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APPENDICES

Appendix A Calculations

1. Catalyst Preparation

1.1 Amount of Ni loading

Example Prepared 1 g of 3 wt% Ni/ZSM-5 catalyst;

- Amount of Ni (MW = 58.70 g/mole)

  Ni = 1*(3/100) g

  = 0.03 g

- Amount of Ni $(NO_3)_2 \cdot 6H_2O$ (MW = 290.81 g/mole)

  Ni $(NO_3)_2 \cdot 6H_2O$ = 0.03*(290.81/58.70)g

  = 0.1486 g

- Amount of ZSM-5 Zeolite

  ZSM-5 Zeolite = 1-0.03 = 0.97 g

1.2 Amount of CeO_2 loading

Example Prepared 1g of 3%Ce-11% Ni/ZSM-5 catalyst;

- Amount of Ni (MW = 58.70 g/mole)

  Ni = 1*(11/100) g

  = 0.11 g

- Amount of Ni $(NO_3)_2 \cdot 6H_2O$ (MW = 290.81 g/mole)

  Ni $(NO_3)_2 \cdot 6H_2O$ = 0.11*(290.81/58.70)g

  = 0.5450 g

- Amount of Ce (MW = 140.12 g/mole)

  Ce = 1*(3/100) g

  = 0.03 g

- Amount of $Ce(NO_3)_3 \cdot 6H_2O$ (MW = 434.23 g/mole)

  $Ce(NO_3)_3 \cdot 6H_2O$ = 0.03*(434.23/140.12)g

  = 0.0930 g

- Amount of ZSM-5 Zeolite

ZSM-5 Zeolite = 1-0.11-0.03 = 0.86 g

2. Steam- to-Methane Ratio for Feed

For mixture system;

Assume: 1:1 H_2O: CH_4 molar ratio;

Where Total flow = 100 ml/min

CH_4 flow = 20 ml/min

Steam flow = 20 ml/min

He balance = 60 ml/min

Finding the flow rate of water in feed;

From thermodynamic steam table;

At 160°C, V_g = 0.3068 m^3/kg (D_g = 0.00326 g/cm^3)

At 25°C, V_f = 0.001003 m^3/kg (D_f = 0.997 g/cm^3)

At evaporator (water feed is in the steam phase)

Then, $M_g = D_g * V_g$

$= 0.00326\ g/cm^3 * 20\ ml$

$= 0.0652\ g$

Thus, water in liquid phase as a feed is

$V_l = M_l/D_l$

$= 0.0652\ g/0.997\ g/cm^3$

$= 0.0654$ ml/min. = 3.9 ml/hr.

3. Metal Crystallite Size from XRD

The thickness of crystallite (L) calculated from Scherrer Equation;

$$L_{khl} = k\lambda/(\beta\cos\theta_0)$$

Where λ = the x-ray wavelength

B = the peak width (expressed in radian)

θ_0 = the angle between the beam and the normal on the reflecting plane (expressed in radian)

k = a constant (or shape factor) (often take as 1)

4. Average Particle Size from TEM

The average particle size (d_s) is calculated on the basis of counting the diameter of numerous particles, according to the equation;

$$d_s = \Sigma\, n_i d_i^3 / \Sigma\, n_i d_i^2$$

Where n_i = number of particles in each size range

d_i = diameter of particle in each size range

Moreover, the particle size distribution is also calculated from:

$$\frac{\text{Number of particles in range}}{\text{Total number of particles}} \times 100\%$$

Appendix B Effect of Ni loading on reduced catalysts for XRD

These XRD patterns show that there are only Ni peaks for the reduced catalysts and the Ni peak intensity is increased with the increasing of Ni loading. It confirms the complete reduction of the catalysts before the reforming reaction was started.

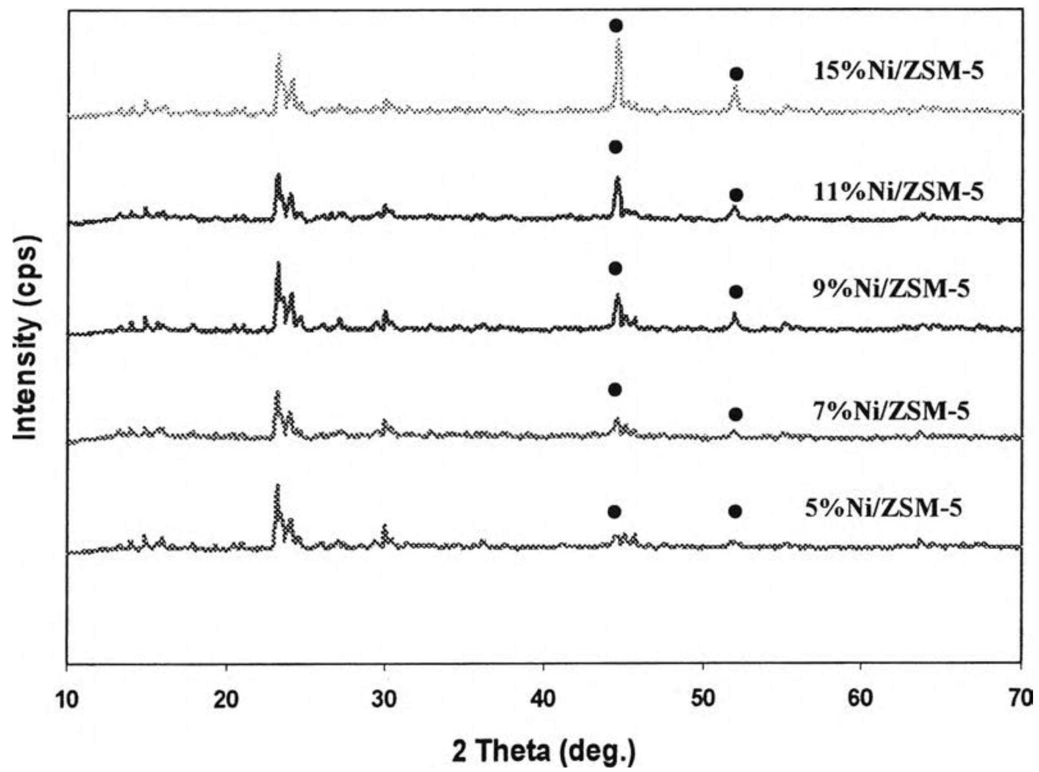

Figure B1 XRD patterns of the reduced Ni/ZSM-5 catalysts with various loadings of Ni, which operated on steam reforming reaction at 700°C and atmospheric pressure for 5 hours; (●), Ni metal phase.

Appendix C Particle size distribution from TEM

1. Effect of Ni loading

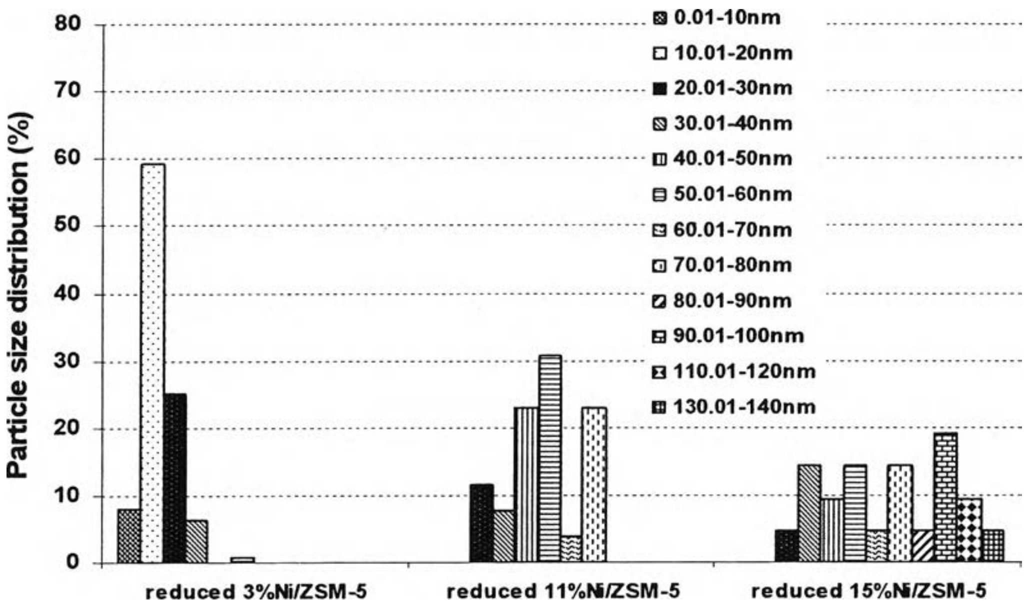

Figure C1 Particle size distribution of the reduced Ni/ZSM-5 catalysts with various loadings of Ni which were calculated from TEM results.

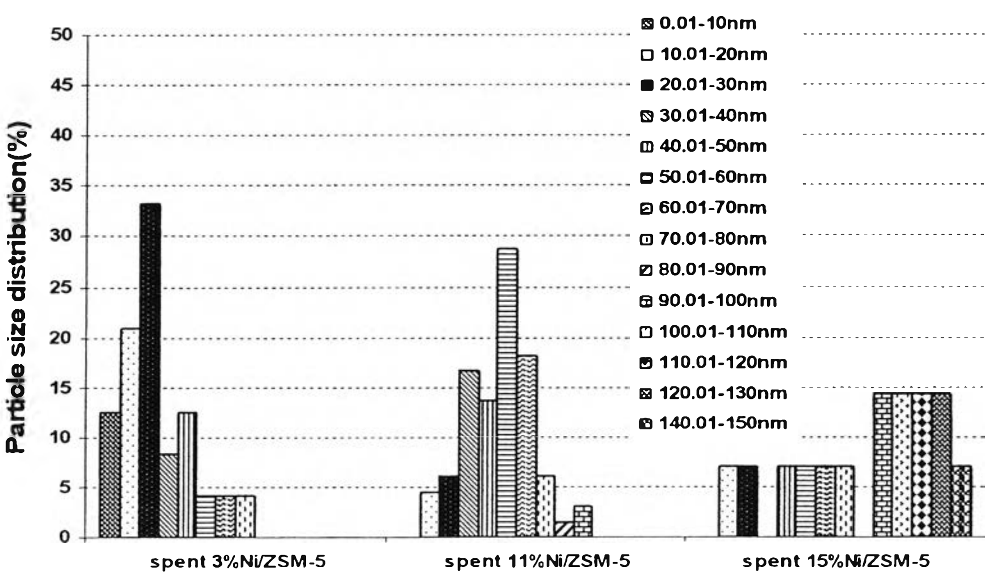

Figure C2 Particle size distribution of the spent Ni/ZSM-5 catalysts with various loadings of Ni which were calculated from TEM results.

2. Effect of CeO_2 addition

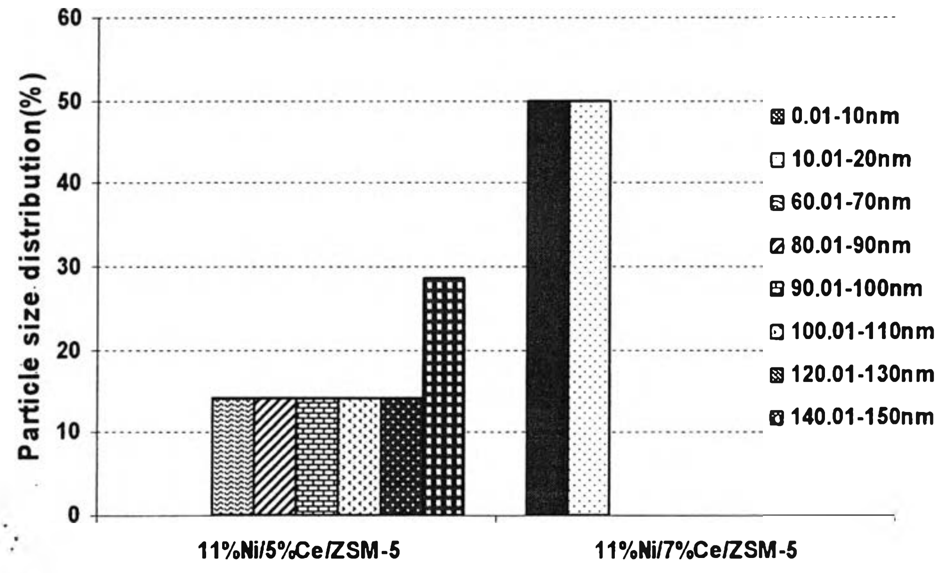

Figure C3 Particle size distribution of the spent Ni/ZSM-5 catalysts with various loadings of CeO_2 which were calculated from TEM results.

Appendix D Stability test of the 11%Ni/5%Ce/ZSM-5 catalyst

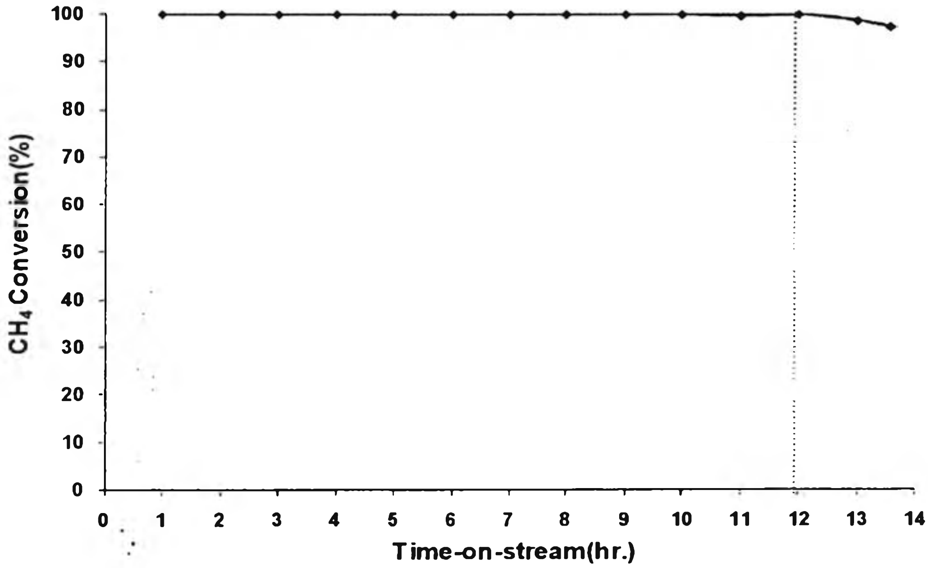

Figure D1 CH_4 conversion of the 11%Ni/5%Ce/ZSM-5 catalyst operated on the reforming reaction at 700°C and a H_2O/CH_4 ratio of 0.8 for the stability test.

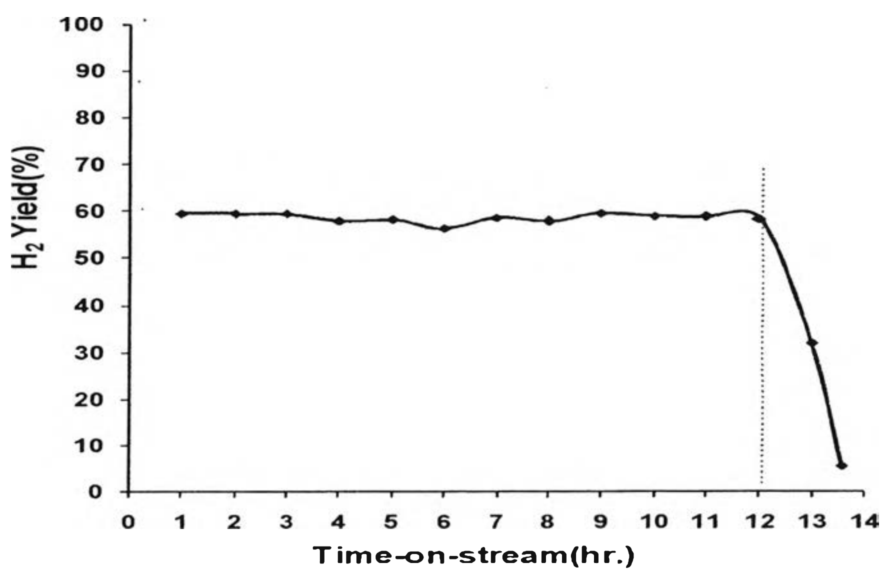

Figure D2 H_2 yield of the 11%Ni/5%Ce/ZSM-5 catalyst operated on the reforming reaction at 700°C and a H_2O/CH_4 ratio of 0.8 for the stability test.

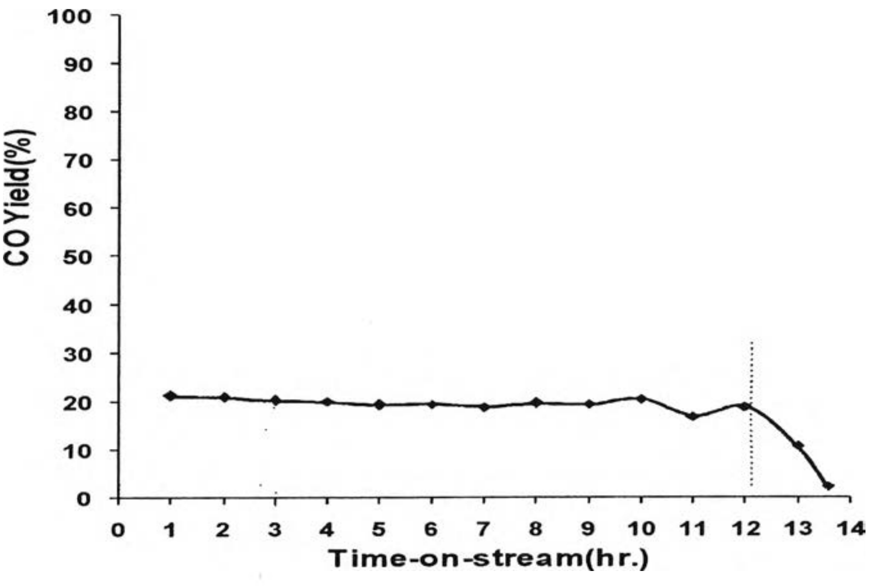

Figure D3 CO yield of the 11%Ni/5%Ce/ZSM-5 catalyst operated on the reforming reaction at 700°C and a H_2O/CH_4 ratio of 0.8 for the stability test.

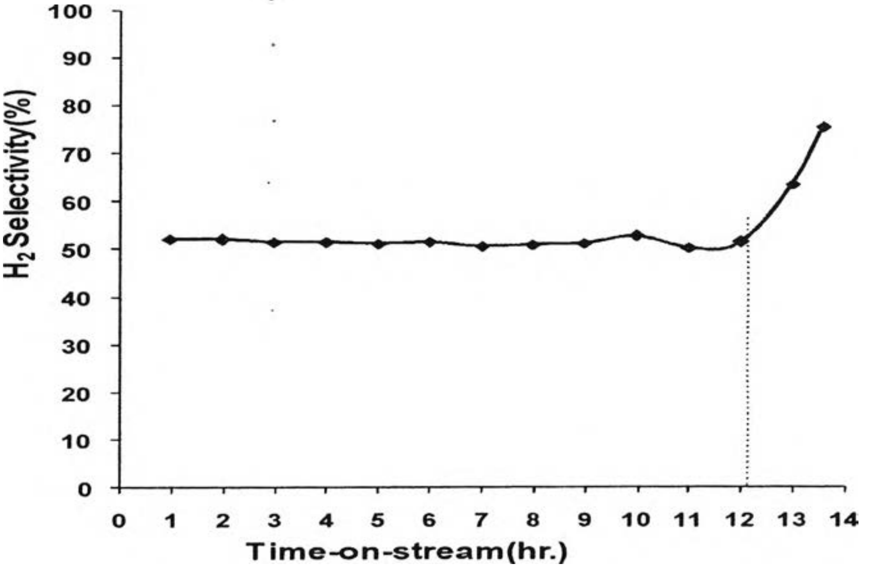

Figure D4 H_2 Selectivity of the 11%Ni/5%Ce/ZSM-5 catalyst operated on the reforming reaction at 700°C and a H_2O/CH_4 ratio of 0.8 for the stability test.

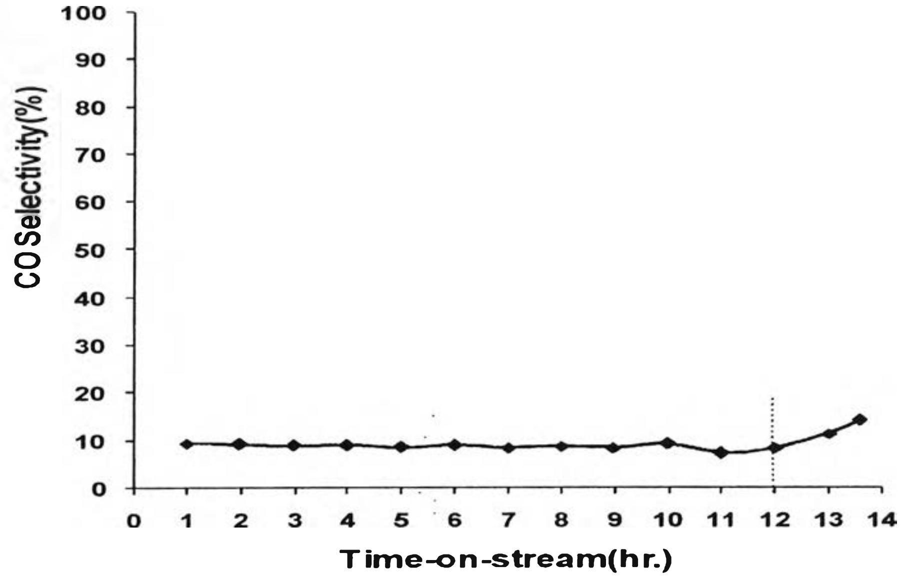

Figure D5 CO selectivity of the 11%Ni/5%Ce/ZSM-5 catalyst operated on the reforming reaction at 700°C and a H_2O/CH_4 ratio of 0.8 for the stability test.

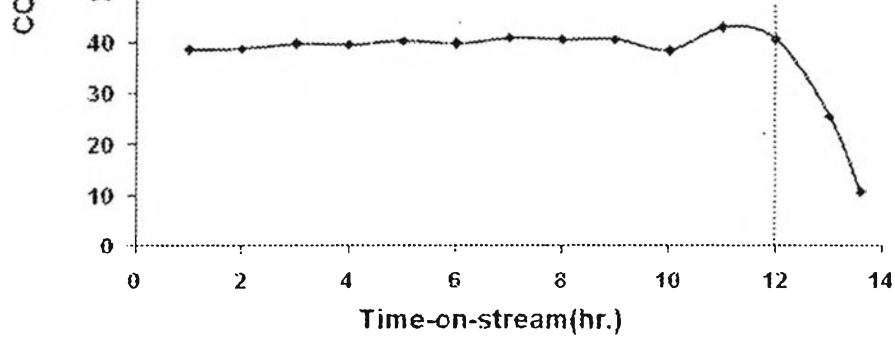

Figure D6 CO_2 selectivity of the 11%Ni/5%Ce/ZSM-5 catalyst operated on the reforming reaction at 700°C and a H_2O/CH_4 ratio of 0.8 for the stability test.

Appendix E CO_2 selectivity of the catalysts in all effect studies

1. Effect of Ni loading

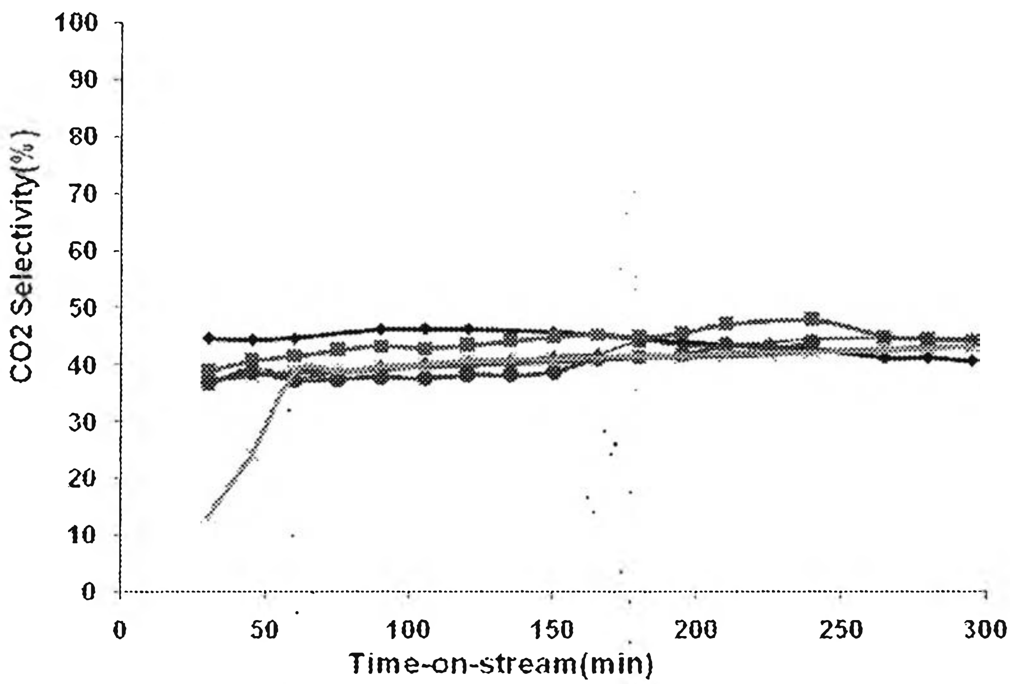

Figure E1 CO_2 selectivity of the Ni/ZSM-5 catalysts with various loadings of Ni, which operated on steam reforming reaction at 700°C and atmospheric pressure for 5 hours; (-♦-), 3%Ni/ZSM-5; (-■-), 5%Ni/ZSM-5; (-▲-), 7%Ni/ZSM-5; (-×-), 9%Ni/ZSM-5; (-●-), 11%Ni/ZSM-5; (-ж-), 15%Ni/ZSM-5.

2. Effect of H_2O/CH_4 ratio

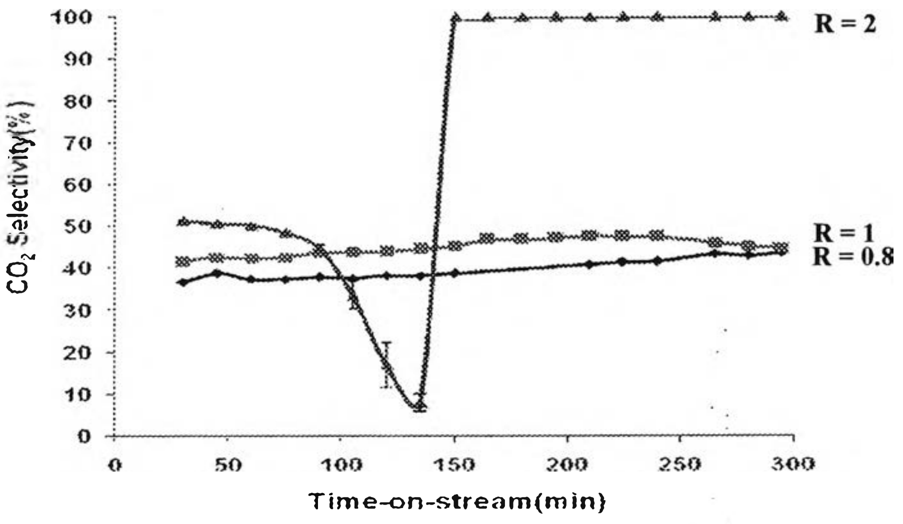

Figure E2 CO_2 selectivity of the 11%Ni/ZSM-5 catalysts with different H_2O/CH_4 ratios, which operated on steam reforming reaction at 700°C and atmospheric pressure for 5 hours.

3. Effect of CeO_2 loading

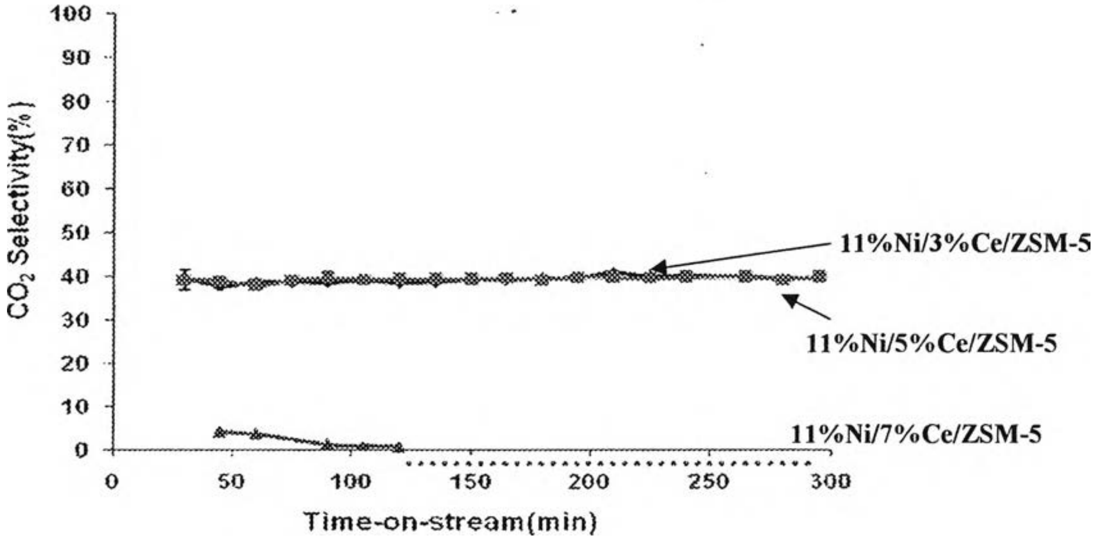

Figure E3 CO_2 selectivity of the 11%Ni/ZSM-5 catalysts with various CeO_2 loadings, which operated on steam reforming reaction at 700°C, H_2O/CH_4 ratio of 0.8, and atmospheric pressure for 5 hours.

Appendix F Experimental data

Table F1 Effect of Ni loading: H_2 selectivity, CO selectivity, CO_2 selectivity, H_2 yield, CO yield, CH_4 conversion

3%Ni loading

rxn. time (min)	Gas	V (L)	$n_{,P}$ (mol)	S_{H2} (%)	S_{CO} (%)	S_{CO2} (%)	$n_{CH4,F}$ (mol)	H_2 Yield (%)	CO Yield (%)	CH4 Conversion
15	H2	0.5973	0.0075	50.37	4.43	45.21	0.0123	43.91	3.86	87.17
	CO2	0.5360	0.0067							
	CO	0.0525	0.0007							
	CH4	0.1256	0.0016							
30	H2	1.0877	0.0136	50.79	4.68	44.53	0.0245	42.62	3.92	83.91
	CO2	0.9537	0.0119							
	CO	0.1002	0.0013							
	CH4	0.3151	0.0039							
45	H2	1.4391	0.0180	50.87	4.82	44.31	0.0368	42.18	4.00	82.90
	CO2	1.2533	0.0157							
	CO	0.1363	0.0017							
	CH4	0.5022	0.0063							
60	H2	1.6617	0.0208	50.71	4.64	44.65	0.0490	41.48	3.79	81.81
	CO2	1.4632	0.0183							
	CO	0.1519	0.0019							
	CH4	0.7126	0.0089							
90	H2	2.0331	0.0255	49.73	4.10	46.17	0.0736	38.99	3.21	78.40
	CO2	1.8875	0.0236							
	CO	0.1676	0.0021							
	CH4	1.2692	0.0159							
105	H2	2.0510	0.0257	49.88	3.92	46.20	0.0858	38.83	3.05	77.86
	CO2	1.8998	0.0238							
	CO	0.1612	0.0020							
	CH4	1.5178	0.0190							
120	H2	2.1566	0.0270	50.06	3.80	46.13	0.0981	38.21	2.90	76.33
	CO2	1.9872	0.0249							
	CO	0.1638	0.0021							
	CH4	1.8542	0.0232							
150	H2	2.4308	0.0304	50.74	3.55	45.71	0.1226	37.57	2.63	74.05
	CO2	2.1901	0.0274							
	CO	0.1699	0.0021							
	CH4	2.5414	0.0318							
180	H2	2.5408	0.0318	51.96	3.47	44.56	0.1471	38.09	2.55	73.31
	CO2	2.1790	0.0273							
	CO	0.1699	0.0021							
	CH4	3.1361	0.0393							

rxn. time (min)	Gas	V (L)	$n_{,P}$ (mol)	S_{H2} (%)	S_{CO} (%)	S_{CO2} (%)	$n_{CH4,F}$ (mol)	H_2 Yield (%)	CO Yield (%)	CH_4 Conversion
195	H2	2.6662	0.0334	52.47	3.62	43.91	0.1594	38.07	2.63	72.56
	CO2	2.2310	0.0279							
	CO	0.1838	0.0023							
	CH4	3.4931	0.0437							
210	H2	2.9080	0.0364	53.10	3.51	43.39	0.1717	37.08	2.45	69.83
	CO2	2.3766	0.0298							
	CO	0.1921	0.0024							
	CH4	4.1352	0.0518							
240	H2	2.8459	0.0356	53.98	3.35	42.67	0.1962	38.52	2.39	71.37
	CO2	2.2500	0.0282							
	CO	0.1768	0.0022							
	CH4	4.4852	0.0562							
265	H2	2.8742	0.0360	55.52	3.30	41.17	0.2166	40.59	2.42	73.10
	CO2	2.1315	0.0267							
	CO	0.1710	0.0021							
	CH4	4.6527	0.0583							
280	H2	2.9320	0.0367	55.24	3.53	41.23	0.2289	40.36	2.58	73.07
	CO2	2.1888	0.0274							
	CO	0.1873	0.0023							
	CH4	4.9222	0.0616							
295	H2	3.0694	0.0384	55.88	3.47	40.65	0.2411	40.35	2.50	72.21
	CO2	2.2329	0.0280							
	CO	0.1904	0.0024							
	CH4	5.3523	0.0670							

Table F2 Effect of Ni loading: H_2 selectivity, CO selectivity, CO_2 selectivity, H_2 yield, CO yield, CH_4 conversion

5%Ni loading

rxn. time (min)	Gas	V (L)	$n_{,P}$ (mol)	S_{H2} (%)	S_{CO} (%)	S_{CO2} (%)	$n_{CH4,F}$ (mol)	H_2 Yield (%)	CO Yield (%)	CH_4 Conversion
15	H2	0.8279	0.0104	56.72	11.69	31.59	0.0123	52.36	10.79	92.31
	CO2	0.4612	0.0058							
	CO	0.1706	0.0021							
	CH4	0.0753	0.0009							
30	H2	1.7872	0.0224	54.24	6.95	38.82	0.0245	53.43	6.84	98.51
	CO2	1.2792	0.0160							
	CO	0.2289	0.0029							
	CH4	0.0292	0.0004							
45	H2	2.5562	0.0320	53.24	6.15	40.61	0.0368	51.35	5.93	96.44
	CO2	1.9494	0.0244							
	CO	0.2952	0.0037							
	CH4	0.1045	0.0013							
60	H2	3.2741	0.0410	52.55	5.94	41.51	0.0490	49.53	5.60	94.25
	CO2	2.5865	0.0324							
	CO	0.3699	0.0046							
	CH4	0.2253	0.0028							
75	H2	3.7741	0.0473	52.15	5.39	42.46	0.0613	48.60	5.02	93.18
	CO2	3.0726	0.0385							
	CO	0.3902	0.0049							
	CH4	0.3338	0.0042							
90	H2	4.2356	0.0530	51.50	5.35	43.16	0.0736	46.79	4.86	90.86
	CO2	3.5498	0.0445							
	CO	0.4398	0.0055							
	CH4	0.5372	0.0067							
105	H2	4.6082	0.0577	51.72	5.47	42.81	0.0858	46.75	4.94	90.40
	CO2	3.8145	0.0478							
	CO	0.4872	0.0061							
	CH4	0.6583	0.0082							
120	H2	4.9539	0.0620	51.43	5.28	43.29	0.0981	45.63	4.68	88.73
	CO2	4.1705	0.0522							
	CO	0.5084	0.0064							
	CH4	0.8829	0.0111							
135	H2	5.4288	0.0680	50.91	4.96	44.13	0.1104	43.86	4.27	86.15
	CO2	4.7062	0.0589							
	CO	0.5289	0.0066							
	CH4	1.2210	0.0153							
150	H2	5.2162	0.0653	50.30	4.93	44.77	0.1226	42.92	4.21	85.33
	CO2	4.6430	0.0581							
	CO	0.5112	0.0064							
	CH4	1.4360	0.0180							

rxn. time (min)	Gas	V (L)	$n_{,P}$ (mol)	S_{H2} (%)	S_{CO} (%)	S_{CO2} (%)	$n_{CH4,F}$ (mol)	H_2 Yield (%)	CO Yield (%)	CH_4 Conversion
165	H2	5.1600	0.0646	49.98	4.77	45.25	0.1349	42.26	4.04	84.55
	CO2	4.6718	0.0585							
	CO	0.4929	0.0062							
	CH4	1.6637	0.0208							
180	H2	5.4539	0.0683	50.65	4.60	44.75	0.1471	42.13	3.83	83.18
	CO2	4.8190	0.0603							
	CO	0.4954	0.0062							
	CH4	1.9765	0.0248							
195	H2	5.3826	0.0674	49.81	4.58	45.61	0.1594	40.64	3.74	81.60
	CO2	4.9291	0.0617							
	CO	0.4951	0.0062							
	CH4	2.3423	0.0293							
210	H2	5.1761	0.0648	48.30	4.69	47.01	0.1717	38.87	3.78	80.47
	CO2	5.0382	0.0631							
	CO	0.5028	0.0063							
	CH4	2.6767	0.0335							
240	H2	4.5985	0.0576	47.61	4.59	47.79	0.1962	37.61	3.63	78.98
	CO2	4.6158	0.0578							
	CO	0.4438	0.0056							
	CH4	3.2929	0.0412							
265	H2	5.1473	0.0645	50.99	4.15	44.86	0.2166	39.72	3.23	77.90
	CO2	4.5288	0.0567							
	CO	0.4185	0.0052							
	CH4	3.8236	0.0479							
280	H2	4.9673	0.0622	51.29	4.34	44.36	0.2289	39.90	3.38	77.79
	CO2	4.2965	0.0538							
	CO	0.4207	0.0053							
	CH4	4.0589	0.0508							
295	H2	5.2034	0.0652	51.43	4.32	44.25	0.2411	39.18	3.29	76.19
	CO2	4.4769	0.0561							
	CO	0.4370	0.0055							
	CH4	4.5859	0.0574							

Table F3 Effect of Ni loading: H_2 selectivity, CO selectivity, CO_2 selectivity, H_2 yield, CO yield, CH_4 conversion

7%Ni loading

rxn. time (min)	Gas	V (L)	$n_{,P}$ (mol)	S_{H2} (%)	S_{CO} (%)	S_{CO2} (%)	$n_{CH4,F}$ (mol)	H_2 Yield (%)	CO Yield (%)	CH_4 Conversion
30	H2	1.9838	0.0248	55.26	8.04	36.70	0.0245	55.26	8.04	99.99
	CO2	1.3175	0.0165							
	CO	0.2885	0.0036							
	CH4	0.0001	0.0000							
45	H2	2.8165	0.0353	53.98	6.67	39.35	0.0368	53.80	6.65	99.67
	CO2	2.0532	0.0257							
	CO	0.3483	0.0044							
	CH4	0.0097	0.0001							
60	H2	3.3914	0.0425	54.78	7.35	37.87	0.0490	54.23	7.28	98.99
	CO2	2.3443	0.0294							
	CO	0.4550	0.0057							
	CH4	0.0397	0.0005							
75	H2	4.1649	0.0522	54.39	7.11	38.49	0.0613	53.48	6.99	98.32
	CO2	2.9475	0.0369							
	CO	0.5447	0.0068							
	CH4	0.0820	0.0010							
90	H2	5.2650	0.0659	53.53	6.71	39.75	0.0736	52.00	6.52	97.14
	CO2	3.9095	0.0490							
	CO	0.6603	0.0083							
	CH4	0.1681	0.0021							
105	H2	5.8059	0.0727	53.23	6.52	40.25	0.0858	51.33	6.28	96.44
	CO2	4.3905	0.0550							
	CO	0.7107	0.0089							
	CH4	0.2442	0.0031							
120	H2	6.6950	0.0838	53.13	6.19	40.68	0.0981	50.73	5.91	95.49
	CO2	5.1255	0.0642							
	CO	0.7804	0.0098							
	CH4	0.3535	0.0044							
135	H2	7.1055	0.0890	53.10	6.16	40.74	0.1104	50.26	5.83	94.66
	CO2	5.4516	0.0683							
	CO	0.8246	0.0103							
	CH4	0.4706	0.0059							
150	H2	7.7021	0.0964	52.53	5.95	41.52	0.1226	49.16	5.57	93.59
	CO2	6.0883	0.0762							
	CO	0.8727	0.0109							
	CH4	0.6278	0.0079							
165	H2	8.4990	0.1064	52.34	5.82	41.84	0.1349	48.32	5.38	92.33
	CO2	6.7937	0.0851							
	CO	0.9457	0.0118							
	CH4	0.8266	0.0104							

rxn. time (min)	Gas	V (L)	$n_{,P}$ (mol)	S_{H2} (%)	S_{CO} (%)	S_{CO2} (%)	$n_{CH4,F}$ (mol)	H_2 Yield (%)	CO Yield (%)	CH_4 Conversion
180	H2	9.2382	0.1157	50.88	5.02	44.10	0.1471	46.15	4.56	90.71
	CO2	8.0079	0.1003							
	CO	0.9122	0.0114							
	CH4	1.0911	0.0137							
195	H2	8.9797	0.1124	51.35	5.49	43.16	0.1594	46.59	4.98	90.72
	CO2	7.5467	0.0945							
	CO	0.9607	0.0120							
	CH4	1.1812	0.0148							
210	H2	9.0225	0.1130	51.14	5.30	43.55	0.1717	46.00	4.77	89.93
	CO2	7.6831	0.0962							
	CO	0.9354	0.0117							
	CH4	1.3801	0.0173							
225	H2	9.1172	0.1142	50.92	5.26	43.82	0.1839	45.40	4.69	89.17
	CO2	7.8460	0.0983							
	CO	0.9415	0.0118							
	CH4	1.5913	0.0199							
240	H2	9.1529	0.1146	50.52	4.95	44.53	0.1962	44.34	4.35	87.76
	CO2	8.0679	0.1010							
	CO	0.8970	0.0112							
	CH4	1.9171	0.0240							
265	H2	9.5642	0.1198	50.72	4.56	44.71	0.2166	43.63	3.93	86.02
	CO2	8.4304	0.1056							
	CO	0.8607	0.0108							
	CH4	2.4181	0.0303							
280	H2	9.5723	0.1199	50.79	4.61	44.60	0.2289	43.29	3.93	85.23
	CO2	8.4051	0.1053							
	CO	0.8692	0.0109							
	CH4	2.6994	0.0338							
295	H2	9.8589	0.1235	50.86	4.65	44.49	0.2411	42.83	3.91	84.20
	CO2	8.6244	0.1080							
	CO	0.9006	0.0113							
	CH4	3.0422	0.0381							

Table F4 Effect of Ni loading: H_2 selectivity, CO selectivity, CO_2 selectivity, H_2 yield, CO yield, CH_4 conversion

9%Ni loading

rxn. time (min)	Gas	V (L)	$n_{,P}$ (mol)	S_{H2} (%)	S_{CO} (%)	S_{CO2} (%)	$n_{CH4,F}$ (mol)	H_2 Yield (%)	CO Yield (%)	CH_4 Conversion
15	H2	1.0214	0.0128	56.09	7.92	35.99	0.0123	56.09	7.92	100.00
	CO2	0.6554	0.0082							
	CO	0.1443	0.0018							
	CH4	0.0000	0.0000							
30	H2	2.0605	0.0258	55.14	7.46	37.40	0.0245	55.14	7.46	100.00
	CO2	1.3975	0.0175							
	CO	0.2788	0.0035							
	CH4	0.0000	0.0000							
45	H2	2.9026	0.0363	54.70	7.20	38.10	0.0368	54.60	7.19	99.82
	CO2	2.0217	0.0253							
	CO	0.3822	0.0048							
	CH4	0.0053	0.0001							
60	H2	3.8568	0.0483	54.15	7.12	38.73	0.0490	53.65	7.05	99.07
	CO2	2.7583	0.0345							
	CO	0.5071	0.0063							
	CH4	0.0363	0.0005							
75	H2	4.7141	0.0590	54.27	6.94	38.80	0.0613	53.40	6.82	98.40
	CO2	3.3702	0.0422							
	CO	0.6025	0.0075							
	CH4	0.0784	0.0010							
90	H2	5.4163	0.0678	53.96	6.85	39.18	0.0736	52.76	6.70	97.77
	CO2	3.9327	0.0492							
	CO	0.6878	0.0086							
	CH4	0.1312	0.0016							
105	H2	6.1354	0.0768	53.74	6.75	39.50	0.0858	52.16	6.55	97.05
	CO2	4.5095	0.0565							
	CO	0.7710	0.0097							
	CH4	0.2023	0.0025							
120	H2	6.8530	0.0858	53.60	6.58	39.81	0.0981	51.62	6.34	96.29
	CO2	5.0896	0.0637							
	CO	0.8418	0.0105							
	CH4	0.2906	0.0036							
135	H2	7.4243	0.0930	53.42	6.47	40.10	0.1104	51.06	6.19	95.58
	CO2	5.5738	0.0698							
	CO	0.8999	0.0113							
	CH4	0.3895	0.0049							
150	H2	7.9355	0.0994	53.17	6.38	40.45	0.1226	50.41	6.05	94.81
	CO2	6.0363	0.0756							
	CO	0.9520	0.0119							
	CH4	0.5080	0.0064							

rxn. time (min)	Gas	V (L)	$n_{,P}$ (mol)	S_{H2} (%)	S_{CO} (%)	S_{CO2} (%)	$n_{CH4,F}$ (mol)	H_2 Yield (%)	CO Yield (%)	CH_4 Conversion
165	H2	8.5188	0.1067	52.95	6.17	40.88	0.1349	49.73	5.79	93.92
	CO2	6.5772	0.0824							
	CO	0.9926	0.0124							
	CH4	0.6546	0.0082							
180	H2	9.0772	0.1137	52.72	6.05	41.23	0.1471	49.10	5.63	93.13
	CO2	7.1002	0.0889							
	CO	1.0418	0.0130							
	CH4	0.8068	0.0101							
195	H2	9.5824	0.1200	52.72	6.03	41.26	0.1594	48.70	5.57	92.38
	CO2	7.4992	0.0939							
	CO	1.0955	0.0137							
	CH4	0.9696	0.0121							
210	H2	9.9914	0.1251	52.59	5.99	41.42	0.1717	48.32	5.50	91.87
	CO2	7.8694	0.0985							
	CO	1.1370	0.0142							
	CH4	1.1142	0.0140							
225	H2	10.1359	0.1269	52.35	5.89	41.76	0.1839	47.66	5.36	91.05
	CO2	8.0867	0.1013							
	CO	1.1399	0.0143							
	CH4	1.3152	0.0165							
240	H2	10.6161	0.1329	52.08	5.70	42.22	0.1962	46.95	5.14	90.16
	CO2	8.6070	0.1078							
	CO	1.1612	0.0145							
	CH4	1.5421	0.0193							
265	H2	11.4100	0.1429	52.09	5.25	42.65	0.2166	46.32	4.67	88.93
	CO2	9.3428	0.1170							
	CO	1.1506	0.0144							
	CH4	1.9156	0.0240							
280	H2	11.3235	0.1418	51.73	5.27	43.00	0.2289	45.47	4.63	87.89
	CO2	9.4127	0.1179							
	CO	1.1529	0.0144							
	CH4	2.2127	0.0277							
295	H2	11.5276	0.1444	51.70	5.26	43.05	0.2411	45.23	4.60	87.48
	CO2	9.5984	0.1202							
	CO	1.1725	0.0147							
	CH4	2.4105	0.0302							

Table F5 Effect of Ni loading: H_2 selectivity, CO selectivity, CO_2 selectivity, H_2 yield, CO yield, CH_4 conversion

11%Ni loading

rxn. time (min)	Gas	V (L)	$n_{,P}$ (mol)	S_{H2} (%)	S_{CO} (%)	S_{CO2} (%)	$n_{CH4,F}$ (mol)	H_2 Yield (%)	CO Yield (%)	CH_4 Conversion
30	H2	2.0760	0.0260	55.48	7.80	36.72	0.0245	55.48	7.80	100.00
	CO2	1.3740	0.0172							
	CO	0.2917	0.0037							
	CH4	0.0000	0.0000							
45	H2	3.0704	0.0384	54.22	7.02	38.76	0.0368	54.22	7.02	100.00
	CO2	2.1949	0.0275							
	CO	0.3974	0.0050							
	CH4	0.0000	0.0000							
60	H2	4.1379	0.0518	55.12	7.56	37.32	0.0490	55.12	7.56	100.00
	CO2	2.8016	0.0351							
	CO	0.5677	0.0071							
	CH4	0.0000	0.0000							
75	H2	5.0568	0.0633	54.91	7.65	37.44	0.0613	54.91	7.65	100.00
	CO2	3.4482	0.0432							
	CO	0.7041	0.0088							
	CH4	0.0000	0.0000							
90	H2	6.1093	0.0765	54.74	7.35	37.91	0.0736	54.74	7.35	100.00
	CO2	4.2302	0.0530							
	CO	0.8203	0.0103							
	CH4	0.0000	0.0000							
105	H2	7.1432	0.0894	54.87	7.48	37.65	0.0858	54.87	7.48	100.00
	CO2	4.9021	0.0614							
	CO	0.9738	0.0122							
	CH4	0.0000	0.0000							
120	H2	8.1520	0.1021	54.55	7.23	38.22	0.0981	54.55	7.23	100.00
	CO2	5.7121	0.0715							
	CO	1.0810	0.0135							
	CH4	0.0000	0.0000							
135	H2	8.9928	0.1126	54.57	7.22	38.21	0.1104	54.57	7.22	100.00
	CO2	6.2970	0.0789							
	CO	1.1892	0.0149							
	CH4	0.0000	0.0000							
150	H2	10.0226	0.1255	54.18	7.08	38.74	0.1226	54.09	7.07	99.84
	CO2	7.1653	0.0897							
	CO	1.3103	0.0164							
	CH4	0.0158	0.0002							
210	H2	11.2544	0.1409	52.77	6.35	40.88	0.1717	50.66	6.09	96.00
	CO2	8.7185	0.1092							
	CO	1.3537	0.0170							
	CH4	0.5482	0.0069							

rxn. time (min)	Gas	V (L)	$n_{,P}$ (mol)	S_{H2} (%)	S_{CO} (%)	S_{CO2} (%)	$n_{CH4,F}$ (mol)	H_2 Yield (%)	CO Yield (%)	CH_4 Conversion
225	H2	11.6087	0.1454	52.48	6.10	41.41	0.1839	49.60	5.77	94.50
	CO2	9.1601	0.1147							
	CO	1.3503	0.0169							
	CH4	0.8081	0.0101							
240	H2	12.2652	0.1536	52.52	5.85	41.63	0.1962	48.83	5.43	92.97
	CO2	9.7209	0.1217							
	CO	1.3651	0.0171							
	CH4	1.1012	0.0138							
265	H2	12.4142	0.1555	51.58	5.07	43.35	0.2166	47.29	4.65	91.67
	CO2	10.4322	0.1306							
	CO	1.2199	0.0153							
	CH4	1.4402	0.0180							
280	H2	12.6704	0.1587	51.79	5.30	42.91	0.2289	47.31	4.84	91.36
	CO2	10.4977	0.1315							
	CO	1.2973	0.0162							
	CH4	1.5793	0.0198							
295	H2	12.4740	0.1562	51.16	5.15	43.69	0.2289	46.28	4.66	90.47
	CO2	10.6525	0.1334							
	CO	1.2567	0.0157							
	CH4	1.7414	0.0218							

Table F6 Effect of Ni loading: H_2 selectivity, CO selectivity, CO_2 selectivity, H_2 yield, CO yield, CH_4 conversion

15%Ni loading

rxn. time (min)	Gas	V (L)	$n_{,P}$ (mol)	S_{H2} (%)	S_{CO} (%)	S_{CO2} (%)	$n_{CH4,F}$ (mol)	H_2 Yield (%)	CO Yield (%)	CH_4 Conversion
30	H2	0.7994	0.0100	69.69	16.99	13.32	0.0245	50.19	12.24	72.03
	CO2	0.1528	0.0019							
	CO	0.1949	0.0024							
	CH4	0.5479	0.0069							
45	H2	1.9340	0.0242	62.16	13.56	24.28	0.0368	52.89	11.54	85.08
	CO2	0.7555	0.0095							
	CO	0.4219	0.0053							
	CH4	0.4382	0.0055							
60	H2	3.7346	0.0468	54.24	7.11	38.66	0.0490	54.17	7.10	99.88
	CO2	2.6620	0.0333							
	CO	0.4893	0.0061							
	CH4	0.0046	0.0001							
75	H2	4.7155	0.0590	54.29	6.88	38.83	0.0613	53.90	6.83	99.28
	CO2	3.3729	0.0422							
	CO	0.5974	0.0075							
	CH4	0.0351	0.0004							
90	H2	5.3193	0.0666	53.82	6.64	39.54	0.0736	52.87	6.53	98.25
	CO2	3.9082	0.0489							
	CO	0.6565	0.0082							
	CH4	0.1030	0.0013							
105	H2	6.1694	0.0773	53.59	6.48	39.92	0.0858	52.24	6.32	97.48
	CO2	4.5960	0.0576							
	CO	0.7462	0.0093							
	CH4	0.1727	0.0022							
120	H2	6.7298	0.0843	53.13	6.20	40.67	0.0981	51.30	5.98	96.56
	CO2	5.1509	0.0645							
	CO	0.7849	0.0098							
	CH4	0.2698	0.0034							
135	H2	7.7331	0.0968	53.00	6.16	40.84	0.1104	50.74	5.89	95.73
	CO2	5.9590	0.0746							
	CO	0.8984	0.0112							
	CH4	0.3765	0.0047							
150	H2	8.4185	0.1054	52.85	6.23	40.91	0.1226	50.37	5.94	95.30
	CO2	6.5168	0.0816							
	CO	0.9926	0.0124							
	CH4	0.4603	0.0058							
165	H2	8.5323	0.1068	52.69	6.10	41.21	0.1349	50.14	5.81	95.16
	CO2	6.6724	0.0836							
	CO	0.9878	0.0124							
	CH4	0.5209	0.0065							

rxn. time (min)	Gas	V (L)	$n_{,P}$ (mol)	S_{H2} (%)	S_{CO} (%)	S_{CO2} (%)	$n_{CH4,F}$ (mol)	H_2 Yield (%)	CO Yield (%)	CH_4 Conversion
180	H2	9.3822	0.1175	52.39	5.99	41.62	0.1471	49.44	5.65	94.38
	CO2	7.4542	0.0933							
	CO	1.0725	0.0134							
	CH4	0.6605	0.0083							
195	H2	10.0526	0.1259	52.47	6.00	41.53	0.1594	49.25	5.64	93.86
	CO2	7.9557	0.0996							
	CO	1.1505	0.0144							
	CH4	0.7816	0.0098							
210	H2	10.2361	0.1282	52.20	5.83	41.97	0.1717	48.85	5.46	93.58
	CO2	8.2288	0.1030							
	CO	1.1436	0.0143							
	CH4	0.8802	0.0110							
265	H2	12.1037	0.1516	52.11	5.44	42.45	0.2166	47.46	4.95	91.07
	CO2	9.8592	0.1235							
	CO	1.2632	0.0158							
	CH4	1.5450	0.0193							
295	H2	12.8086	0.1604	51.72	5.10	43.18	0.2411	46.09	4.55	89.13
	CO2	10.6952	0.1339							
	CO	1.2639	0.0158							
	CH4	2.0941	0.0262							

Table F7 Effect of Ni loading: H_2 selectivity, CO selectivity, CO_2 selectivity, H_2 yield, CO yield, CH_4 conversion

11%Ni loading at R = 1

rxn. time (min)	Gas	V (L)	$n_{,P}$ (mol)	S_{H2} (%)	S_{CO} (%)	S_{CO2} (%)	$n_{CH4,F}$ (mol)	H_2 Yield (%)	CO Yield (%)	CH_4 Conversion
30	H2	2.0609	0.0258	52.72	5.54	41.74	0.0245	52.72	5.54	100.00
	CO2	1.6314	0.0204							
	CO	0.2167	0.0027							
	CH4	0.0000	0.0000							
45	H2	2.9952	0.0375	52.17	5.25	42.59	0.0368	51.82	5.21	99.33
	CO2	2.4451	0.0306							
	CO	0.3012	0.0038							
	CH4	0.0195	0.0002							
60	H2	3.8887	0.0487	52.22	5.48	42.30	0.0490	51.13	5.36	97.91
	CO2	3.1498	0.0394							
	CO	0.4080	0.0051							
	CH4	0.0818	0.0010							
75	H2	4.5779	0.0573	52.05	5.36	42.60	0.0613	50.55	5.20	97.12
	CO2	3.7467	0.0469							
	CO	0.4714	0.0059							
	CH4	0.1408	0.0018							
90	H2	5.1279	0.0642	51.41	4.96	43.64	0.0736	49.06	4.73	95.43
	CO2	4.3532	0.0545							
	CO	0.4943	0.0062							
	CH4	0.2684	0.0034							
105	H2	5.6597	0.0709	51.28	4.81	43.91	0.0858	48.22	4.52	94.02
	CO2	4.8457	0.0607							
	CO	0.5304	0.0066							
	CH4	0.4100	0.0051							
120	H2	5.9662	0.0747	51.20	4.79	44.01	0.0981	47.11	4.41	92.02
	CO2	5.1277	0.0642							
	CO	0.5585	0.0070							
	CH4	0.6253	0.0078							
135	H2	6.3259	0.0792	50.82	4.53	44.65	0.1104	45.32	4.04	89.19
	CO2	5.5585	0.0696							
	CO	0.5639	0.0071							
	CH4	0.9529	0.0119							
150	H2	6.0843	0.0762	50.43	4.23	45.34	0.1226	44.35	3.72	87.94
	CO2	5.4701	0.0685							
	CO	0.5102	0.0064							
	CH4	1.1806	0.0148							
165	H2	5.1954	0.0651	49.58	3.68	46.75	0.1349	41.61	3.08	83.92
	CO2	4.8984	0.0613							
	CO	0.3852	0.0048							
	CH4	1.7317	0.0217							

rxn. time (min)	Gas	V (L)	$n_{i,P}$ (mol)	S_{H2} (%)	S_{CO} (%)	S_{CO2} (%)	$n_{CH4,F}$ (mol)	H_2 Yield (%)	CO Yield (%)	CH_4 Conversion
180	H2	5.2611	0.0659	49.53	3.70	46.77	0.1471	40.18	3.00	81.12
	CO2	4.9681	0.0622							
	CO	0.3929	0.0049							
	CH4	2.2190	0.0278							
195	H2	4.9613	0.0621	49.25	3.53	47.22	0.1594	38.83	2.78	78.83
	CO2	4.7560	0.0596							
	CO	0.3556	0.0045							
	CH4	2.6942	0.0337							
210	H2	4.7417	0.0594	48.84	3.45	47.71	0.1717	37.55	2.65	76.88
	CO2	4.6318	0.0580							
	CO	0.3345	0.0042							
	CH4	3.1701	0.0397							
225	H2	4.3515	0.0545	49.28	3.30	47.42	0.1839	37.87	2.54	76.84
	CO2	4.1868	0.0524							
	CO	0.2914	0.0036							
	CH4	3.4024	0.0426							
240	H2	4.3492	0.0545	49.23	3.34	47.43	0.1962	37.03	2.51	75.22
	CO2	4.1905	0.0525							
	CO	0.2950	0.0037							
	CH4	3.8826	0.0486							
265	H2	4.2348	0.0530	50.81	3.12	46.07	0.2166	37.74	2.32	74.27
	CO2	3.8400	0.0481							
	CO	0.2604	0.0033							
	CH4	4.4506	0.0557							
280	H2	4.1036	0.0514	51.80	3.07	45.14	0.2289	38.52	2.28	74.36
	CO2	3.5762	0.0448							
	CO	0.2428	0.0030							
	CH4	4.6858	0.0587							
295	H2	4.1306	0.0517	52.10	3.14	44.76	0.2411	38.58	2.32	74.05
	CO2	3.5488	0.0444							
	CO	0.2486	0.0031							
	CH4	4.9972	0.0626							

Table F8 Effect of Ni loading: H_2 selectivity, CO selectivity, CO_2 selectivity, H_2 yield, CO yield, CH_4 conversion

11%Ni loading at R = 2

rxn. time (min)	Gas	V (L)	$n_{i,P}$ (mol)	S_{H2} (%)	S_{CO} (%)	S_{CO2} (%)	$n_{CH4,F}$ (mol)	H_2 Yield (%)	CO Yield (%)	CH_4 Conversion
30	H2	0.6467	0.0081	47.35	0.98	51.67	0.0245	37.19	0.77	78.54
	CO2	0.7056	0.0088							
	CO	0.0134	0.0002							
	CH4	0.4202	0.0053							
45	H2	1.0259	0.0128	47.78	1.42	50.80	0.0368	38.31	1.14	80.19
	CO2	1.0909	0.0137							
	CO	0.0305	0.0004							
	CH4	0.5820	0.0073							
60	H2	1.0169	0.0127	48.26	1.29	50.45	0.0490	36.65	0.98	75.95
	CO2	1.0629	0.0133							
	CO	0.0272	0.0003							
	CH4	0.9422	0.0118							
75	H2	1.1161	.0.0140	49.64	1.28	49.08	0.0613	36.03	0.93	72.59
	CO2	1.1036	0.0138							
	CO	0.0288	0.0004							
	CH4	1.3420	0.0168							
90	H2	0.9520	0.0119	53.00	1.16	45.85	0.0736	38.57	0.84	72.77
	CO2	0.8235	0.0103							
	CO	0.0208	0.0003							
	CH4	1.5999	0.0200							
105	H2	0.8054	0.0101	61.66	0.76	37.59	0.0858	43.01	0.53	69.76
	CO2	0.4910	0.0061							
	CO	0.0099	0.0001							
	CH4	2.0724	0.0260							
120	H2	0.7461	0.0093	76.47	0.18	23.35	0.0981	51.75	0.12	67.67
	CO2	0.2279	0.0029							
	CO	0.0017	0.0000							
	CH4	2.5324	0.0317							
135	H2	0.7295	0.0091	89.40	0.00	10.60	0.1104	60.84	0.00	68.06
	CO2	0.0865	0.0011							
	CO	0.0000	0.0000							
	CH4	2.8150	0.0353							
150	H2	0.7874	0.0099	94.93	0.00	5.07	0.1226	64.19	0.00	67.62
	CO2	0.0421	0.0005							
	CO	0.0000	0.0000							
	CH4	3.1706	0.0397							
165	H2	0.0000	0.0000	0.00	0.00	100.00	0.1349	0.00	0.00	68.22
	CO2	0.0205	0.0003							
	CO	0.0000	0.0000							
	CH4	3.4235	0.0429							

rxn. time (min)	Gas	V (L)	$n_{,P}$ (mol)	S_{H2} (%)	S_{CO} (%)	S_{CO2} (%)	$n_{CH4,F}$ (mol)	H_2 Yield (%)	CO Yield (%)	CH_4 Conversion
180	H2	0.0000	0.0000	0.00	0.00	100.00	0.1471	0.00	0.00	66.94
	CO2	0.0232	0.0003							
	CO	0.0000	0.0000							
	CH4	3.8842	0.0486							
195	H2	0.0000	0.0000	0.00	0.00	100.00	0.1594	0.00	0.00	66.77
	CO2	0.0254	0.0003							
	CO	0.0000	0.0000							
	CH4	4.2299	0.0530							
210	H2	0.0000	0.0000	0.00	0.00	100.00	0.1717	0.00	0.00	66.72
	CO2	0.0274	0.0003							
	CO	0.0000	0.0000							
	CH4	4.5620	0.0571							
225	H2	0.0000	0.0000	0.00	0.00	100.00	0.1839	0.00	0.00	66.90
	CO2	0.0293	0.0004							
	CO	0.0000	0.0000							
	CH4	4.8623	0.0609							
240	H2	0.0000	0.0000	0.00	0.00	100.00	0.1962	0.00	0.00	66.92
	CO2	0.0313	0.0004							
	CO	0.0000	0.0000							
	CH4	5.1820	0.0649							
265	H2	0.0000	0.0000	0.00	0.00	100.00	0.2166	0.00	0.00	67.99
	CO2	0.0336	0.0004							
	CO	0.0000	0.0000							
	CH4	5.5372	0.0693							
280	H2	0.0000	0.0000	0.00	0.00	100.00	0.2289	0.00	0.00	66.55
	CO2	0.0372	0.0005							
	CO	0.0000	0.0000							
	CH4	6.1140	0.0766							
295	H2	0.0000	0.0000	0.00	0.00	100.00	0.2411	0.00	0.00	67.12
	CO2	0.0385	0.0005							
	CO	0.0000	0.0000							
	CH4	6.3324	0.0793							

Table F9 Effect of Ni loading: H_2 selectivity, CO selectivity, CO_2 selectivity, H_2 yield, CO yield, CH_4 conversion

11%Ni loading at R = 2 (repeat)

rxn. time (min)	Gas	V (L)	$n_{i,P}$ (mol)	S_{H2} (%)	S_{CO} (%)	S_{CO2} (%)	$n_{CH4,F}$ (mol)	H_2 Yield (%)	CO Yield (%)	CH_4 Conversion
30	H2	0.8052	0.0101	47.46	1.51	51.03	0.0245	39.60	1.26	83.43
	CO2	0.8658	0.0108							
	CO	0.0255	0.0003							
	CH4	0.3244	0.0041							
45	H2	0.9508	0.0119	47.76	1.60	50.64	0.0368	38.46	1.29	80.52
	CO2	1.0079	0.0126							
	CO	0.0318	0.0004							
	CH4	0.5723	0.0072							
60	H2	1.0053	0.0126	48.57	1.52	49.91	0.0490	37.65	1.17	77.51
	CO2	1.0330	0.0129							
	CO	0.0314	0.0004							
	CH4	0.8807	0.0110							
75	H2	0.8927	0.0112	50.83	1.29	47.88	0.0613	37.70	0.95	74.16
	CO2	0.8409	0.0105							
	CO	0.0226	0.0003							
	CH4	1.2652	0.0158							
90	H2	0.8519	0.0107	55.23	1.14	43.62	0.0736	39.88	0.82	72.20
	CO2	0.6728	0.0084							
	CO	0.0176	0.0002							
	CH4	1.6332	0.0205							
105	H2	0.6886	0.0086	70.00	0.42	29.58	0.0858	48.61	0.29	69.44
	CO2	0.2910	0.0036							
	CO	0.0041	0.0001							
	CH4	2.0947	0.0262							
120	H2	0.6328	0.0079	89.26	0.00	10.74	0.0981	61.89	0.00	69.34
	CO2	0.0762	0.0010							
	CO	0.0000	0.0000							
	CH4	2.4015	0.0301							
135	H2	0.7056	0.0088	94.33	0.00	5.67	0.1104	64.02	0.00	67.87
	CO2	0.0424	0.0005							
	CO	0.0000	0.0000							
	CH4	2.8317	0.0355							
150	H2	0.0000	0.0000	0.00	0.00	100.00	0.1226	0.00	0.00	67.17
	CO2	0.0465	0.0006							
	CO	0.0000	0.0000							
	CH4	3.2149	0.0403							
165	H2	0.0000	0.0000	0.00	0.00	100.00	0.1349	0.00	0.00	69.14
	CO2	0.0203	0.0003							
	CO	0.0000	0.0000							
	CH4	3.3244	0.0416							

rxn. time (min)	Gas	V (L)	$n_{,P}$ (mol)	S_{H2} (%)	S_{CO} (%)	S_{CO2} (%)	$n_{CH4,F}$ (mol)	H_2 Yield (%)	CO Yield (%)	CH_4 Conversion
180	H2	0.0000	0.0000	0.00	0.00	100.00	0.1471	0.00	0.00	67.80
	CO2	0.0229	0.0003							
	CO	0.0000	0.0000							
	CH4	3.7839	0.0474							
195	H2	0.0000	0.0000	0.00	0.00	100.00	0.1594	0.00	0.00	68.41
	CO2	0.0243	0.0003							
	CO	0.0000	0.0000							
	CH4	4.0213	0.0504							
210	H2	0.0000	0.0000	0.00	0.00	100.00	0.1717	0.00	0.00	71.38
	CO2	0.0236	0.0003							
	CO	0.0000	0.0000							
	CH4	3.9230	0.0491							
225	H2	0.0000	0.0000	0.00	0.00	100.00	0.1839	0.00	0.00	65.41
	CO2	0.0284	0.0004							
	CO	0.0000	0.0000							
	CH4	5.0803	0.0636							
240	H2	0.0000	0.0000	0.00	0.00	100.00	0.1962	0.00	0.00	67.91
	CO2	0.0297	0.0004							
	CO	0.0000	0.0000							
	CH4	5.0282	0.0630							
265	H2	0.0000	0.0000	0.00	0.00	100.00	0.2166	0.00	0.00	68.12
	CO2	0.0332	0.0004							
	CO	0.0000	0.0000							
	CH4	5.5155	0.0691							
280	H2	0.0000	0.0000	0.00	0.00	100.00	0.2289	0.00	0.00	68.34
	CO2	0.0347	0.0004							
	CO	0.0000	0.0000							
	CH4	5.7870	0.0725							
295	H2	0.0000	0.0000	0.00	0.00	100.00	0.2411	0.00	0.00	68.04
	CO2	0.0367	0.0005							
	CO	0.0000	0.0000							
	CH4	6.1539	0.0771							

Table F10 Effect of Ni loading: H_2 selectivity, CO selectivity, CO_2 selectivity, H_2 yield, CO yield, CH_4 conversion

11%Ni/3%Ce/ZSM-5

rxn. time (min)	Gas	V (L)	$n_{i,P}$ (mol)	S_{H2} (%)	S_{CO} (%)	S_{CO2} (%)	$n_{CH4,F}$ (mol)	H_2 Yield (%)	CO Yield (%)	CH_4 Conversion
30	H2	1.9902	0.0249	53.85	6.52	39.63	0.0245	53.85	6.52	100.00
	CO2	1.4646	0.0183							
	CO	0.2409	0.0030							
	CH4	0.0000	0.0000							
45	H2	2.9983	0.0375	54.92	7.35	37.73	0.0368	54.92	7.35	100.00
	CO2	2.0598	0.0258							
	CO	0.4010	0.0050							
	CH4	0.0000	0.0000							
60	H2	3.9535	0.0495	54.15	7.17	38.68	0.0490	54.15	7.17	100.00
	CO2	2.8242	0.0354							
	CO	0.5233	0.0066							
	CH4	0.0000	0.0000							
75	H2	4.9440	0.0619	54.35	7.02	38.63	0.0613	54.35	7.02	100.00
	CO2	3.5133	0.0440							
	CO	0.6385	0.0080							
	CH4	0.0000	0.0000							
90	H2	5.8203	0.0729	54.23	7.18	38.58	0.0736	54.23	7.18	100.00
	CO2	4.1404	0.0518							
	CO	0.7710	0.0097							
	CH4	0.0000	0.0000							
105	H2	7.0084	0.0878	53.97	6.98	39.04	0.0858	53.97	6.98	100.00
	CO2	5.0697	0.0635							
	CO	0.9066	0.0114							
	CH4	0.0000	0.0000							
120	H2	7.9314	0.0993	54.26	7.20	38.55	0.0981	54.26	7.20	100.00
	CO2	5.6347	0.0706							
	CO	1.0524	0.0132							
	CH4	0.0000	0.0000							
135	H2	8.8436	0.1107	54.27	7.11	38.62	0.1104	54.22	7.10	99.90
	CO2	6.2936	0.0788							
	CO	1.1580	0.0145							
	CH4	0.0088	0.0001							
150	H2	9.6608	0.1210	53.87	6.91	39.22	0.1226	53.74	6.89	99.76
	CO2	7.0326	0.0881							
	CO	1.2393	0.0155							
	CH4	0.0232	0.0003							
165	H2	10.5529	0.1321	53.85	7.05	39.10	0.1349	53.60	7.02	99.55
	CO2	7.6640	0.0960							
	CO	1.3817	0.0173							
	CH4	0.0489	0.0006							

rxn. time (min)	Gas	V (L)	$n_{,P}$ (mol)	S_{H2} (%)	S_{CO} (%)	S_{CO2} (%)	$n_{CH4,F}$ (mol)	H_2 Yield (%)	CO Yield (%)	CH_4 Conversion
180	H2	11.5149	0.1442	53.58	6.94	39.48	0.1471	53.32	6.91	99.52
	CO2	8.4857	0.1063							
	CO	1.4922	0.0187							
	CH4	0.0559	0.0007							
195	H2	12.3656	0.1548	53.55	6.81	39.64	0.1594	53.20	6.77	99.35
	CO2	9.1553	0.1146							
	CO	1.5729	0.0197							
	CH4	0.0828	0.0010							
210	H2	12.9959	0.1627	52.67	6.60	40.73	0.1717	52.25	6.54	99.19
	CO2	10.0485	0.1258							
	CO	1.6278	0.0204							
	CH4	0.1114	0.0014							
225	H2	14.1365	0.1770	53.40	6.70	39.90	0.1839	52.84	6.63	98.97
	CO2	10.5645	0.1323							
	CO	1.7741	0.0222							
	CH4	0.1518	0.0019							
240	H2	15.1237	0.1894	53.15	6.78	40.08	0.1962	52.50	6.69	98.79
	CO2	11.4039	0.1428							
	CO	1.9281	0.0241							
	CH4	0.1898	0.0024							
265	H2	16.8270	0.2107	53.64	6.51	39.85.	0.2166	52.88	6.42	98.58
	CO2	12.4985	0.1565							
	CO	2.0422	0.0256							
	CH4	0.2459	0.0031							
280	H2	17.7465	0.2222	53.96	6.71	39.33	0.2289	53.09	6.60	98.38
	CO2	12.9343	0.1620							
	CO	2.2058	0.0276							
	CH4	0.2954	0.0037							
295	H2	18.7468	0.2348	53.53	6.76	39.71	0.2411	52.60	6.64	98.26
	CO2	13.9069	0.1741							
	CO	2.3658	0.0296							
	CH4	0.3351	0.0042							

Table F11 Effect of Ni loading: H_2 selectivity, CO selectivity, CO_2 selectivity, H_2 yield, CO yield, CH_4 conversion

11%Ni/5%Ce/ZSM-5

rxn. time (min)	Gas	V (L)	$n_{i,P}$ (mol)	S_{H2} (%)	S_{CO} (%)	S_{CO2} (%)	$n_{CH4,F}$ (mol)	H_2 Yield (%)	CO Yield (%)	CH_4 Conversion
30	H2	2.0334	0.0255	52.48	5.61	41.91	0.0245	51.92	5.55	98.93
	CO2	1.6239	0.0203							
	CO	0.2174	0.0027							
	CH4	0.0209	0.0003							
45	H2	2.9547	0.0370	54.66	7.24	38.10	0.0368	54.19	7.18	99.15
	CO2	2.0596	0.0258							
	CO	0.3916	0.0049							
	CH4	0.0251	0.0003							
60	H2	3.9524	0.0495	54.20	7.08	38.72	0.0490	53.65	7.01	99.00
	CO2	2.8241	0.0354							
	CO	0.5163	0.0065							
	CH4	0.0393	0.0005							
75	H2	4.9110	0.0615	54.65	7.25	38.10	0.0613	54.10	7.18	99.01
	CO2	3.4240	0.0429							
	CO	0.6519	0.0082							
	CH4	0.0486	0.0006							
90	H2	5.9609	0.0746	54.46	7.15	38.39	0.0736	53.84	7.07	98.86
	CO2	4.2028	0.0526							
	CO	0.7827	0.0098							
	CH4	0.0667	0.0008							
105	H2	6.8563	0.0859	54.45	7.16	38.39	0.0858	53.84	7.08	98.88
	CO2	4.8339	0.0605							
	CO	0.9021	0.0113							
	CH4	0.0769	0.0010							
120	H2	7.8253	0.0980	54.25	7.13	38.62	0.0981	53.58	7.04	98.77
	CO2	5.5715	0.0698							
	CO	1.0289	0.0129							
	CH4	0.0962	0.0012							
135	H2	8.6799	0.1087	54.40	7.26	38.33	0.1104	53.69	7.17	98.68
	CO2	6.1158	0.0766							
	CO	1.1586	0.0145							
	CH4	0.1165	0.0015							
150	H2	9.7067	0.1216	54.49	7.31	38.20	0.1226	53.77	7.21	98.69
	CO2	6.8061	0.0852							
	CO	1.3020	0.0163							
	CH4	0.1280	0.0016							
165	H2	10.7044	0.1340	54.06	7.25	38.69	0.1349	53.28	7.14	98.57
	CO2	7.6625	0.0960							
	CO	1.4354	0.0180							
	CH4	0.1545	0.0019							

rxn. time (min)	Gas	V (L)	$n_{,P}$ (mol)	S_{H2} (%)	S_{CO} (%)	S_{CO2} (%)	$n_{CH4,F}$ (mol)	H_2 Yield (%)	CO Yield (%)	CH_4 Conversion
195	H2	12.5481	0.1571	54.11	7.24	38.66	0.1594	53.24	7.12	98.40
	CO2	8.9651	0.1123							
	CO	1.6779	0.0210							
	CH4	0.2035	0.0025							
210	H2	13.4906	0.1689	53.79	7.14	39.06	0.1717	52.92	7.03	98.38
	CO2	9.7961	0.1227							
	CO	1.7918	0.0224							
	CH4	0.2217	0.0028							
225	H2	14.0460	0.1759	53.51	7.32	39.17	0.1839	52.64	7.20	98.37
	CO2	10.2819	0.1288							
	CO	1.9210	0.0241							
	CH4	0.2389	0.0030							
240	H2	15.2983	0.1916	53.78	7.13	39.09	0.1962	52.85	7.00	98.27
	CO2	11.1192	0.1392							
	CO	2.0274	0.0254							
	CH4	0.2705	0.0034							
265	H2	17.1792	0.2151	54.00	6.81	39.19	0.2166	53.05	6.70	98.25
	CO2	12.4677	0.1561							
	CO	2.1679	0.0271							
	CH4	0.3021	0.0038							
280	H2	18.1681	0.2275	54.02	6.79	39.19	0.2289	53.00	6.66	98.11
	CO2	13.1793	0.1650							
	CO	2.2840	0.0286							
	CH4	0.3448	0.0043							
295	H2	18.9237	0.2370	54.06	6.81	39.12	0.2411	53.02	6.68	98.07
	CO2	13.6947	0.1715							
	CO	2.3846	0.0299							
	CH4	0.3709	0.0046							

Table F12 Effect of Ni loading: H_2 selectivity, CO selectivity, CO_2 selectivity, H_2 yield, CO yield, CH_4 conversion

11%Ni/5%Ce/ZSM-5 (repeat)

rxn. time (min)	Gas	V (L)	$n_{i,P}$ (mol)	S_{H2} (%)	S_{CO} (%)	S_{CO2} (%)	$n_{CH4,F}$ (mol)	H_2 Yield (%)	CO Yield (%)	CH_4 Conversion
30	H2	2.2345	0.0280	53.37	10.37	36.26	0.0245	57.05	22.16	100.00
	CO2	1.5182	0.0190							
	CO	0.4341	0.0054							
	CH4	0.0000	0.0000							
45	H2	3.3782	0.0423	51.45	8.80	39.75	0.0368	57.50	19.66	100.00
	CO2	2.6103	0.0327							
	CO	0.5775	0.0072							
	CH4	0.0000	0.0000							
60	H2	4.1781	0.0523	52.95	10.21	36.84	0.0490	53.34	20.57	100.00
	CO2	2.9064	0.0364							
	CO	0.8055	0.0101							
	CH4	0.0000	0.0000							
75	H2	5.4656	0.0684	51.11	8.85	40.04	0.0613	55.82	19.33	100.00
	CO2	4.2816	0.0536							
	CO	0.9466	0.0119							
	CH4	0.0000	0.0000							
90	H2	6.5526	0.0821	50.64	8.48	40.88	0.0736	55.77	18.67	100.00
	CO2	5.2890	0.0662							
	CO	1.0968	0.0137							
	CH4	0.0000	0.0000							
105	H2	7.7306	0.0968	51.13	8.60	40.27	0.0858	56.39	18.97	100.00
	CO2	6.0896	0.0763							
	CO	1.3006	0.0163							
	CH4	0.0000	0.0000							
120	H2	8.7085	0.1091	51.15	9.00	39.85	0.0981	55.59	19.55	100.00
	CO2	6.7840	0.0850							
	CO	1.5318	0.0192							
	CH4	0.0000	0.0000							
135	H2	10.0604	0.1260	51.28	8.68	40.04	0.1104	57.08	19.33	100.00
	CO2	7.8564	0.0984							
	CO	1.7037	0.0213							
	CH4	0.0000	0.0000							
150	H2	10.7010	0.1340	51.04	8.80	40.17	0.1226	54.64	18.83	100.00
	CO2	8.4224	0.1055							
	CO	1.8442	0.0231							
	CH4	0.0000	0.0000							
165	H2	12.3417	0.1545	51.16	8.52	40.31	0.1349	57.29	19.09	100.00
	CO2	9.7237	0.1218							
	CO	2.0563	0.0258							
	CH4	0.0000	0.0000							

rxn. time (min)	Gas	V (L)	$n_{,P}$ (mol)	S_{H2} (%)	S_{CO} (%)	S_{CO2} (%)	$n_{CH4,F}$ (mol)	H_2 Yield (%)	CO Yield (%)	CH_4 Conversion
195	H2	14.0711	0.1762	50.63	8.45	40.93	0.1594	55.27	18.44	100.00
	CO2	11.3759	0.1425							
	CO	2.3476	0.0294							
	CH4	0.0000	0.0000							
210	H2	15.5454	0.1947	51.21	8.58	40.21	0.1717	56.70	19.01	99.99
	CO2	12.2080	0.1529							
	CO	2.6054	0.0326							
	CH4	0.0009	0.0000							
225	H2	16.7736	0.2100	51.41	8.73	39.86	0.1839	57.10	19.38	99.94
	CO2	13.0057	0.1629							
	CO	2.8467	0.0356							
	CH4	0.0089	0.0001							
240	H2	17.2262	0.2157	51.02	8.81	40.18	0.1962	54.98	18.98	99.88
	CO2	13.5651	0.1699							
	CO	2.9731	0.0372							
	CH4	0.0191	0.0002							
265	H2	19.3262	0.2420	51.13	8.63	40.23	0.2166	55.86	18.87	99.74
	CO2	15.2048	0.1904							
	CO	3.2635	0.0409							
	CH4	0.0456	0.0006							
280	H2	19.3837	0.2427	51.58	9.30	39.12	0.2289	53.02	19.13	99.73
	CO2	14.7036	0.1841							
	CO	3.4960	0.0438							
	CH4	0.0491	0.0006							
295	H2	21.5382	0.2697	51.21	8.62	40.16	0.2411	55.92	18.83	99.59
	CO2	16.8907	0.2115							
	CO	3.6265	0.0454							
	CH4	0.0780	0.0010							

Table F13 Effect of Ni loading: H_2 selectivity, CO selectivity, CO_2 selectivity, H_2 yield, CO yield, CH_4 conversion

11%Ni/7%Ce/ZSM-5

rxn. time (min)	Gas	V (L)	$n_{,P}$ (mol)	S_{H2} (%)	S_{CO} (%)	S_{CO2} (%)	$n_{CH4,F}$ (mol)	H_2 Yield (%)	CO Yield (%)	CH_4 Conversion
45	H2	0.2006	0.0025	85.83	9.99	4.18	0.0368	84.07	9.79	97.95
	CO2	0.0098	0.0001							
	CO	0.0234	0.0003							
	CH4	0.0603	0.0008							
60	H2	0.3541	0.0044	89.60	6.73	3.67	0.0490	87.89	6.60	98.09
	CO2	0.0145	0.0002							
	CO	0.0266	0.0003							
	CH4	0.0750	0.0009							
90	H2	0.5890	0.0074	96.54	2.11	1.35	0.0736	94.05	2.06	97.42
	CO2	0.0082	0.0001							
	CO	0.0129	0.0002							
	CH4	0.1514	0.0019							
105	H2	0.6469	0.0081	97.64	1.37	0.99	0.0858	95.22	1.34	97.52
	CO2	0.0065	0.0001							
	CO	0.0091	0.0001							
	CH4	0.1700	0.0021							
120	H2	0.7086	0.0089	98.24	0.96	0.79	0.0981	95.87	0.94	97.59
	CO2	0.0057	0.0001							
	CO	0.0069	0.0001							
	CH4	0.1888	0.0024							

Appendix G Calibration curves for product gases

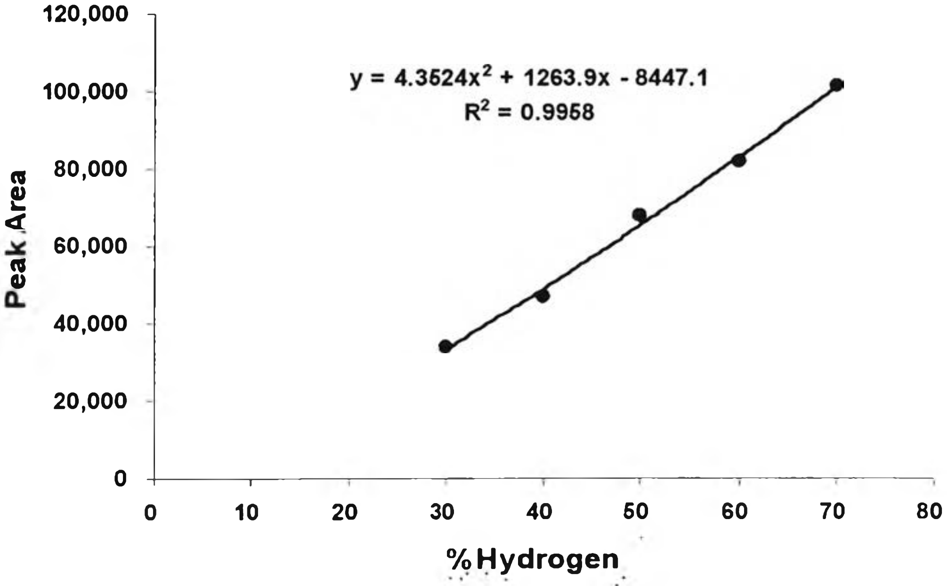

Figure G1 H_2 calibration curve.

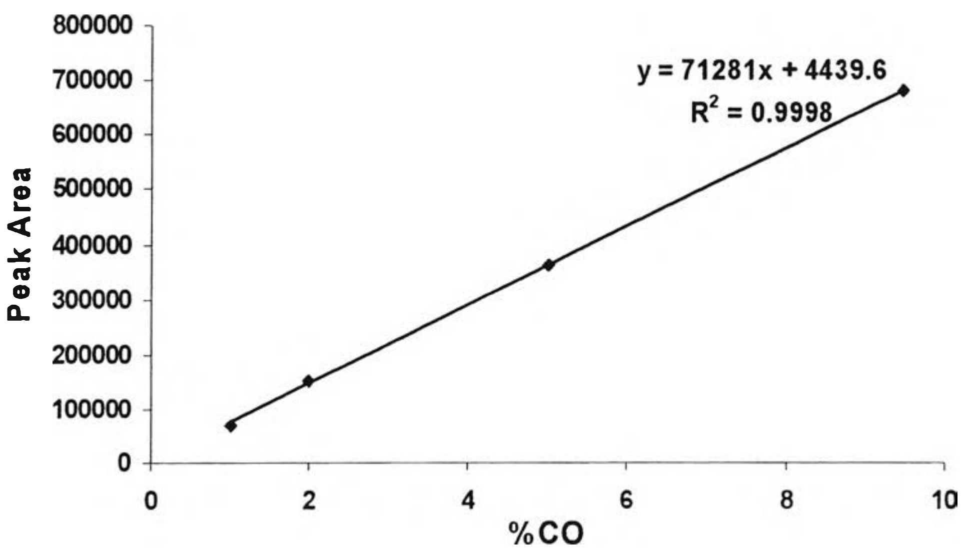

Figure G2 CO calibration curve.

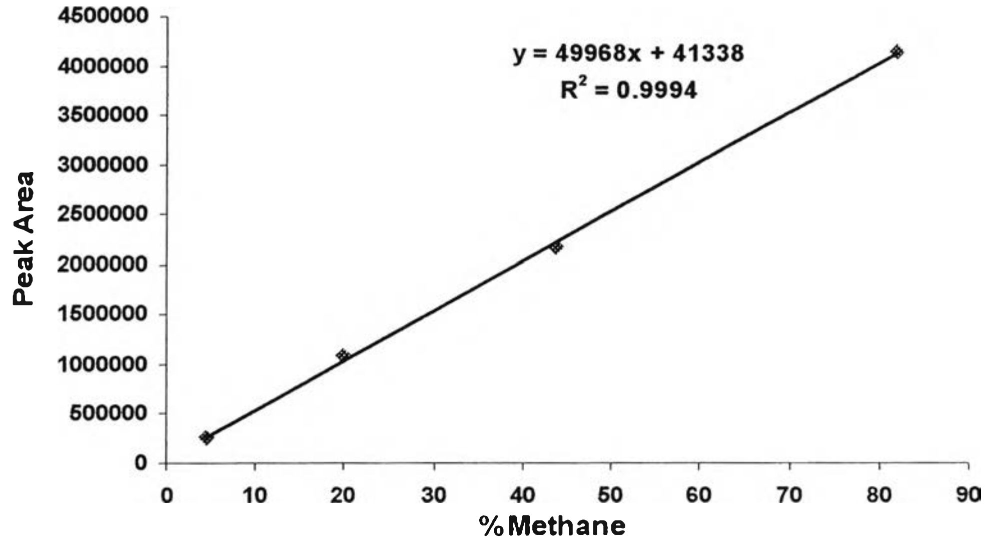

Figure G3 CH_4 calibration curve.

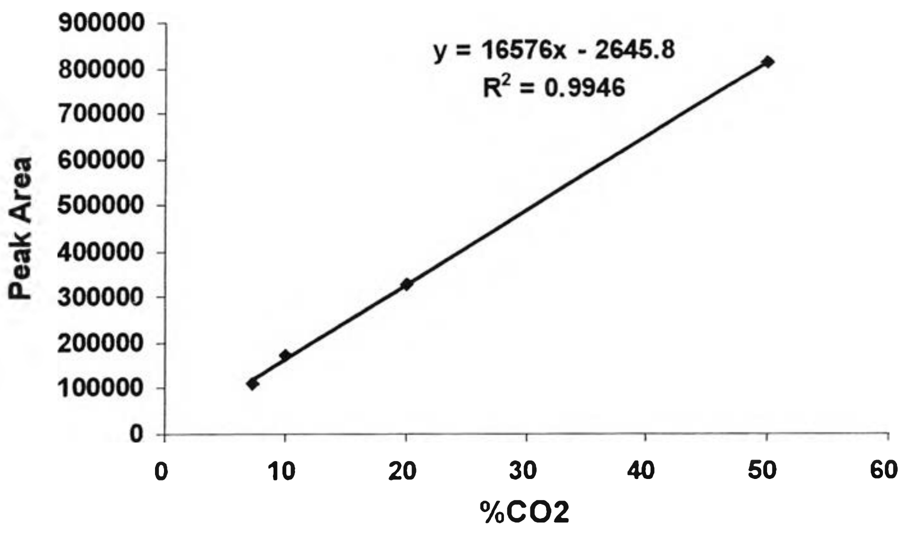

Figure G4 CO_2 calibration curve.

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1. Noisra, W., Luengnaruemitchai, A., and Jitkarnka, S. (2007, October 29-30) Hydrogen Production from the Steam Reforming of Methane over Ni Supported on ZSM-5 Zeolite Catalysts at Thailand Chemical Engineering & Applied Chemistry Conference 2007, Chiang Mai, Thailand.