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APPENDICES

Appendix A Adsorbent Physical Characterization

The technical specification of the adsorbents that was certified by Carbokarn Co., Ltd. is summarized in Table A1.

Table A1 Physical characteristic properties of investigated adsorbents

Physical Characterization	Adsorbent Specification	
	Coconut Shell Activated Carbon (CSAC)	Palm Shell Activated Carbon (PSAC)
Apparent Density (g/cm^3)	> 0.48	> 0.48
Moisture Content (%w/w)	< 8.0	< 8.0
Ash Content (%w/w)	< 3.5	< 5.0
pH	9-11	9-11
Iodine Number (mg/g)	> 1,100	> 1,100
Hardness Number (%)	> 98.0	> 98.0

The zeta potential of all samples as a function of pH (pH_{pzc}) is summarized in Table A2.

Table A2 Zeta potential measurements of activated carbon

Adsorbents	pH_{pzc}	Adsorbents	pH_{pzc}
CSAC – Untreated	4.5	CSAC – Treated by H_2SO_4	3.3
CSAC – Treated by KOH	7.6	CSAC – Treated by HNO_3	2.5
CSAC – Treated by NaOH	7.5	CSAC – Treated by H_3PO_4	2.7
CSAC – Treated by NH_4OH	7.3	PSAC – Untreated	5.2

Nitrogen adsorption-desorption isotherms of the adsorbents were conducted using an Autosorb-1MP (Quantachrome Instrument) in Table A3.

Table A3 BET surface area, micropore volume, and average pore diameter of investigated adsorbents

Adsorbent	Physical Characterization			
	BET Surface area (m^2/g)	Micropore volume (cm^3/g)	Total pore volume (cm^3/g)	Average pore diameter (Å)
CSAC – Untreated	1,062	0.57	0.59	22.45
CSAC – Treated by KOH	900	0.48	0.50	22.29
CSAC – Treated by NaOH	1,019	0.55	0.57	22.20
CSAC – Treated by NH_4OH	1,022	0.55	0.57	22.15
CSAC – Treated by H_2SO_4	996	0.53	0.55	22.26
CSAC – Treated by HNO_3	988	0.53	0.55	22.30
CSAC – Treated by H_3PO_4	922	0.49	0.51	22.28
PSAC – Untreated	1,058	0.56	0.59	22.28

Fourier transform infrared spectroscopy (FTIR) was used to qualitatively evaluate the chemical structure of carbon materials in Table A4.

Table A4 IR assignments o functional groups on carbon surfaces

Surface group	Adsorption peaks (cm-1)						
	In reference	This work					
		CSAC	CSAC/NaOH	CSAC/NH_4OH	CSAC/H_2SO_4	CSAC/HNO_3	CSAC/H_3PO_4
-OH	3435	3430	3400	3408	3409	3394	3436
CH_2	2920	2925	2922	2925	2918	2921	2923
C=C	1629	1633	1628	1630	1629	1615	1631
C=O	1558	-	1558	1572	-	1566	-
COOH	1382-1392	-	1385	-	-	1390	1384
COC	1157	-	-	-	-	1134	-
COH	1118	1115	1120	1133	1118	-	1130

Appendix B Adsorption and Desorption Curves in Different Scale

The breakthrough curves of methane and carbon dioxide were plotted in terms of concentration ratio versus time, as shown in Figures 4.3 and 4.4 are shown in Figure B1 and B2.

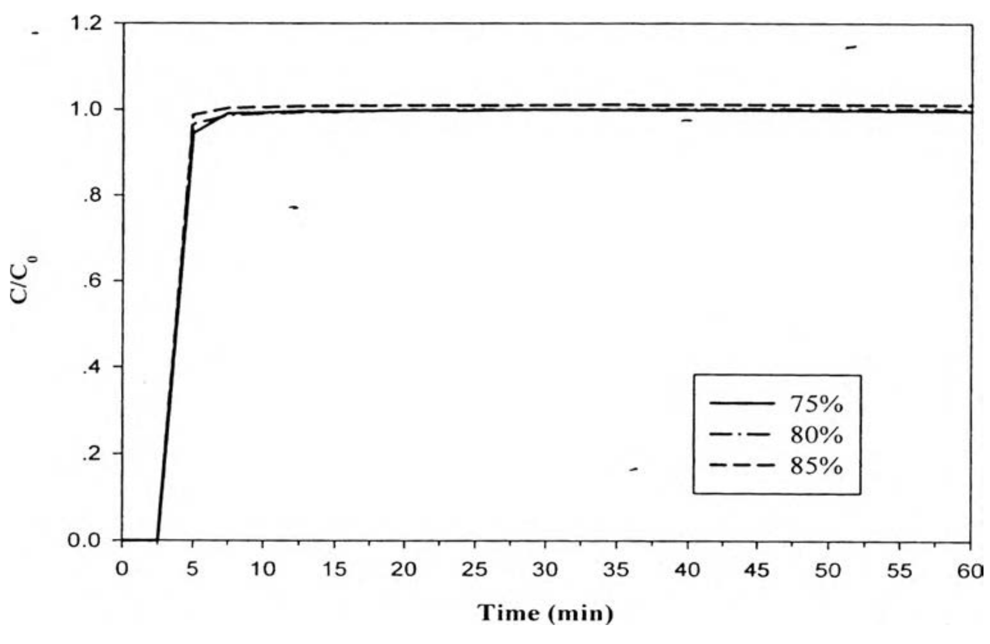

Figure B1 Breakthrough curves of methane from the adsorption on the CSAC with the initial concentration of methane at 75, 80, and 85 vol% at room temperature.

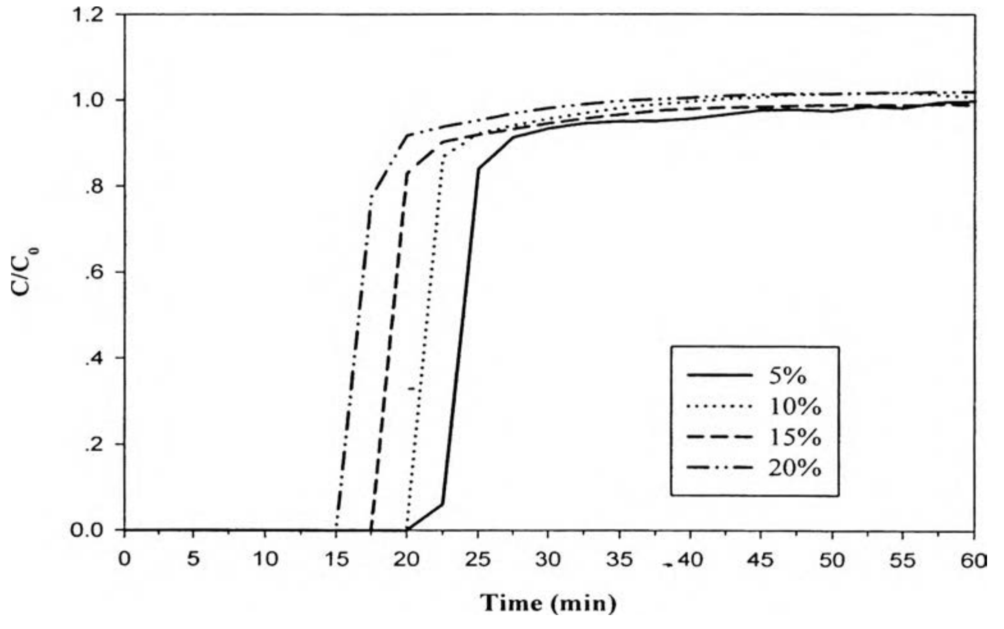

Figure B2 Breakthrough curves of carbon dioxide from the adsorption on the CSAC with the initial concentration of carbon dioxide at 5, 10, 15, and 20 vol% at room temperature.

Some of the adsorption and desorption curves from the breakthrough experiments are rewritten in a different scale. The breakthrough curves in Figure 4.8 are shown here in Figure B3.

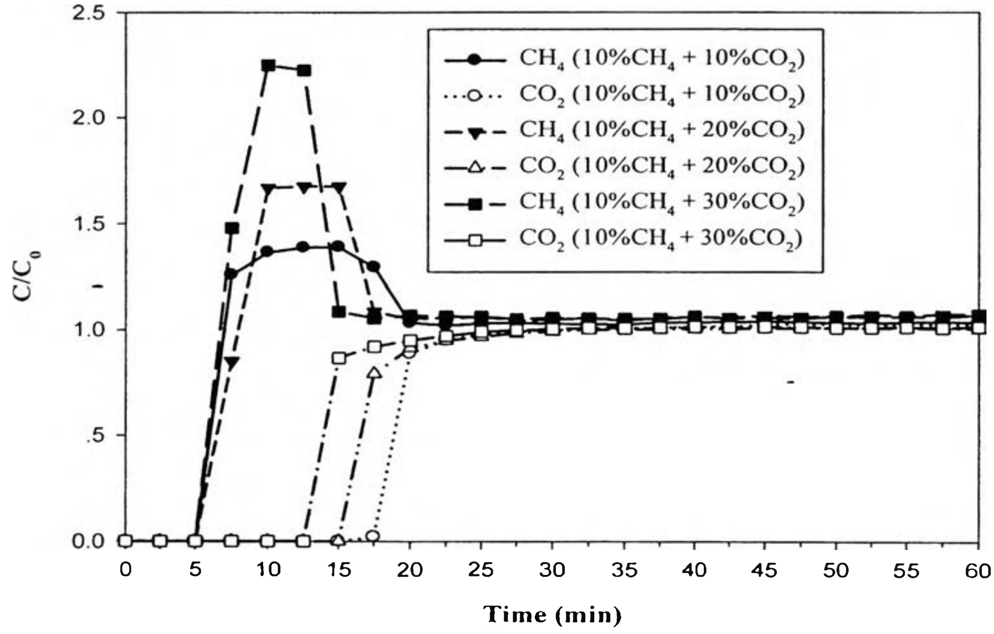

Figure B3 Breakthrough curves of methane and carbon dioxide from the competitive adsorption on the CSAC with the initial concentration of methane at 10 vol% and carbon dioxide at 10, 20, and 30 vol% at room temperature.

Competitive adsorption at 10 vol% and carbon dioxide composition was varied from 10 to 30 vol% profiles in Figures 4.5 to 4.7 are shown in Figures B4 to B6.

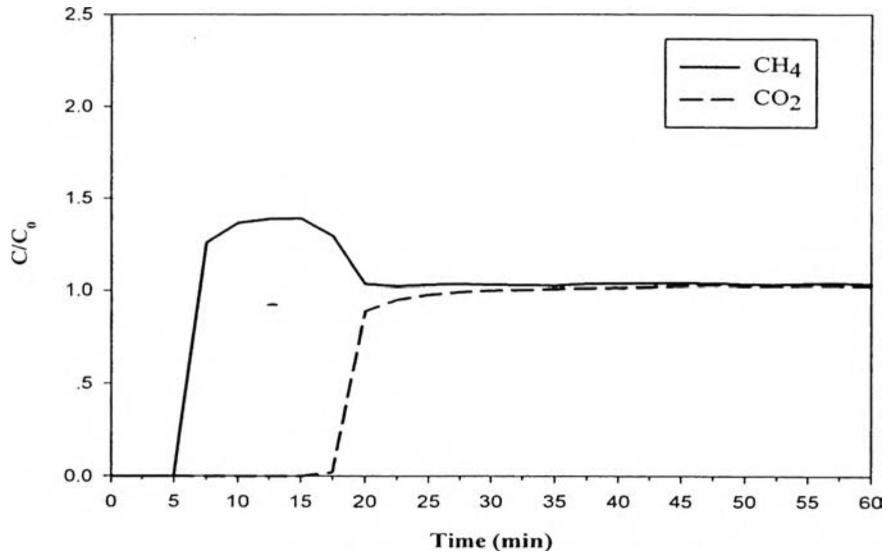

Figure B4 Breakthrough curves of methane and carbon dioxide from the competitive adsorption on the CSAC with the initial concentration of methane at 10 vol% and carbon dioxide at 10 vol% at room temperature.

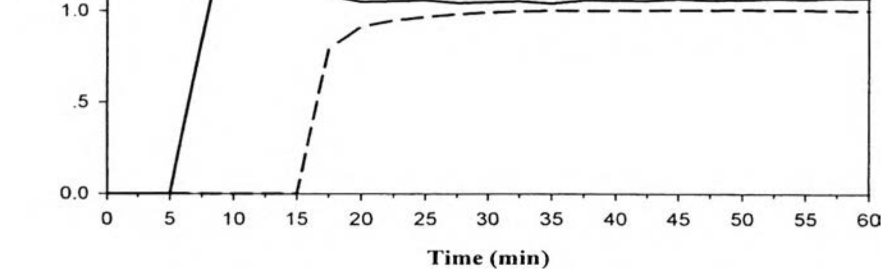

Figure B5 Breakthrough curves of methane and carbon dioxide from the competitive adsorption on the CSAC with the initial concentration of methane at 10 vol% and carbon dioxide at 20 vol% at room temperature.

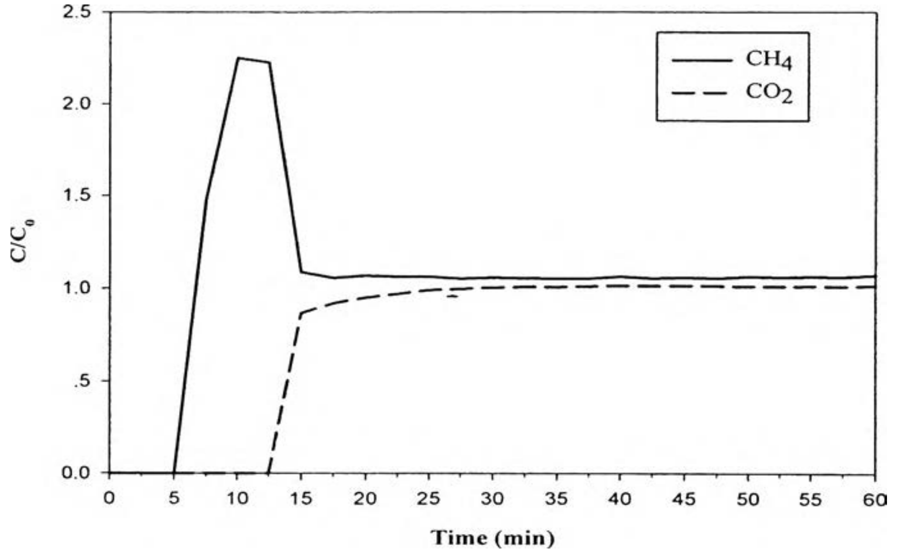

Figure B6 Breakthrough curves of methane and carbon dioxide from the competitive adsorption on the CSAC with the initial concentration of methane at 10 vol% and carbon dioxide at 30 vol% at room temperature.

The breakthrough curves and the desorption cycles in Figures 4.9 to 4.22 are shown in Figures B7 to B21.

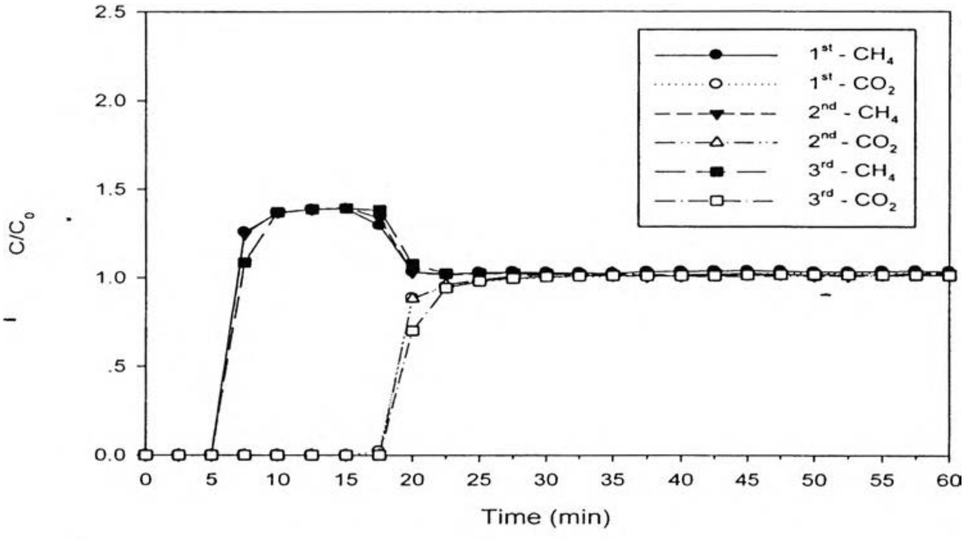

Figure B7 Breakthrough curves of methane and carbon dioxide from the 3-cycle adsorption process on untreated CSAC with the initial concentration of methane at 10 vol% and carbon dioxide at 10 vol% at room temperature.

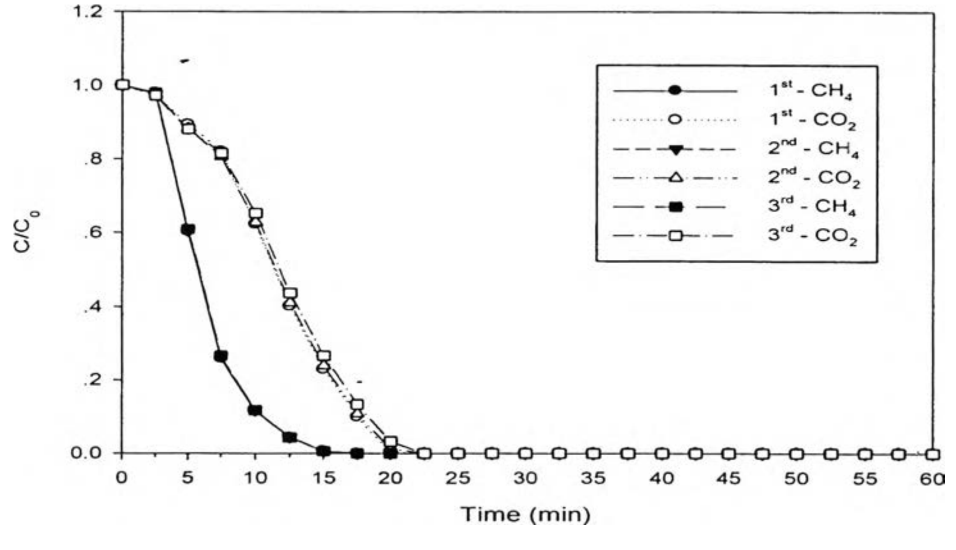

Figure B8 Three desorption cycles of methane and carbon dioxide from the CSAC with the initial concentration of methane at 10 vol% and carbon dioxide at 10 vol% at room temperature.

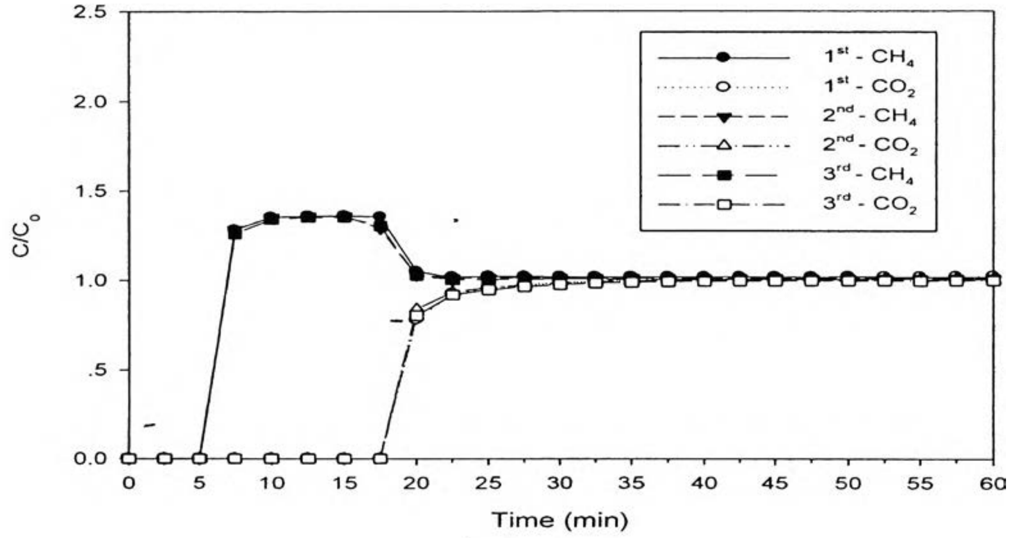

Figure B9 Breakthrough curves of methane and carbon dioxide from the 3-cycle adsorption process on the CSAC treated by sodium hydroxide with the initial concentration of methane at 10 vol% and carbon dioxide at 10 vol% at room temperature.

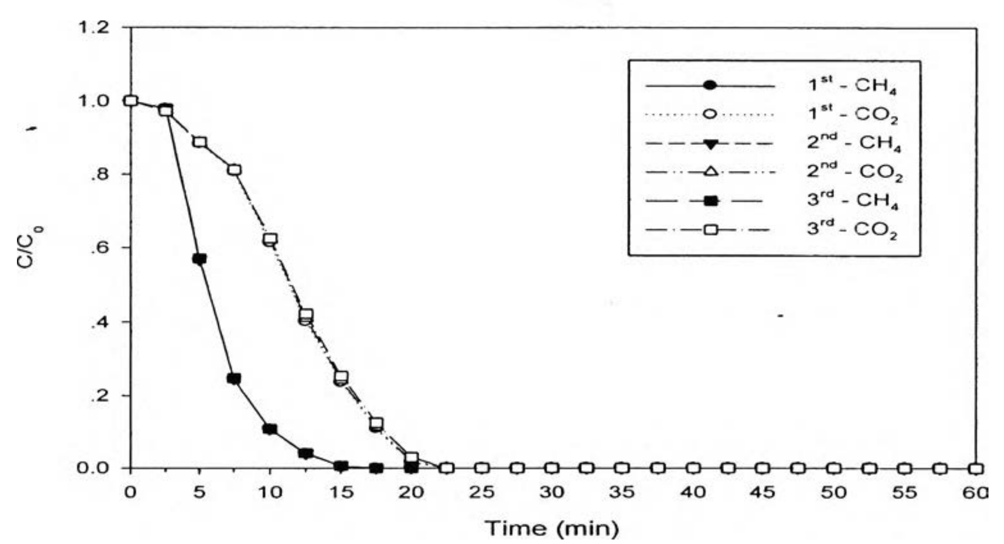

Figure B10 Three desorption cycles of methane and carbon dioxide from the CSAC treated by sodium hydroxide with the initial concentration of methane at 10 vol% and carbon dioxide at 10 vol% at room temperature.

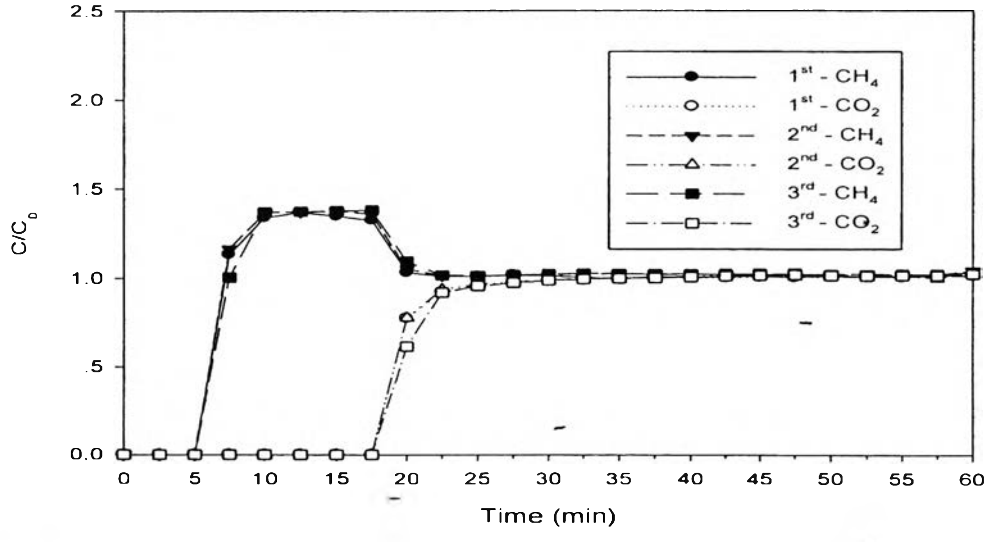

Figure B11 Breakthrough curves of methane and carbon dioxide from the 3-cycle adsorption process on the CSAC treated by ammonium hydroxide with the initial concentration of methane at 10 vol% and carbon dioxide at 10 vol% at room temperature.

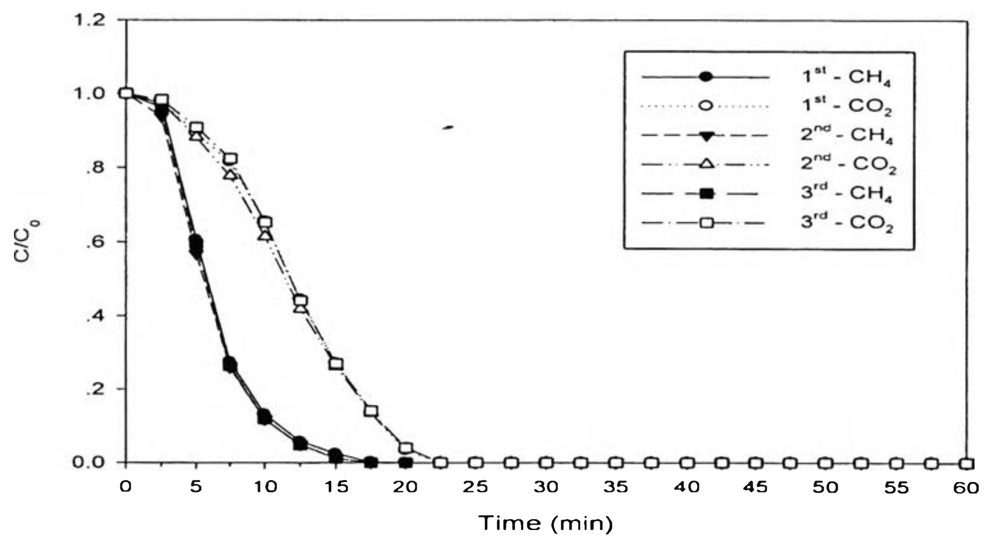

Figure B12 Three desorption cycles of methane and carbon dioxide from the CSAC treated by ammonium hydroxide with the initial concentration of methane at 10 vol% and carbon dioxide at 10 vol% at room temperature.

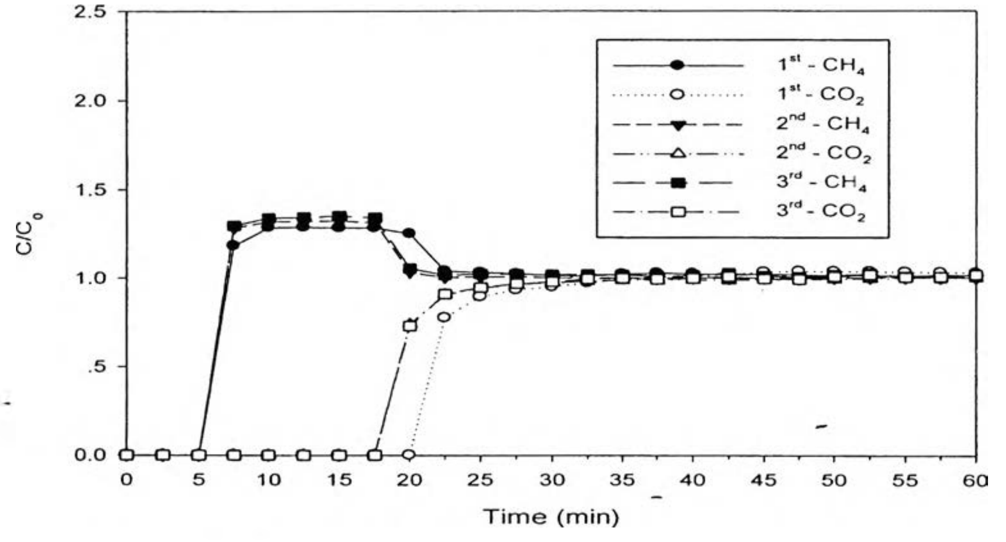

Figure B13 Breakthrough curves of methane and carbon dioxide from the 3-cycle adsorption process on the CSAC treated by potassium hydroxide with the initial concentration of methane at 10 vol% and carbon dioxide at 10 vol% at room temperature.

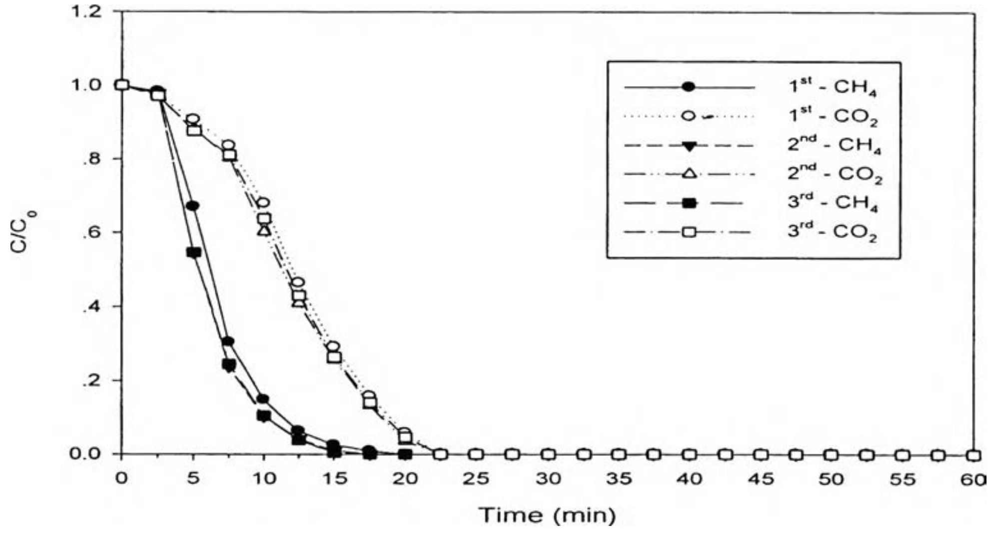

Figure B14 Three desorption cycles of methane and carbon dioxide from the CSAC treated by potassium hydroxide with the initial concentration of methane at 10 vol% and carbon dioxide at 10 vol% at room temperature.

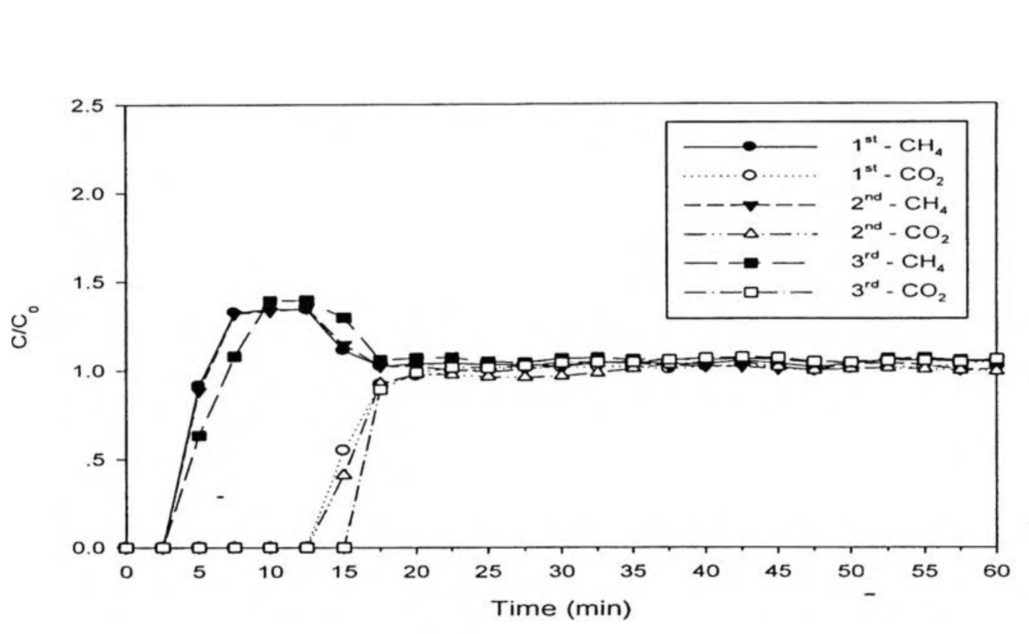

Figure B15 Breakthrough curves of methane and carbon dioxide from the 3-cycle adsorption process on the CSAC treated by sulfuric acid with the initial concentration of methane at 10 vol% and carbon dioxide at 10 vol% at room temperature.

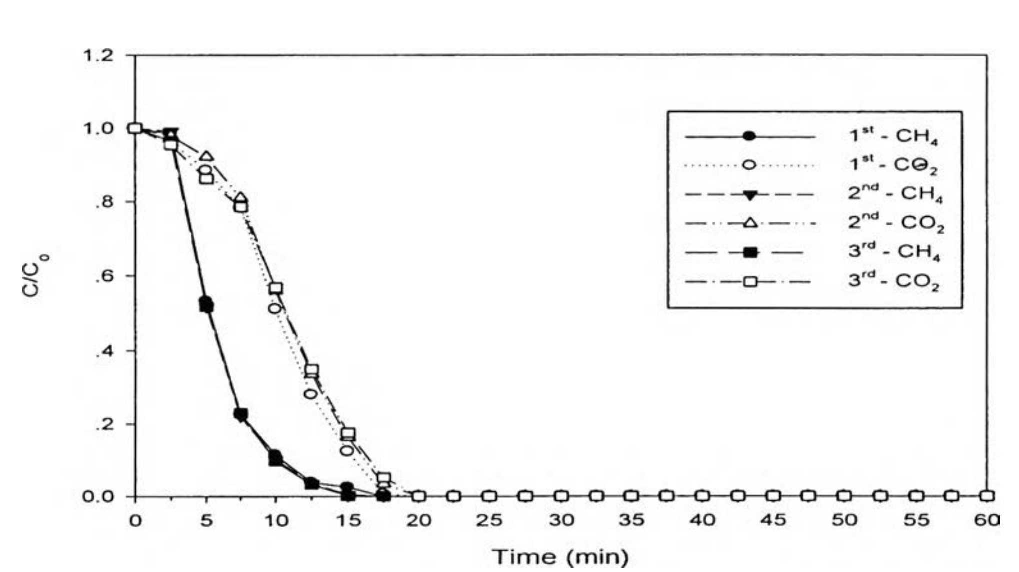

Figure B16 Three desorption cycles of methane and carbon dioxide from the CSAC treated by sulfuric acid with the initial concentration of methane at 10 vol% and carbon dioxide at 10 vol% at room temperature.

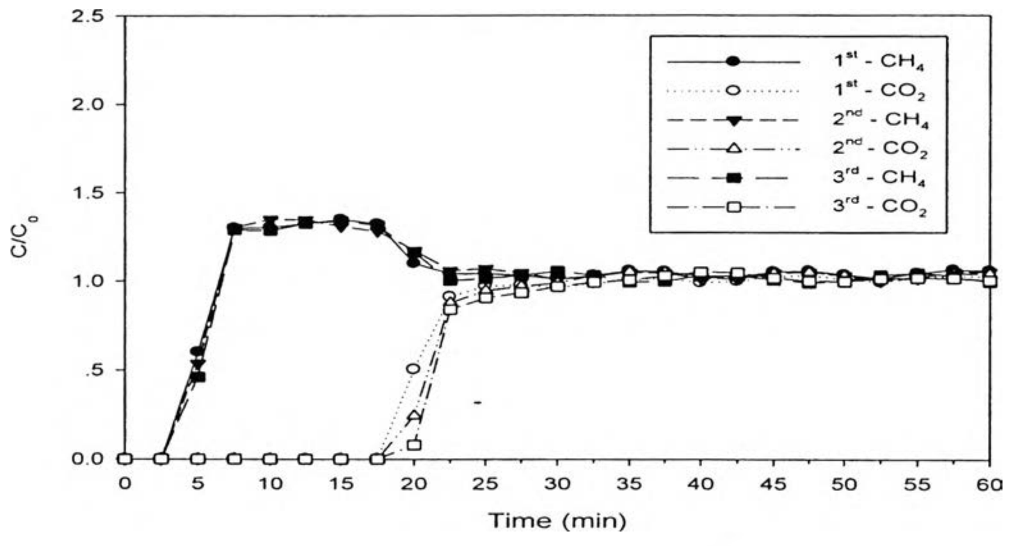

Figure B17 Breakthrough curves of methane and carbon dioxide from the 3-cycle adsorption process on the CSAC treated by nitric acid with the initial concentration of methane at 10 vol% and carbon dioxide at 10 vol% at room temperature.

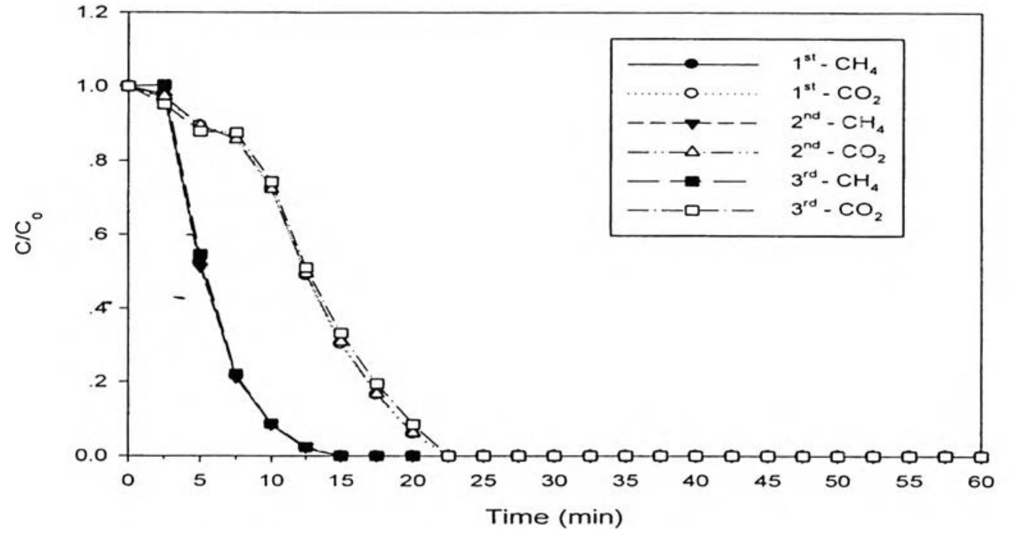

Figure B18 Three desorption cycles of methane and carbon dioxide from the CSAC treated by nitric acid with the initial concentration of methane at 10 vol% and carbon dioxide at 10 vol% at room temperature.

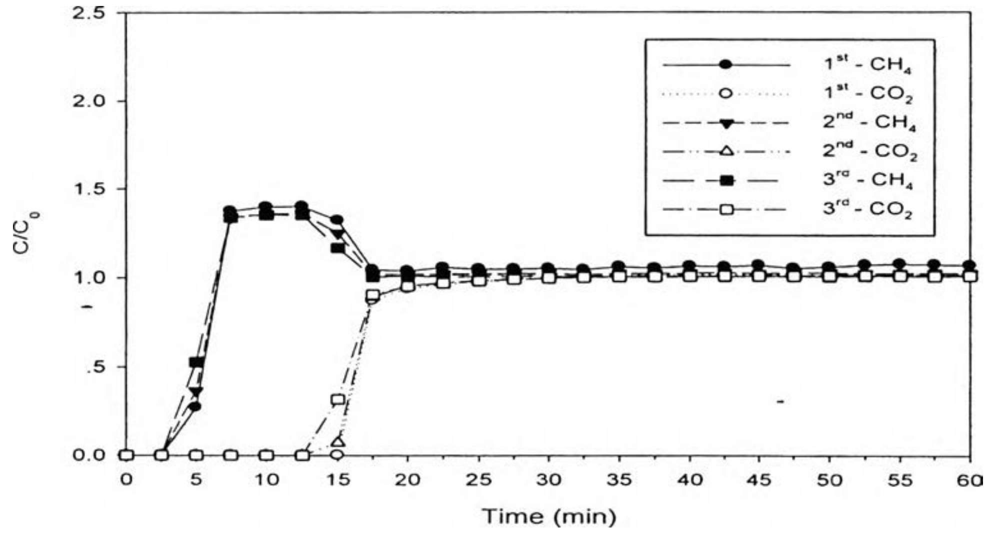

Figure B19 Breakthrough curves of methane and carbon dioxide from the 3-cycle adsorption process on the CSAC treated by phosphoric acid with the initial concentration of methane at 10 vol% and carbon dioxide at 10 vol% at room temperature.

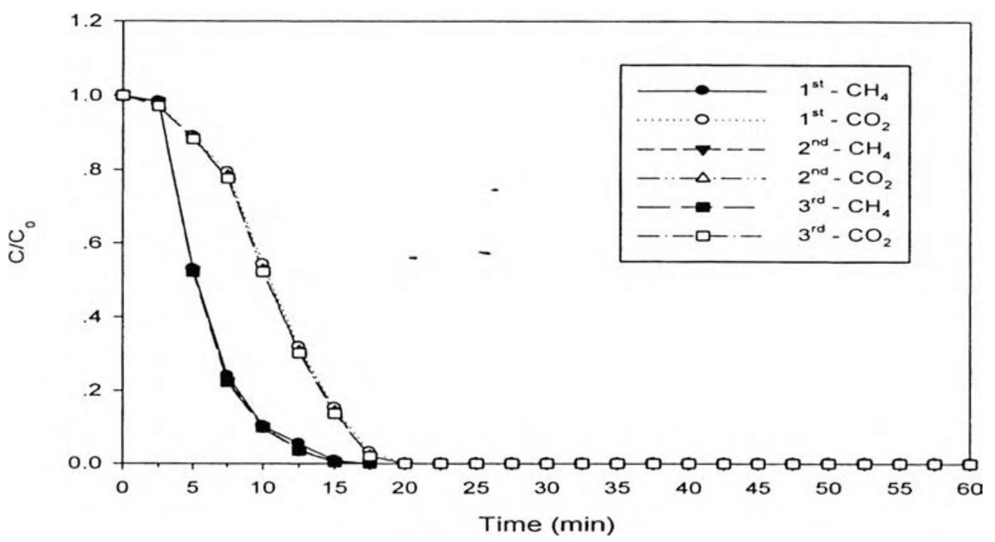

Figure B20 Three desorption cycles of methane and carbon dioxide from the CSAC treated by phosphoric acid with the initial concentration of methane at 10 vol% and carbon dioxide at 10 vol% at room temperature.

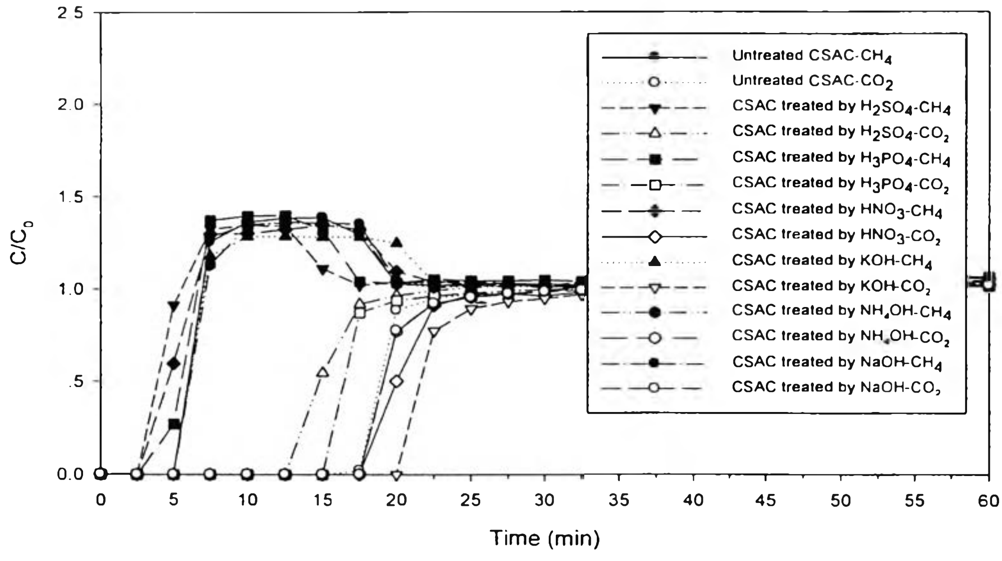

Figure B21 Breakthrough curves of methane and carbon dioxide from the competitive adsorption on the untreated CSAC, CSAC treated by sulfuric acid, CSAC treated by phosphoric acid, CSAC treated by nitric acid, CSAC treated by potassium hydroxide, CSAC treated by ammonium hydroxide and CSAC treated by sodium hydroxide with the initial concentration of methane at 10 vol% and carbon dioxide at 10 vol% at room temperature.

The breakthrough curves of CSAC treated MES on varies concentration in Figures 4.31 to 4.34 are shown in Figures B22 to B25.

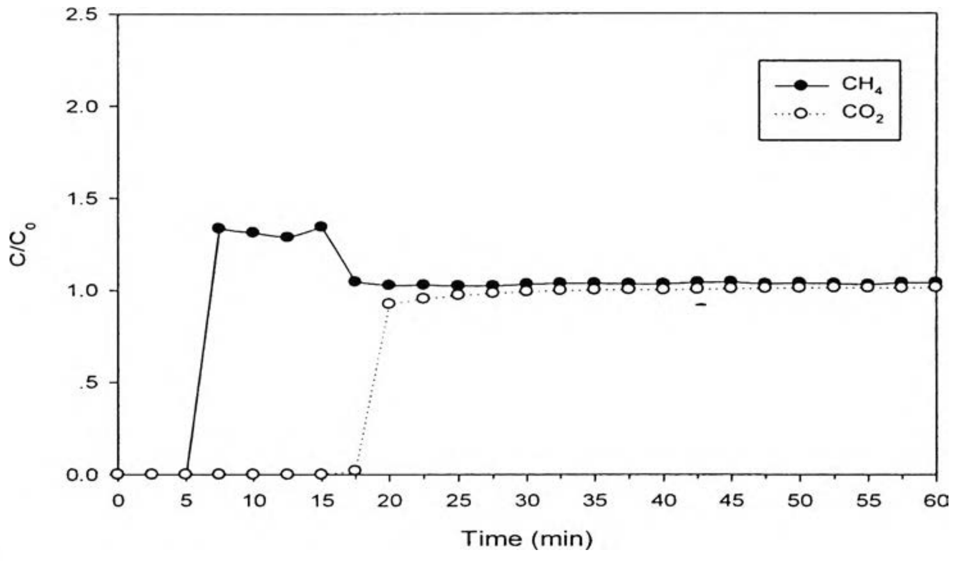

Figure B22 Breakthrough curves of methane and carbon dioxide from the competitive adsorption on the CSAC treated by MES at 15 mg/l with the initial concentration of methane at 10 vol% and carbon dioxide at 10 vol% at room temperature.

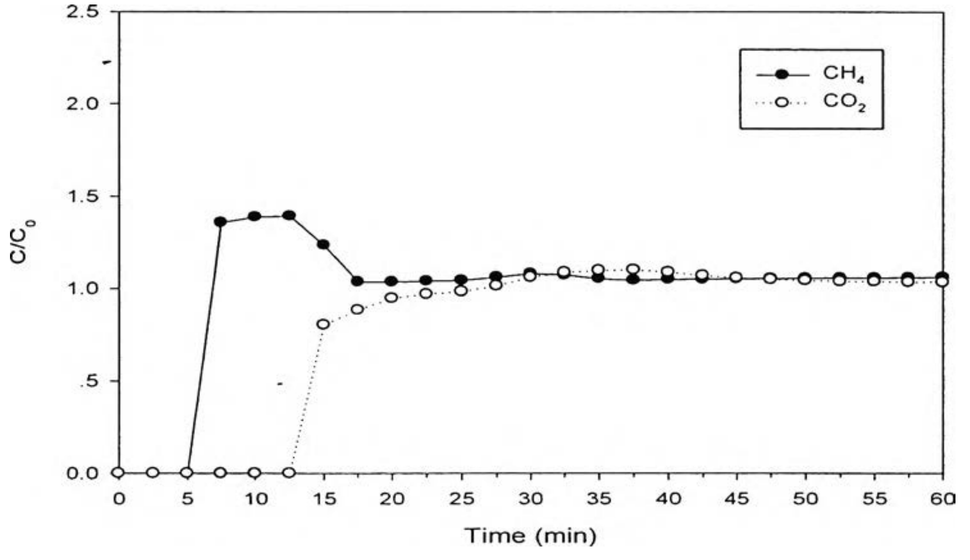

Figure B23 Breakthrough curves of methane and carbon dioxide from the competitive adsorption on the CSAC treated by MES at 50 mg/l with the initial concentration of methane at 10 vol% and carbon dioxide at 10 vol% at room temperature.

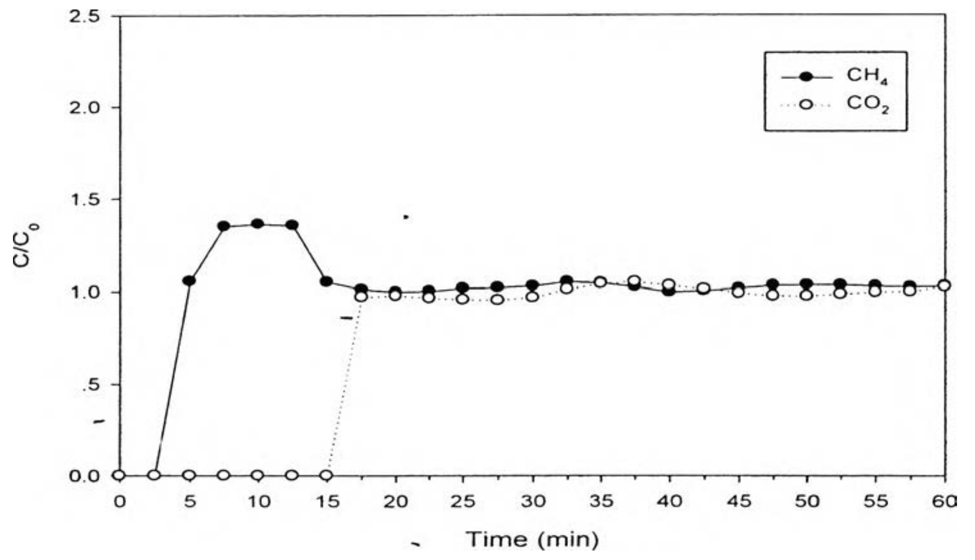

Figure B24 Breakthrough curves of methane and carbon dioxide from the competitive adsorption on the CSAC treated by MES at 152.8 mg/l with the initial concentration of methane at 10 vol% and carbon dioxide at 10 vol% at room temperature.

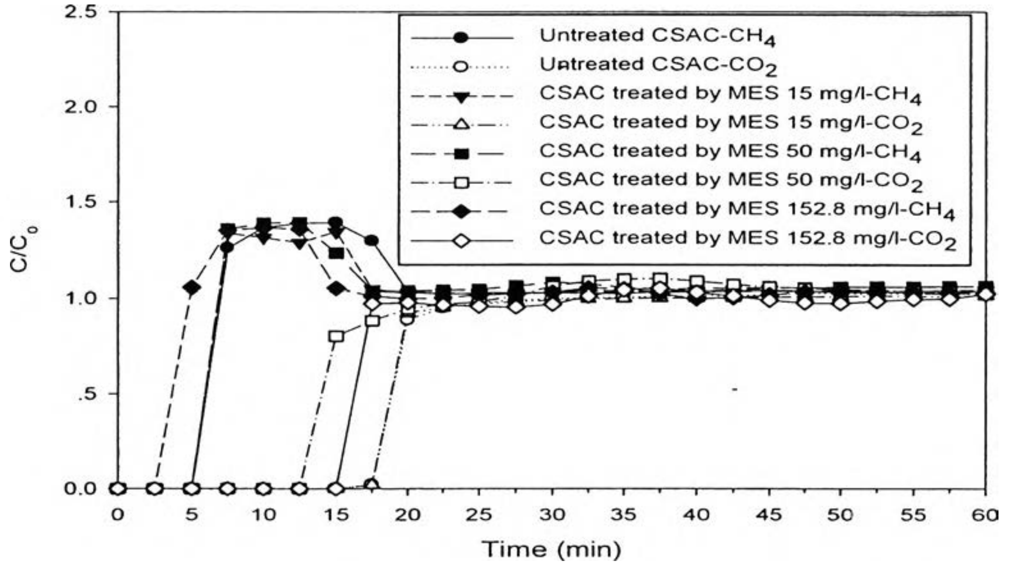

Figure B25 Breakthrough curves of methane and carbon dioxide from the competitive adsorption on the untreated CSAC, CSAC treated by MES at 15mg/l, 50 mg/l, and 152.8 mg/l with the initial concentration of methane at 10 vol% and carbon dioxide at 10 vol% at room temperature.

Table B1 Summary of breakthrough time adsorption capacity and selectivity of investigate CSAC

Adsorbent	Breakthrough time (min)		Total adsorption (mmol/g)	CH_4 adsorption (mmol/g)	CO_2 adsorption (mmol/g)	Adsorption selectivity
	CH_4	CO_2				
CSAC	3.46	17.00	3.41	0.58	2.84	0.20
CSAC/H_2SO_4	1.76	14.64	2.74	0.29	2.44	0.12
CSAC/H_3PO_4	2.26	16.53	3.13	0.38	2.76	0.14
CSAC/HNO_3	2.22	20.19	3.74	0.37	3.37	0.11
CSAC/KOH	4.91	21.80	4.46	0.82	3.64	0.23
CSAC/NH_4OH	5.24	19.51	4.13	0.87	3.25	0.27
CSAC/NaOH	4.60	19.41	4.01	0.77	3.24	0.24
CSAC/MES at 15 mg/l	3.92	18.97	3.82	0.65	3.16	0.21
CSAC/MES at 50 mg/l	3.18	12.80	2.67	0.53	2.13	0.25
CSAC/MES at 152.8 mg/l	2.21	17.00	3.20	0.37	2.84	0.13

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Proceedings:

1. Samanwong, N; Rangsunvigit, P; Kulprathipanja, S; and Kitiyanan, B. (2014, April 22) CO_2 and CH_4 Competitive Adsorption on Coconut Shell Activated Carbon. Proceedings of The 5th Research Symposium on Petroleum, Petrochemicals and Advanced Materials and The 20th PPC Symposium on Petroleum, Petrochemicals, and Polymers, Bangkok, Thailand.

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1. Samanwong, N; Rangsunvigit, P; Kulprathipanja, S; and Kitiyanan, B. (2014, May 7-8) Competitive adsorption of carbon dioxide and methane on activated carbon. Paper presented at 2014 International Conference on Environment and Renewable Energy, Paris, France.