REFERENCES

Aiello, R., Fiscus, J. E., Loye, H.-C., and Amiridis, M. D., (2000) Hydrogen production via the direct cracking of methane over Ni/SiO_2. Catalyst deactivation and regeneration. Applied Catalysis A: General 192, 227.

Bampenrat, A., Meeyoo, V., Kitiyanan, B., Rangsunvigit, P., and Rirksomboon, T. (2010) Naphthalene steam reforming over Mn-doped CeO_2-ZrO_2 supported nickel catalysts. Appiled Catalysis A: General 373. 154-159.

Boehm, R., Chen, Y., Earl, B., Hsieh, S., and Moujaes, S. (2003) H_2 Technology Survey UNLV Program, University of Nevada Las Vegas, Center for Energy Research.

Bradford, M.C.J. and M.A. Vannice (1996) Catalytic reforming of methane with carbon dioxide over nickel catalysts. I. Catalyst characterization and activity. Applied Catalysis A, 142. 73-96.

Craciun, R., Daniell, W., and Knözinger, H. (2002) The effect of CeO_2 structure on the activity of supported Pd catalysts used for methane steam reforming; Applied Catalysis A, 230. 153-168.

Gadalla, A.M. and Bower, B. (1988) The role of catalyst support on the activity of nickel for reforming methane with CO_2; Chemical Engineering Science, 11. 3049 - 3062.

Hegarty, M.E.S., O'Connor, A.M., and Ross, J.R.H. (1998) Syngas production from natural gas using ZrO_2-supported metals. Catalysis Today, 42. 225.

Inui, T. (1997) Rapid catalytic processes in reforming of methane and successive synthesis of methanol and its derivatives; Applied Surface Science, 121/122, 26-33.

JiXiang, C., Qunying, W., Jianxiang, Z., and Jiyan, Z. (2008): Effect of preparation methods on structure and performance of $Ni/Ce_{0.75}Zr_{0.25}O_2$ catalysts for CH_4-CO_2 reforming; Fuel, 87. 2901-2907.

Katsuki, K., Ken-Ichiro, S., Tomokazu, E., and Yuji, I. (2004) Methane steam reforming over Ce-ZrO_2-supported noble metal catalysts at low temperature. Fuel Processing Technology, 86. 319-326.

Kim, M.H., Lee, E.K., Jun, J.H., Han, G.Y., Kong, S. J., Lee, B.K., Lee, T. J., and Yoon, K. J. (2003) Hydrogen production by catalytic decomposition of methane over

activated carbons. Deactivation study, Korean Journal Chemical Engineering, 20. 835.

Koubaissy, B., Pietraszek, A., Roger, A.C., and Kiennemann, A. (2010) CO_2 reforming of methane over Ce-Zr-Ni-Me mixed catalysts. Catalysis Today, 157. 436 – 439.

Longya, X., Jinxiang, L., Yide, X., Hong, Y., Qingxia, W., and Liwu, L. (2000) The suppression of coke deposition by the modification of Mn on Fe/silicalite-2 catalyst in dehydrogenation of C_2H_6 with CO_2. Appiled Catalysis A: General 193. 95-101.

Park, J., H., Lee, D., Lee, H., C., and Park, E., D. (2010) Steam reforming of liquid petroleum gas over Mn-promoted Ni/γ-Al_2O_3 catalysts. Korean Journal Chemical Engineering, 27(4). 1132-1138.

Rakass, S., Oudghiri-Hassani, H., Rowntree, P., and Abatzoglou, N. (2006) Steam reforming of methane over unsupported nickel catalysts, Journal of Power Sources, 158(1). 485-496

Rostrup-Nielsen, J.R. and Bak Hansen, J.-H. (1993) CO_2-reforming of methane over transition metals; Journal of Catalysis, 144. 38-49.

Rostrup-Nielsen, J.R., Sehested, J., and Nørskov, J.K. (2002) Hydrogen and synthesis gas by steam- and CO_2 reforming. Advances in Catalysis, 47. 65-139.

Thammachart, M., Meeyoo, V., Risksomboon, T., and Osuwan,, S. (2001) Catalytic activity of CeO_2–ZrO_2 mixed oxide catalysts prepared via sol–gel technique: CO oxidation. Catalysis Today, 68. 53-61.

Wang, S. and Lu, G.Q. (1998b): CO_2 reforming of methane on Ni catalysts: Effect of the support phase and preparation technique. Applied Catalysis B, 16. 269-277.

Xiaodong, W., Liang, Q., and Weng, D. (2006): Effect of Manganese Doping on Oxygen Storage Capacity of Ceria-Zirconia Mixed Oxides. Journal of Rare Earths, 24. 549-553.

Yamazaki, O., Nozaki, T., Omata, K., and Fujimoto, K. (1992): Chemistry Letters, 1953-1954.

"Methane (natural gas)" Simon Cotton. 1 June 2010
<http://www.chm.bris.ac.uk/motm/methane/methaneh.htm>

"Methane." *Wikipedia*. 1 June 2010
<http://en.wikipedia.org/wiki/Methane>
"Methane" Wisconsin Department of Health and Family Services. 1 June 2010
<http://dhfs.wisconsin.gov/eh>

APPENDICES

Appendix A Experimental Data of Flow Meter Gas Calibration of Mass Flow Controllers

1. Methane

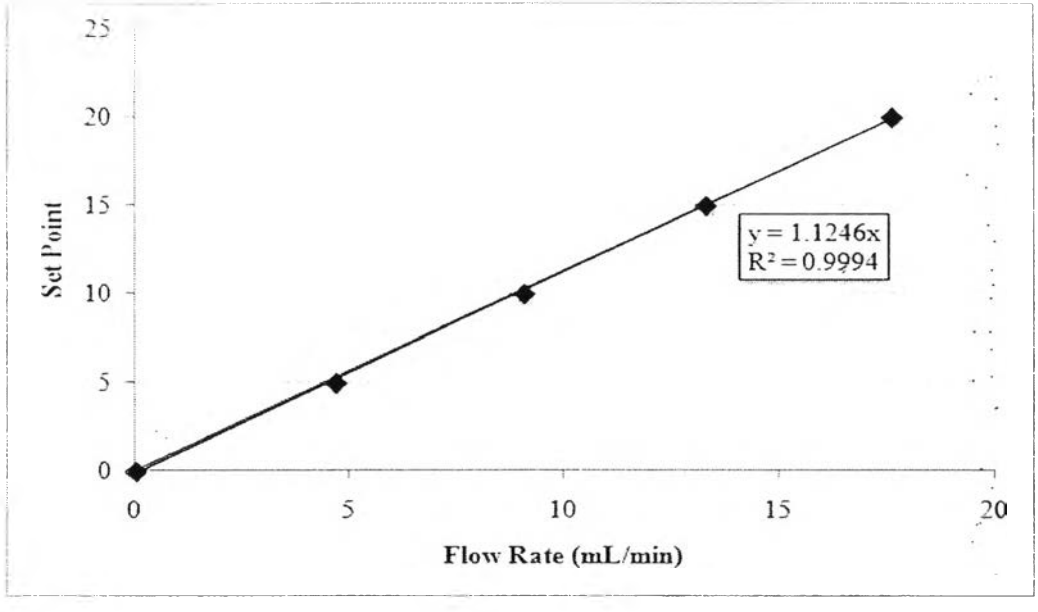

Figure A1 Relationship between flow rate and set point of methane.

2. DI water

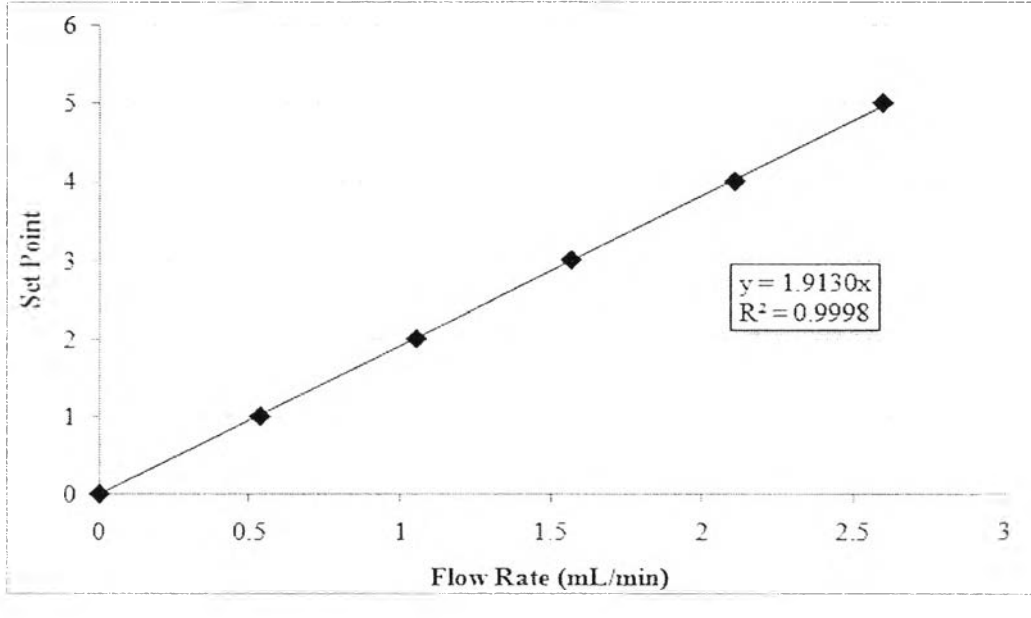

Figure A2 Relationship between flow rate and set point of DI water.

3. Carbon monoxide

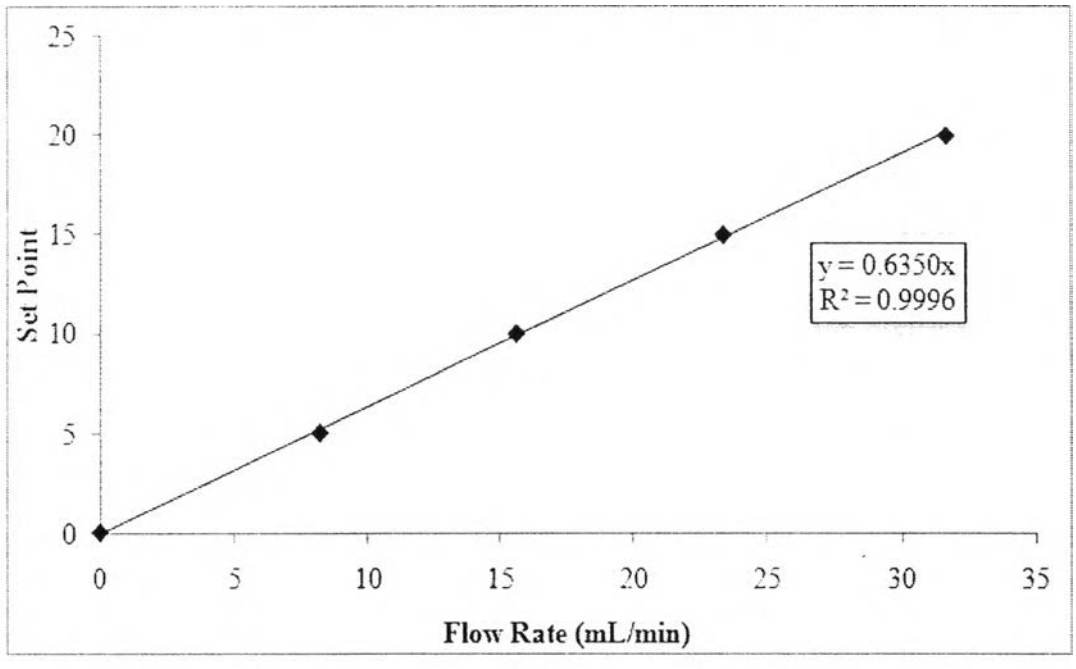

Figure A3 Relationship between flow rate and set point of carbon monoxide.

4. Carbon dioxide

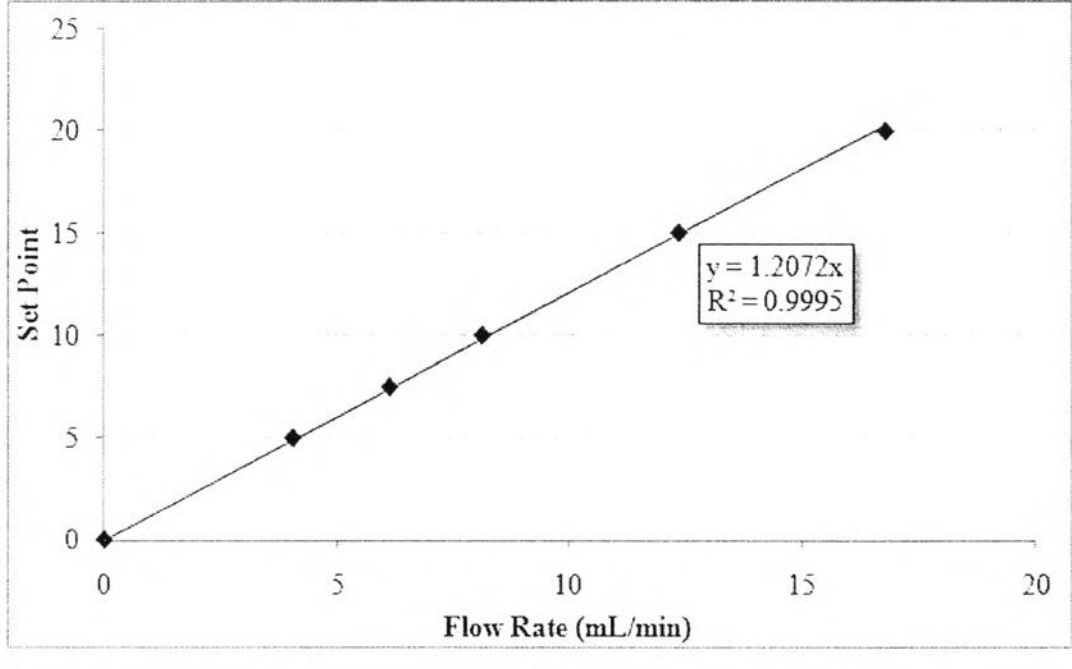

Figure A4 Relationship between flow rate and set point of carbon dioxide.

Appendix B Experimental Data of Gas Calibration of GC 8A Equipped with a CTR I under He Carrier

1. Methane

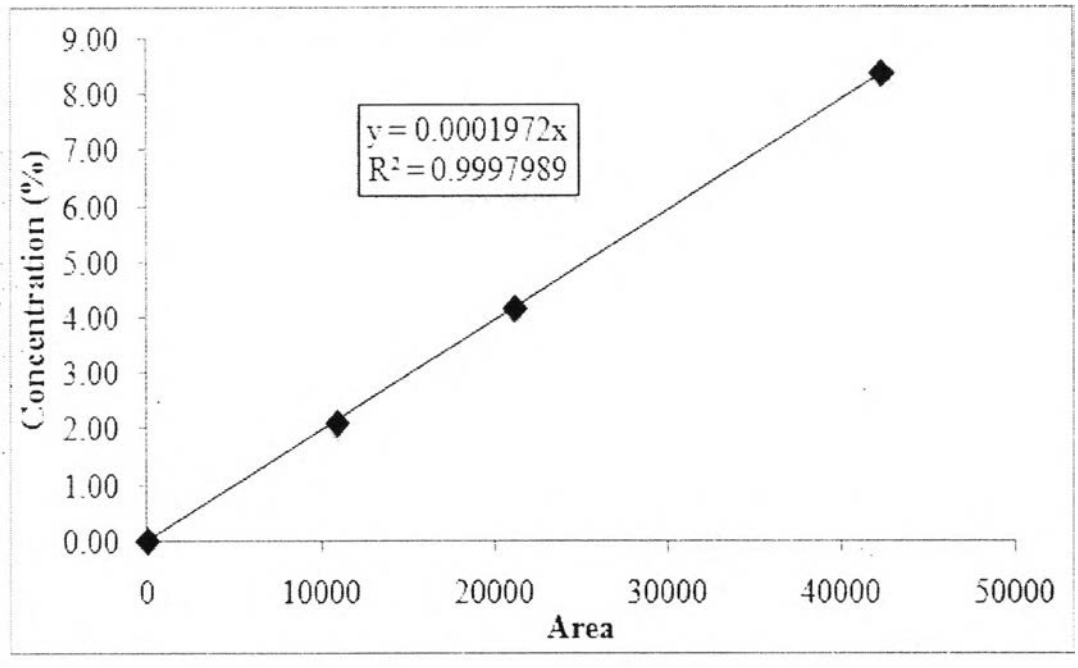

Figure B1 Relationship between Area and Concentration of Methane.

2. Hydrogen

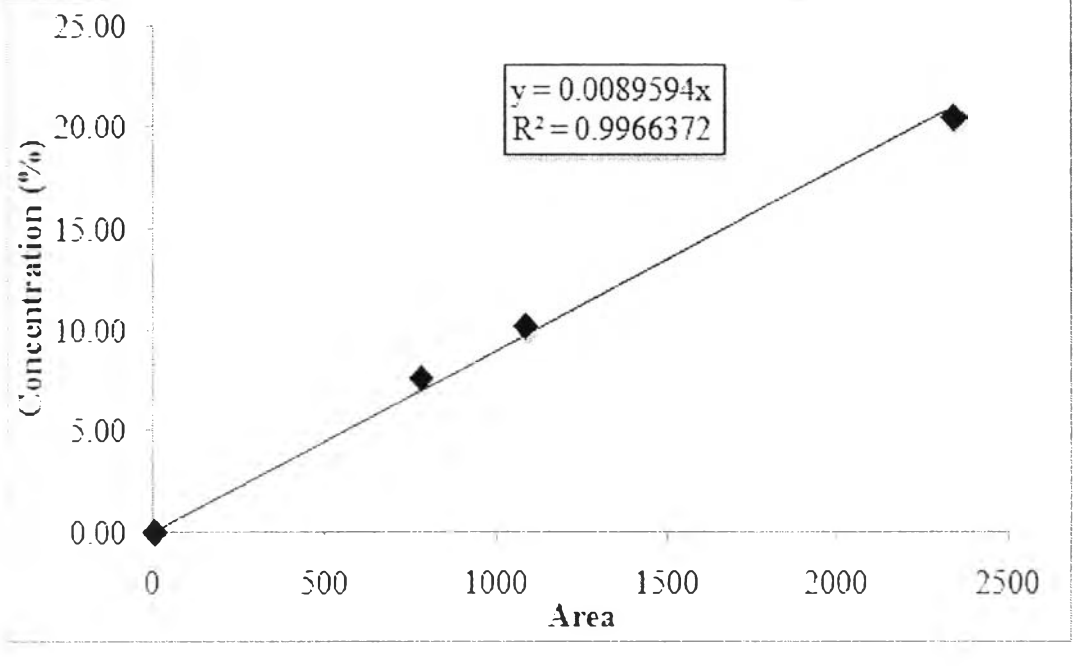

Figure B2 Relationship between area and concentration of hydrogen.

3. Carbon Monoxide

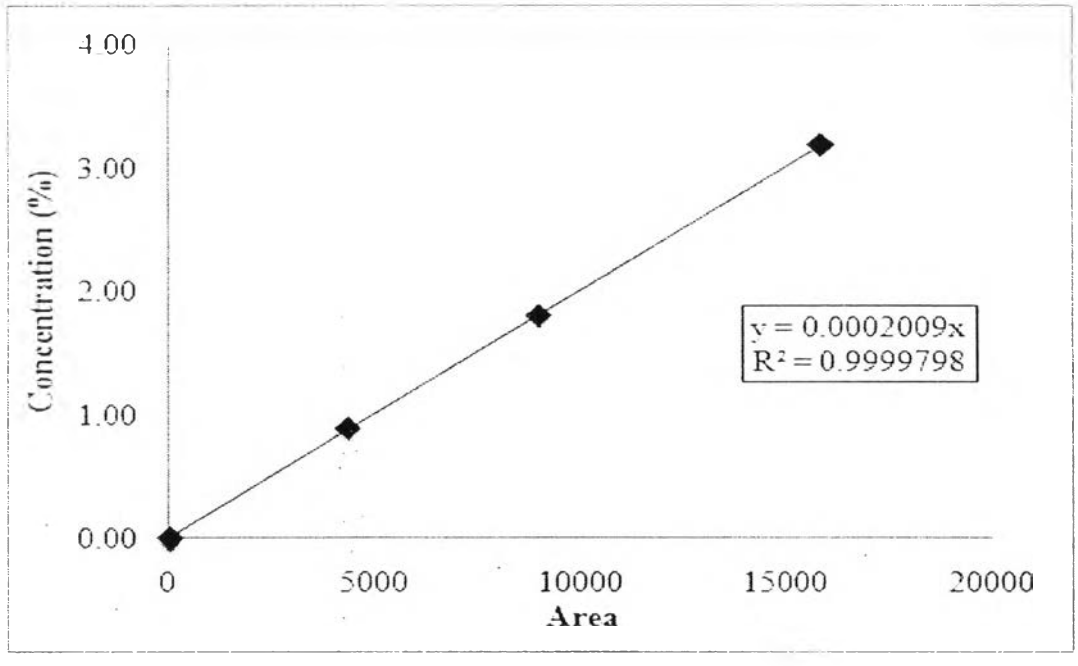

Figure B3 Relationship between area and concentration of carbon monoxide.

4. Carbon Dioxide

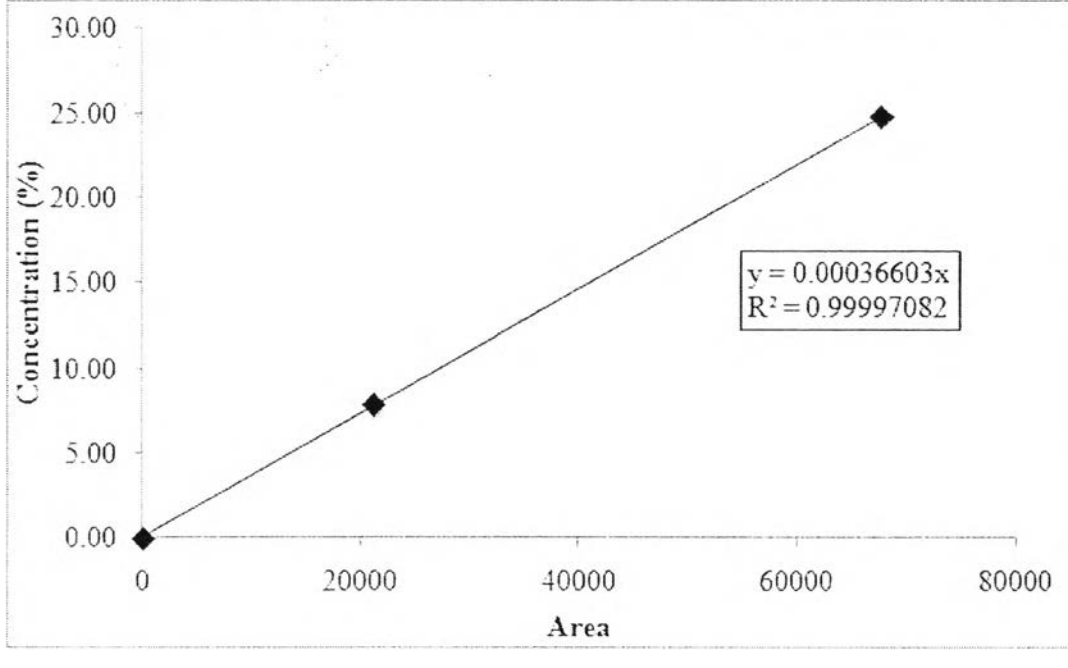

Figure B4 Relationship between area and concentration of carbon dioxide.

5. Argon

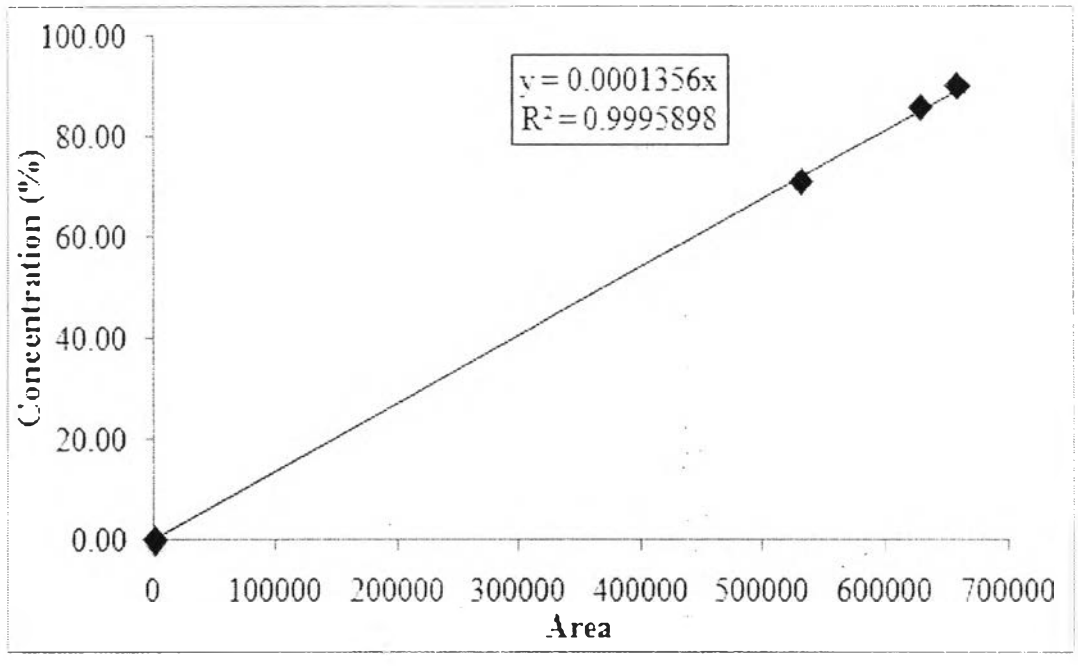

Figure B5 Relationship between area and concentration of Argon.

Appendix C Experimental Data of Gas Calibration of GC 8A Equipped with a CTR I under Ar Carrier

1. Methane

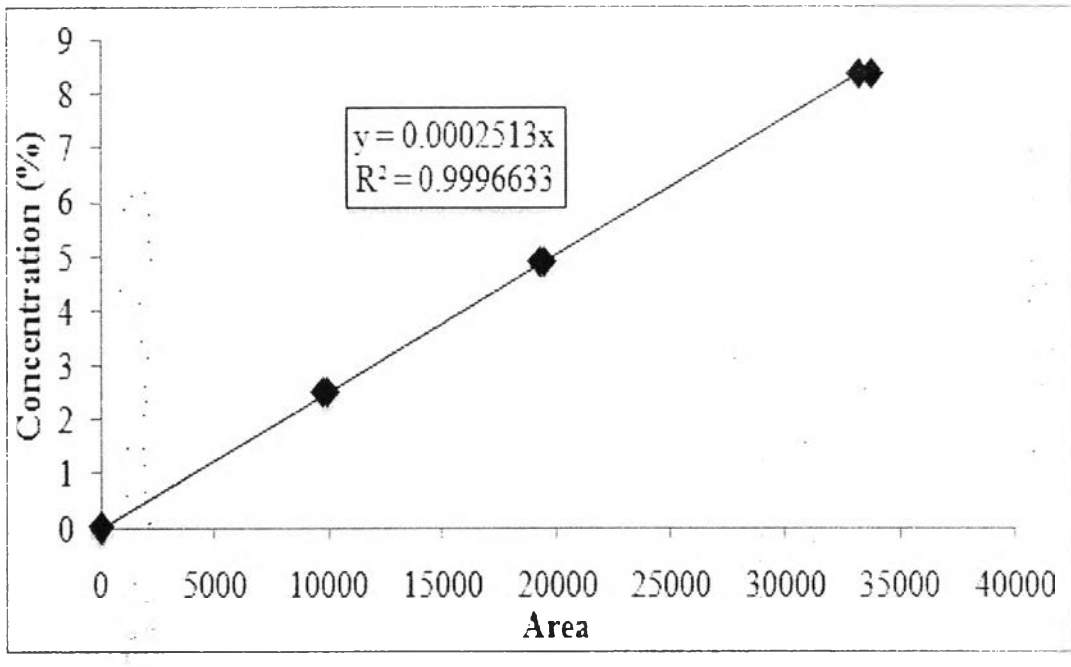

Figure C1 Relationship between Area and Concentration of Methane.

2. Hydrogen

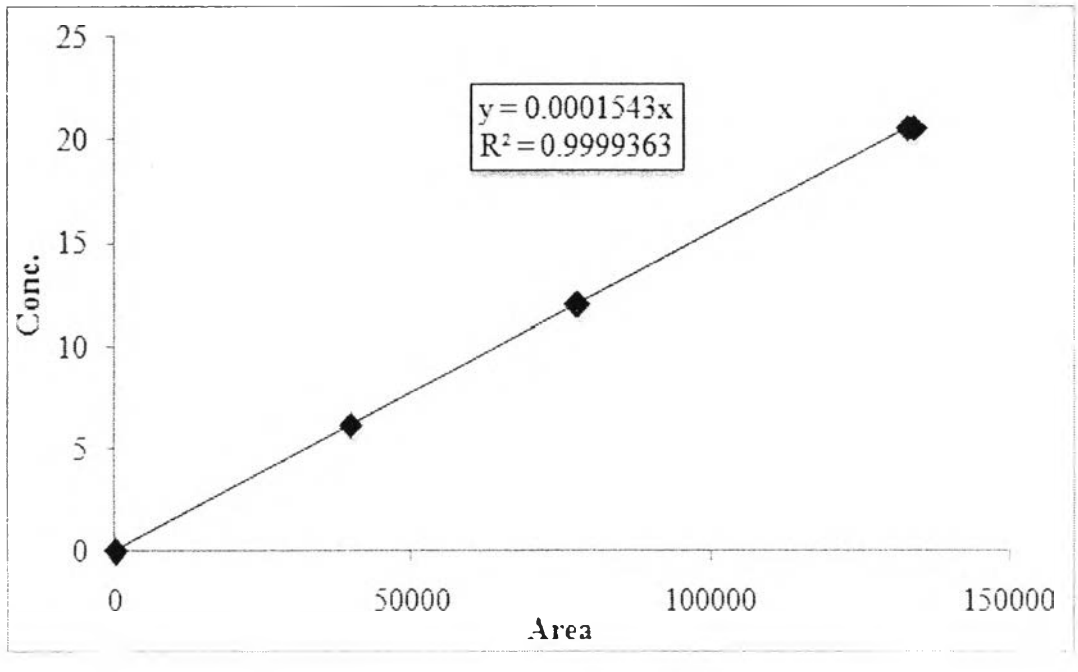

Figure C2 Relationship between area and concentration of hydrogen.

3. Carbon Monoxide

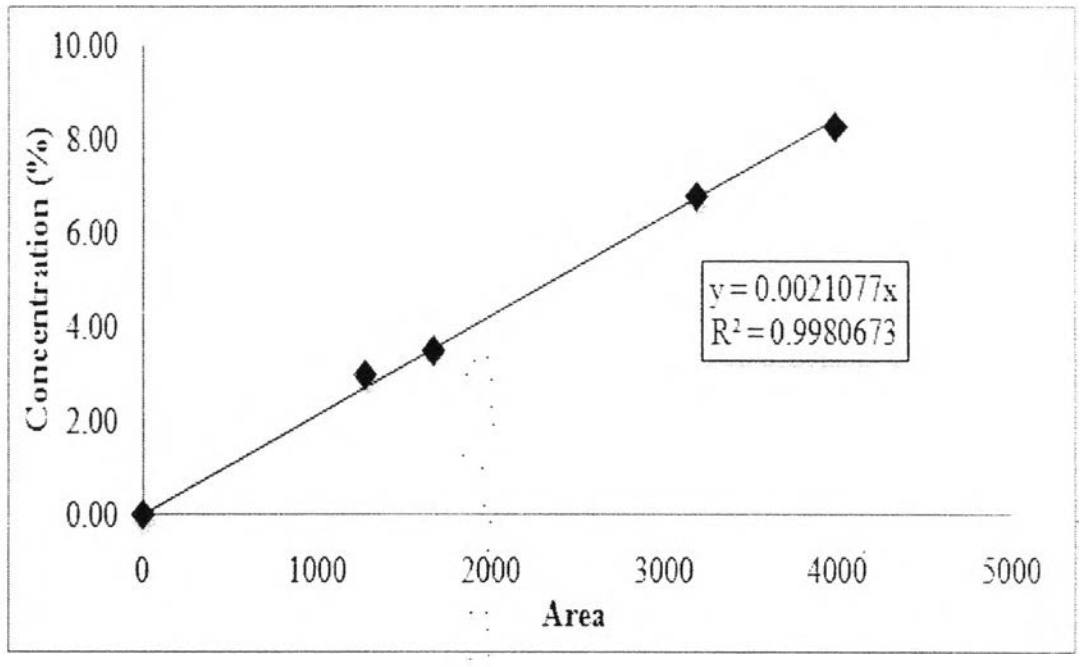

Figure C3 Relationship between area and concentration of carbon monoxide.

4. Carbon Dioxide

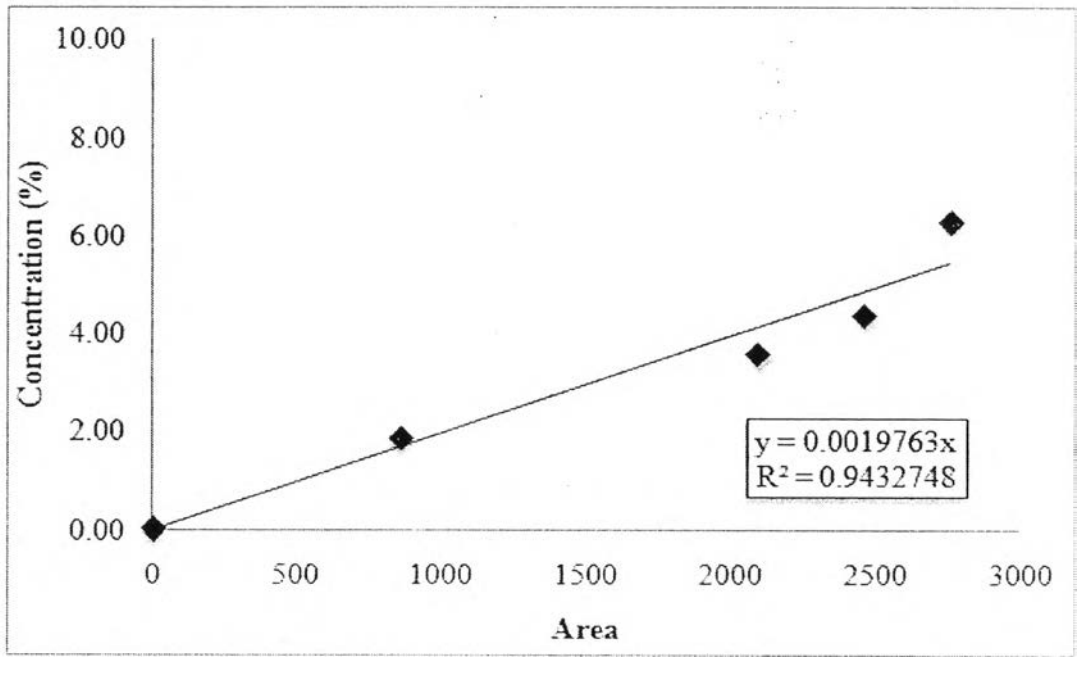

Figure C4 Relationship between area and concentration of carbon dioxide.

Appendix D Experimental Data of Catalytic Activity on MSR at 700°C, S/C = 4/1 (GSHV = 42000h^{-1})

Table D1 Catalytic activity test over 15Ni/CZO catalyst

Parameters	Time on Stream (h)				
	1	2	3	4	5
X_{CH4}	74.76	71.82	70.53	69.44	66.44
Y_{H2}	83.46	82.62	80.78	76.32	74.92
H_2/CO	3.05	3.12	3.17	3.08	3.13
S_{CO}	87.78	90.66	90.98	94.19	93.63
S_{CO2}	12.22	9.34	9.02	5.81	6.37

Table D2 Catalytic activity test over 15Ni5Mn/CZO (C) catalyst

Parameters	Time on Stream (h)				
	1	2	3	4	5
X_{CH4}	78.63	75.40	74.40	73.50	72.28
Y_{H2}	86.03	85.18	82.54	81.24	81.06
H_2/CO	5.71	5.47	5.00	4.83	4.76
S_{CO}	82.65	81.80	83.37	83.88	84.67
S_{CO2}	17.35	18.20	16.63	16.12	15.33

Table D3 Catalytic activity test over 15Ni10Mn/CZO (C) catalyst

Parameters	Time on Stream (h)				
	1	2	3	4	5
X_{CH4}	57.66	57.43	53.35	51.20	53.02
Y_{H2}	63.51	62.31	60.53	61.15	60.96
H_2/CO	4.51	4.64	4.75	4.78	4.73
S_{CO}	76.20	75.39	75.55	76.24	75.86
S_{CO2}	23.80	24.61	24.45	23.76	24.14

Table D4 Catalytic activity test over 15Ni15Mn/CZO (C) catalyst

Parameters	Time on Stream (h)				
	1	2	3	4	5
X_{CH4}	55.70	52.65	47.16	45.59	44.63
Y_{H2}	55.95	53.38	49.16	48.97	48.24
H_2/CO	3.33	3.19	3.30	3.34	3.15
S_{CO}	81.45	80.40	80.79	80.41	81.03
S_{CO2}	18.55	19.60	19.21	19.59	18.97

Table D5 Catalytic activity test over 15Ni5Mn/CZO (S) catalyst

Parameters	Time on Stream (h)				
	1	2	3	4	5
X_{CH4}	78.73	78.26	78.02	77.30	75.87
Y_{H2}	87.28	86.78	86.16	85.67	84.05
H_2/CO	5.99	5.83	5.46	5.05	5.30
S_{CO}	76.14	76.59	77.67	78.97	78.03
S_{CO2}	23.86	23.41	22.33	21.03	21.97

Table D6 Catalytic activity test over 15Ni10Mn/CZO (S) catalyst

Parameters	Time on Stream (h)				
	1	2	3	4	5
X_{CH4}	75.75	73.97	73.40	72.65	70.22
Y_{H2}	67.35	66.15	67.02	65.18	63.82
H_2/CO	4.20	4.06	4.14	4.05	3.98
S_{CO}	75.87	76.98	74.53	76.40	73.93
S_{CO2}	24.13	23.02	25.47	23.60	26.07

Table D7 Catalytic activity test over 15Ni15Mn/CZO (S) catalyst

Parameters	Time on Stream (h)				
	1	2	3	4	5
X_{CH4}	72.52	71.27	69.52	68.72	67.00
Y_{H2}	71.95	69.77	65.95	63.87	63.20
H_2/CO	6.77	6.04	5.56	5.36	5.39
S_{CO}	51.96	56.80	59.22	61.41	61.81
S_{CO2}	48.04	43.20	40.78	38.59	38.19

Appendix E Experimental Data of Catalytic Activity on MSR at 800°C, S/C = 4/1 (GSHV = 42000h^{-1})

Table E1 Catalytic activity test over 15Ni/CZO catalyst

Parameters	Time on Stream (h)				
	1	2	3	4	5
X_{CH4}	82.56	81.92	80.71	79.17	78.25
Y_{H2}	91.10	89.26	88.34	87.47	86.45
H_2/CO	3.96	3.89	3.86	3.86	3.84
S_{CO}	80.40	81.02	80.09	80.39	81.13
S_{CO2}	19.60	18.98	19.91	19.61	18.87

Table E2 Catalytic activity test over 15Ni5Mn/CZO (C) catalyst

Parameters	Time on Stream (h)				
	1	2	3	4	5
X_{CH4}	77.77	70.78	68.96	65.96	64.64
Y_{H2}	97.72	87.57	81.76	73.40	75.28
H_2/CO	5.70	5.63	5.17	4.86	5.04
S_{CO}	61.48	61.03	65.79	57.84	66.01
S_{CO2}	38.52	38.97	34.21	42.16	33.99

Table E3 Catalytic activity test over 15Ni10Mn/CZO (C) catalyst

Parameters	Time on Stream (h)				
	1	2	3	4	5
X_{CH4}	75.10	64.78	63.36	62.84	62.08
Y_{H2}	81.52	77.12	75.33	77.90	78.38
H_2/CO	4.16	6.24	6.55	6.85	7.10
S_{CO}	70.35	54.96	52.28	53.50	48.59
S_{CO2}	29.65	45.04	47.72	46.50	51.41

Table E4 Catalytic activity test over 15Ni15Mn/CZO (C) catalyst

Parameters	Time on Stream (h)				
	1	2	3	4	5
X_{CH4}	68.61	66.56	65.18	64.64	63.60
Y_{H2}	60.73	51.16	54.54	55.65	55.89
H_2/CO	5.38	4.70	5.24	5.44	5.76
S_{CO}	63.04	63.62	62.00	63.75	64.21
S_{CO2}	36.96	36.38	38.00	36.25	35.79

Table E5 Catalytic activity test over 15Ni5Mn/CZO (S) catalyst

Parameters	Time on Stream (h)				
	1	2	3	4	5
X_{CH4}	73.79	73.75	73.42	72.73	72.81
Y_{H2}	76.01	78.67	67.74	69.77	76.01
H_2/CO	6.50	5.92	5.12	5.23	5.81
S_{CO}	57.39	62.06	61.44	60.92	58.43
S_{CO2}	42.61	37.94	38.56	39.08	41.57

Table E6 Catalytic activity test over 15Ni10Mn/CZO (S) catalyst

Parameters	Time on Stream (h)				
	1	2	3	4	5
X_{CH4}	68.39	66.85	66.22	65.60	67.46
Y_{H2}	73.06	68.08	72.14	67.31	64.07
H_2/CO	5.66	6.67	6.63	6.41	6.24
S_{CO}	60.87	53.99	52.66	53.20	54.43
S_{CO2}	39.13	46.01	47.34	46.80	45.57

Table E7 Catalytic activity test over 15Ni15Mn/CZO (S) catalyst

Parameters	Time on Stream (h)				
	1	2	3	4	5
X_{CH4}	68.65	64.14	64.17	62.42	62.10
Y_{H2}	66.43	64.71	64.29	62.20	60.00
H_2/CO	4.82	4.74	4.81	4.67	4.60
S_{CO}	63.46	64.63	63.58	65.60	66.80
S_{CO2}	36.54	35.37	36.42	34.40	33.20

Appendix F Experimental Data of Catalytic Activity on MSR at 600°C, S/C = 4/1 (GSHV = 42000h^{-1})

Table F1 Catalytic activity test over 15Ni/CZO catalyst

Parameters	Time on Stream (h)				
	1	2	3	4	5
X_{CH4}	58.89	57.05	55.80	54.73	44.12
Y_{H2}	44.10	41.34	42.81	39.79	32.64
H_2/CO	5.72	5.78	6.42	6.32	6.08
S_{CO}	62.98	63.58	60.30	56.70	64.28
S_{CO2}	37.02	36.42	39.70	43.30	35.72

Table F2 Catalytic activity test over 15Ni5Mn/CZO (C) catalyst

Parameters	Time on Stream (h)				
	1	2	3	4	5
X_{CH4}	54.56	53.30	51.81	52.81	52.44
Y_{H2}	40.33	31.72	32.44	34.57	33.75
H_2/CO	5.97	5.86	5.23	5.30	5.81
S_{CO}	63.38	62.15	61.40	63.08	66.08
S_{CO2}	36.62	37.85	38.60	36.92	33.92

Table F3 Catalytic activity test over 15Ni5Mn/CZO (S) catalyst

Parameters	Time on Stream (h)				
	1	2	3	4	5
X_{CH4}	60.90	60.22	59.64	59.34	60.76
Y_{H2}	45.85	46.63	47.03	47.42	44.86
H_2/CO	6.73	7.72	7.99	8.28	8.13
S_{CO}	57.15	50.78	48.57	46.43	47.49
S_{CO2}	42.85	49.22	51.43	53.57	52.51

Appendix G Experimental Data of Catalytic Activity on MSR at 600°C, S/C = 3/1 (GSHV = 42000h^{-1})

Table G1 Catalytic activity test over 15Ni/CZO catalyst

Parameters	Time on Stream (h)				
	30	60	90	120	180
X_{CH4}	57.03	42.55	-	-	-
Y_{H2}	44.10	43.37	-	-	-
H_2/CO	6.40	6.76	-	-	-
S_{CO}	54.90	100.00	-	-	-
S_{CO2}	45.10	0.00	-	-	-

Table G2 Catalytic activity test over 15Ni5Mn/CZO (C) catalyst

Parameters	Time on Stream (h)				
	30	60	90	120	180
X_{CH4}	55.51	44.23	42.42	-	-
Y_{H2}	43.61	42.02	41.29	-	-
H_2/CO	8.21	6.30	6.52	-	-
S_{CO}	49.27	100.00	100.00	-	-
S_{CO2}	50.73	0.00	0.00	-	-

Table G3 Catalytic activity test over 15Ni5Mn/CZO (S) catalyst

Parameters	Time on Stream (h)				
	30	60	90	120	180
X_{CH4}	58.16	57.13	55.22	54.11	54.38
Y_{H2}	45.16	41.29	38.54	33.85	34.33
H_2/CO	7.12	6.64	6.29	5.26	5.24
S_{CO}	51.81	51.45	54.05	56.38	58.78
S_{CO2}	48.19	48.55	45.95	43.62	41.22

CURRICULUM VITAE

Name: Mr. Setthawut Thongkhong

Date of Birth: February 6, 1986

Nationality: Thai

University Education:

2002-2006 Bachelor Degree of Chemical Engineering, Sirindhorn International Institute of Technology, Thammasart University, Thailand

Work Experience:

2005	Position:	Trainee (2 months)
	Company name:	Nitro Chemical Industry Co., Ltd.

Proceedings:

1. Thongkhong, S., Rirksomboon, T., and Meeyoo, V. (2011, April 26) Methane Steam Reforming using Mn-promoted Nickel/Ceria-Zirconia Mixed Oxide Catalysts. Proceedings of The 2nd Research Symposium on Petroleum, Petrochemicals, and Advanced Materials and The 17th PPC Symposium on Petroleum, Petrochemicals, and Polymers, Bangkok, Thailand.