (min)	Peak area of CO ₂	Retention Time	C _A	C _A /C ₀
0	0	-	0.1412	0.0315
3	0	-	0.1412	0.0315
6	0	-	0.1412	0.0315
9	0	-	0.1412	0.0315
12	0	-	0.1412	0.0315
15	0	-	0.1412	0.0315
18	0	-	0.1412	0.0315
21	0	-	0.1412	0.0315
24	10.28	1.45	1.6929	0.3810
27	22.73	1.45	3.5722	0.8040
30	24.64	1.42	3.8605	0.8689
33	26.36	1.45	4.1202	0.9273
36	26.77	1.45	4.1821	0.9412
39	27.20	1.43	4.2470	0.9558
42	27.77	1.43	4.3330	0.9752
45	27.41	1.45	4.2787	0.9630
48	27.67	1.40	4.3179	0.9718
51	27.97	1.43	4.3632	0.9820
54	27.88	1.43	4.3496	0.9789
57	28.12	1.43	4.3858	0.9871
60	28.40	1.42	4.4281	0.9966
63	28.50	1.45	4.4432	1

TABLE D18 Required flow rate and actual flow rate for different carbon dioxide concentration (4th Calibration curve)

1% CO ₂	Peak Area	Flow of N ₂ (mL/min)	Flow of CO ₂ (mL/min)	Actual N ₂ flow (mL/min)	Actual CO ₂ flow (mL/min)		
Trial(1)	7.11	70	5.0001	70	5		
Trial(2)	7.01			AVG	7.08667		
Trial(3)	7.14			STDEV	0.06807	%SD	0.96052

2% CO ₂	Peak Area	Flow of N ₂ (mL/min)	Flow of CO ₂ (mL/min)	Actual N ₂ flow (mL/min)	Actual CO ₂ flow (mL/min)		
Trial(1)	10.39	70	10.7687	70	11		
Trial(2)	10.61			AVG	10.4833		
Trial(3)	10.45			STDEV	0.11372	%SD	0.108482

3% CO ₂	Peak Area	Flow of N ₂ (mL/min)	Flow of CO ₂ (mL/min)	Actual N ₂ flow (mL/min)	Actual CO ₂ flow (mL/min)		
Trial(1)	13.85	70	17.5000	70	18		
Trial(2)	13.89			AVG	13.88		
Trial(3)	13.91			STDEV	0.03055	%SD	0.22005

4% CO ₂	Peak Area	Flow of N ₂ (mL/min)	Flow of CO ₂ (mL/min)	Actual N ₂ flow (mL/min)	Actual CO ₂ flow (mL/min)		
Trial(1)	16.66	70	25.4556	70	26		
Trial(2)	16.71			AVG	16.8233		
Trial(3)	17.10			STDEV	0.2409	%SD	1.43195

5% CO ₂	Area	Flow of N ₂ (mL/min)	Flow of CO ₂ (mL/min)	Actual N ₂ flow (mL/min)	Actual CO ₂ flow (mL/min)		
Trial(1)	19.80	70	34.9983	70	35		
Trial(2)	19.33			AVG	19.5967		
Trial(3)	19.66			STDEV	0.24132	%SD	1.23141

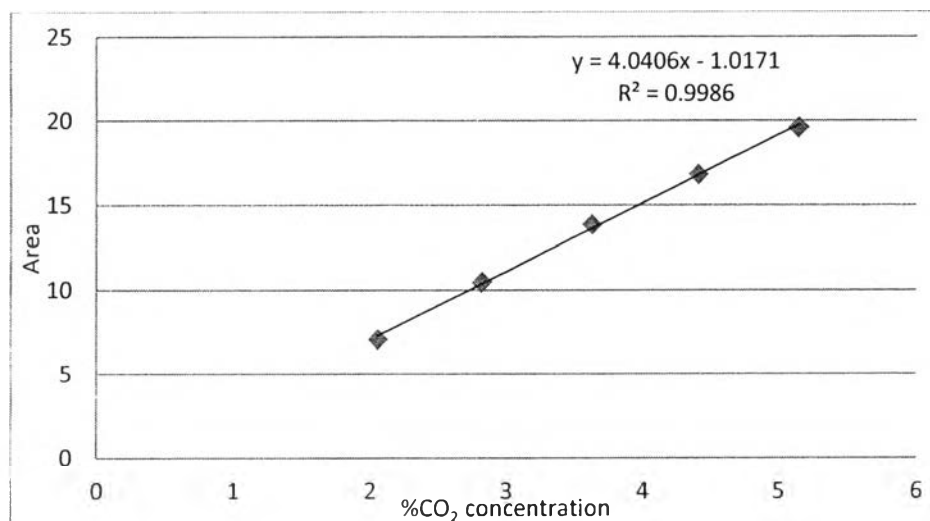


Figure D4 4th Calibration curve of standard CO₂ concentration for 3mL /min.

From the calibration curve obtaining an equation $y = 4.0406x - 1.0171$; y = peak area of CO₂, 4.0406= sensitivity, -1.0171= interception, $x = C_A$.

TABLE D19 Adsorption data from Gas Chromatogram of Biopolymer-Pz at 25 °C

Time (min)	Peak area of CO ₂	Retention Time	C_A	C_A / C_0
0	0	-	0.2517	0.0579
3	13.03	1.28	3.4765	0.7983
6	15.92	1.33	4.1917	0.9625
9	15.90	1.32	4.1868	0.9614
12	16.27	1.33	4.2783	0.9824
15	15.71	1.32	4.1396	0.9506
18	15.81	1.33	4.1645	0.9562
21	16.13	1.28	4.2437	0.9744
24	16.58	1.32	4.3551	1

TABLE D20 Adsorption data from Gas Chromatogram of moisturized Biopolymer-Pz at 25 °C

Time (min)	Peak area of CO ₂	Retention Time	C _A	C _A /C ₀
0	0	-	0.2517	0.0579
3	14.57	1.32	3.8576	0.8873
6	16.12	1.32	4.2412	0.9755
9	16.20	1.33	4.2610	0.9801
12	16.21	1.32	4.2635	0.9806
15	16.04	1.30	4.2214	0.9710
18	16.15	1.28	4.2487	0.9772
21	16.18	1.30	4.2561	0.9789
24	16.55	1.32	4.3476	1

TABLE D21 Summarized data obtained for CO₂ adsorption with 4.4084% CO₂ concentration

Adsorbent Type	Weight (g)	Adsorption Temperature (°C)	Flow rate (mL/min)	Molar flow rate (mol/min) x 10 ⁻⁴	t _{tot} (min)	t _{math/lab} (min)	t _q (min)	C _c	Q _{ads} (mmol/g)	Q _{eds} (mg/g)
Pure Act.C	0.5226	25	4.98	2.04	60	38.2541	21.7458	0.044084	0.3742	16.4654
	0.5068	45	4.95	2.02	45	33.0667	11.9333	0.044084	0.2101	9.2455
	0.5041	55	5.01	2.05	33	23.3030	9.6970	0.044084	0.1737	7.6446
3.12wt%Pz-Ac	0.5005	25	5.02	2.05	69	39.8789	29.1211	0.044084	0.5266	23.1689
	0.5055	45	5.04	2.06	42	26.0345	15.9656	0.044084	0.2870	12.6268
	0.5080	55	5.13	2.10	30	19.0693	10.9307	0.044084	0.1990	8.7560
Moisturized Act.C	0.5450	25	5.22	2.13	39	30.9511	8.0489	0.044084	0.1390	6.1152
	0.5063	45	5.05	2.07	24	19.4038	4.5962	0.044084	0.0826	3.6365
	0.5024	55	5.09	2.08	18	14.3307	3.6693	0.044084	0.0670	2.9488
Moisturized 3.12wt% Pz-Act.C	0.5124	25	5.04	2.06	45	29.2004	15.7996	0.044084	0.2802	12.3274
	0.5059	45	5.05	2.07	33	24.6201	8.3799	0.044084	0.1511	6.6486
	0.5001	55	5.11	2.09	18	11.8321	6.1679	0.044084	0.1136	4.9992
Repeated Pure Act.C	0.5041	25	5.06	2.07	54	32.6976	21.3024	0.044084	0.3855	16.9617
Regenerated Pure Act.C	0.5041	25	5.10	2.09	48	28.4493	19.5507	0.044084	0.3566	15.6895
Repeated 3.12wt% Pz-Act.C	0.5079	25	5.06	2.07	63	33.0618	29.9382	0.044084	0.5377	23.6595
Regenerated 3.12wt% Pz-Act.C	0.5079	25	5.06	2.07	63	37.4134	25.5866	0.044084	0.4532	19.9407
Biopolymer-Pz	0.2490	25	3.02	1.24	24	21.3439	2.6561	0.044084	0.0581	2.5553
Moisturized Biopolymer-Pz	0.2599	25	3.02	1.24	24	21.8389	2.1611	0.044084	0.0453	1.9919

$$\text{Molar flow rate} = \frac{PxV}{R \times T}$$

Example of calculation of Pure Act.C at 25 °C

Pressure= 1atm= 101325 Pa, V= Volume (4.98 m³ x 10⁻⁶), R= 8.31451 Pa*m³*K⁻¹*mol,

T= temperature= Kelvin (K) = (25°C) +273

$$t_q = \int_0^{\infty} \left(1 - \frac{c_A}{c_0}\right) dt$$

t_q= stoichiometric time determined from the breakthrough curve via MATLAB software version 7.10.0.499

$$Q_{ads} = \frac{FC_0t_q}{W}$$

Q_{ads} = dynamic adsorption capacity (0.3742 mmol/g) F = molar flow rate (4.98 mol/min) $\times 10^{-4}$, C_0 = 0.044084, t_q = 21.7458 mins, W = 0.5226 g

Table D22 Summary of CO₂ adsorption with activated carbon and piperazine-activated carbon

	Q _{ads} (mmol/g)					
	Dry Condition		Moisture effect		Regeneration	
Adsorption Temp (°C)	Pure Act. C (Aver. 2 runs)	3.12wt%Pz-Ac (Aver. 2 runs)	Act.C	3.12wt% Pz-Act.C	Act.C	3.12wt% Pz-Act.C
25	0.3799 ± 0.0080	0.5322 ± 0.0078	0.1390	0.2802	0.3566	0.4532
45	0.2101	0.2870	0.0826	0.1511		
55	0.1737	0.1990	0.0670	0.1136		

Note:

Effect of amine = $((0.5322-0.3799)/0.3799) \times 100 = 40.09\%$ increase of adsorption

Effect of moisture = 63.41 % adsorption reduction of act. C, purely due to active site deactivation.

= 47.35 % adsorption reduction for 3.12 wt % PZ-Act. C.

Regeneration efficiency = 93.87 % and 85.16 % for act.C and 3.12 wt % PZ-Act. C

Effect of temperature:

Pure Act. C: adsorption decreases 44.70 % at 45 °C and 54.28 % at 55 °C with respect to 25 °C

Moisturized Act. C: adsorption decreases 40.58% at 45 °C and 51.80 % at 55 °C with respect to 25°C

PZ-Act. C: adsorption decreases 46.07 % at 45 °C and 62.61 % at 55 °C with respect to 25°C

Moisturized PZ-act. C: adsorption decreases 46% at 45 °C and 59% at 55 °C with respect to 25 °C

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