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APPENDICES

Appendix A Experimental Data of Effect of Stage Number of Plasma Reactors

Table A1 Effect of stage number of plasma reactors on reactant conversions and product yields for the combined steam reforming and partial oxidation of natural gas at a constant total feed flow rate of 100 cm^3/min (steam content, 10 mol%; input voltage, 14.5 kV; input frequency, 300 Hz; and electrode gap distance, 6 mm)

Residence time (s)	Number of stage	Reactant conversion (%)					Product yield (%)		
		CH_4	C_2H_6	C_3H_8	CO_2	O_2	H_2	C_2	CO
1.37	1	22.28	31.22	39.42	-2.81	34.62	63.38	21.75	53.99
2.74	2	37.55	38.76	55.26	-5.45	26.12	106.57	30.99	106.71
4.11	3	39.58	45.60	68.95	7.78	36.79	120.75	41.35	134.84
5.48	4	52.22	52.94	76.10	4.70	43.30	121.51	43.37	158.39

Table A2 Effect of stage number of plasma reactors on concentrations of outlet gas for the combined steam reforming and partial oxidation of natural gas at a constant total feed flow rate of 100 cm^3/min (steam content, 10 mol%; input voltage, 14.5 kV; input frequency, 300 Hz; and electrode gap distance, 6 mm).

Residence time (s)	Number of stage	Concentration of outlet gas (mol%)								
		H_2	CO	CH_4	CO_2	C_2H_2	C_2H_4	C_2H_6	C_3H_8	C_4H_{10}
1.37	1	19.63	9.49	35.41	14.16	0.477	1.437	2.343	2.030	0.176
2.74	2	35.28	19.84	27.54	12.21	1.057	1.825	1.943	1.366	0.179
4.11	3	39.74	24.51	28.17	11.83	1.570	2.189	1.822	1.039	0.262
5.48	4	41.62	29.65	21.69	10.83	1.939	2.122	1.529	0.746	0.203

Table A3 Effect of stage number of plasma reactors on product selectivities for the combined steam reforming and partial oxidation of natural gas at a constant total feed flow rate of 100 cm^3/min (steam content, 10 mol%; input voltage, 14.5 kV; input frequency, 300 Hz; and electrode gap distance, 6 mm)

Residence time (s)	Number of stage	Product selectivity (%)				
		H_2	C_2H_2	C_2H_4	CO	C_4H_{10}
1.37	1	68.216	6.020	18.122	59.915	4.434
2.74	2	81.002	9.009	15.565	84.618	3.061
4.11	3	78.345	10.665	14.875	83.285	3.554
5.48	4	67.038	11.135	12.191	85.175	2.332

Table A4 Effect of stage number of plasma reactors on product molar ratios for the combined steam reforming and partial oxidation of natural gas at a constant total feed flow rate of 100 cm^3/min (steam content, 10 mol%; input voltage, 14.5 kV; input frequency, 300 Hz; and electrode gap distance, 6 mm)

Residence time (s)	Number of stage	Molar ratio			
		H_2/CO	H_2/C_2H_2	H_2/C_2H_4	C_2H_4/C_2H_2
1.37	1	2.067	41.136	13.666	3.010
2.74	2	1.778	33.401	19.334	1.728
4.11	3	1.621	25.323	18.156	1.395
5.48	4	1.404	21.473	19.614	1.095

Table A5 Effect of stage number of plasma reactors on power consumptions and coke formation for the combined steam reforming and partial oxidation of natural gas at a constant total feed flow rate of 100 cm^3/min (steam content, 10 mol%; input voltage, 14.5 kV; input frequency, 300 Hz; and electrode gap distance, 6 mm)

Residence time (s)	Number of stage	Power consumption (× 10^{-17} Ws/molecule)	
		per reactant converted	per H_2 produced
1.37	1	19.784	12.244
2.74	2	18.735	10.007
4.11	3	3.485	2.043
5.48	4	8.106	5.520

Table A6 Effect of stage number of plasma reactors on reactant conversions and product yields for the combined steam reforming and partial oxidation of natural gas at a constant residence time of 4.11 s (steam content, 10 mol%; input voltage, 14.5 kV; input frequency, 300 Hz; and electrode gap distance, 6 mm)

Feed flow rate (cm^3/min)	Number of stage	Reactant conversion (%)					Product yield (%)		
		CH_4	C_2H_6	C_3H_8	CO_2	O_2	H_2	C_2	CO
33.3	1	35.10	40.52	56.50	-1.58	35.96	118.70	34.40	122.56
66.6	2	39.82	45.17	68.31	6.11	30.83	124.36	43.95	139.49
100.0	3	39.58	45.60	68.95	7.78	36.79	120.76	41.35	134.84
133.3	4	39.29	47.35	70.49	-2.04	45.02	119.35	46.48	121.46

Table A7 Effect of stage number of plasma reactors on concentrations of outlet gas for the combined steam reforming and partial oxidation of natural gas at a constant residence time of 4.11 s (steam content, 10 mol%; input voltage, 14.5 kV; input frequency, 300 Hz; and electrode gap distance, 6 mm)

Feed flow rate (cm^3/min)	Number of stage	Concentrations of outlet gas (mol%)								
		H_2	CO	CH_4	CO_2	C_2H_2	C_2H_4	C_2H_6	C_3H_8	C_4H_{10}
33.3	1	38.07	21.99	28.99	11.92	1.49	1.59	1.93	1.36	0.17
66.6	2	39.57	24.52	27.07	11.63	1.80	2.06	1.76	1.00	0.24
100.0	3	39.75	24.51	28.17	11.83	1.57	2.19	1.82	1.04	0.26
133.3	4	38.80	22.26	28.52	12.53	1.90	2.36	1.78	0.98	0.28

Table A8 Effect of stage number of plasma reactors on product selectivities for the combined steam reforming and partial oxidation of natural gas at a constant residence time of 4.11 s (steam content, 10 mol%; input voltage, 14.5 kV; input frequency, 300 Hz; and electrode gap distance, 6 mm)

Feed flow rate (cm^3/min)	Number of stage	Product selectivity (%)				
		H_2	C_2H_2	C_2H_4	CO	C_4H_{10}
33.3	1	89.839	12.735	13.615	93.88	2.885
66.6	2	81.124	12.851	14.718	87.50	3.368
100.0	3	78.345	10.665	14.875	83.28	3.554
133.3	4	75.956	13.358	16.613	78.31	3.882

Table A9 Effect of stage number of plasma reactors on product molar ratios for the combined steam reforming and partial oxidation of natural gas at a constant residence time of 4.11 s (steam content, 10 mol%; input voltage, 14.5 kV; input frequency, 300 Hz; and electrode gap distance, 6 mm)

Feed flow rate (cm^3/min)	Number of stage	Molar ratio			
		H_2/CO	H_2/C_2H_2	H_2/C_2H_4	C_2H_4/C_2H_2
33.3	1	1.731	25.523	23.874	1.069
66.6	2	1.614	21.976	19.189	1.145
100.0	3	1.621	25.323	18.156	1.395
133.3	4	1.743	20.433	16.429	1.244

Table A10 Effect of stage number of plasma reactors on power consumptions and coke formation for the combined steam reforming and partial oxidation of natural gas at a constant residence time of 4.11 s (steam content, 10 mol%; input voltage, 14.5 kV; input frequency, 300 Hz; and electrode gap distance, 6 mm)

Feed flow rate (cm^3/min)	Number of stage	Power consumption (× 10^{-17} Ws/molecule)	
		per reactant converted	per H_2 produced
33.3	1	52.483	25.483
66.6	2	14.881	8.375
100.0	3	3.485	2.043
133.3	4	8.960	5.115

Appendix B Experimental Data of Effect of HCs/O_2 Feed Molar Ratio

Table B1 Effect of HCs/O_2 feed molar ratio on reactant conversions and product yields for the combined steam reforming and partial oxidation of natural gas (3 stages of plasma reactors; steam content, 10 mol%; total feed flow rate, 100 cm^3/min; input voltage, 14.5 kV; input frequency, 300 Hz; and electrode gap distance, 6 mm)

HCs/O_2 feed molar ratio	Reactant conversion (%)					Product yield (%)		
	CH_4	C_2H_6	C_3H_8	CO_2	O_2	H_2	C_2	CO
2/1	39.585	45.596	68.952	7.775	36.788	120.756	41.351	134.845
3/1	31.155	37.452	60.247	0.723	10.349	114.765	46.562	87.562
6/1	19.911	26.399	52.374	4.367	4.367	84.160	45.689	25.265
w/o O_2	13.975	28.533	80.262	3.707		115.974	40.837	6.641

Table B2 Effect of HCs/O_2 feed molar ratio on concentrations of outlet gas for the combined steam reforming and partial oxidation of natural gas (3 stages of plasma reactors; steam content, 10 mol%; total feed flow rate, 100 cm^3/min; input voltage, 14.5 kV; input frequency, 300 Hz; and electrode gap distance, 6 mm)

HCs/O_2 feed molar ratio	Concentration of outlet gas (mol%)								
	H_2	CO	CH_4	CO_2	C_2H_2	C_2H_4	C_2H_6	C_3H_8	C_4H_{10}
2/1	39.745	24.514	28.174	11.832	1.570	2.189	1.822	1.039	0.262
3/1	37.756	16.166	33.805	13.178	1.832	2.466	2.119	1.318	0.308
6/1	26.228	4.514	41.241	15.254	1.431	2.651	2.601	1.694	0.429
w/o O_2	32.893	1.164	52.613	16.786	0.932	2.648	3.121	0.860	0.570

Table B3 Effect of HCs/O_2 feed molar ratio on product selectivities for the combined steam reforming and partial oxidation of natural gas (3 stages of plasma reactors; steam content, 10 mol%; total feed flow rate, 100 cm^3/min; input voltage, 14.5 kV; input frequency, 300 Hz; and electrode gap distance, 6 mm)

HCs/O_2 feed molar ratio	Product selectivity (%)				
	H_2	C_2H_2	C_2H_4	CO	C_4H_{10}
2/1	78.345	10.665	14.875	83.285	3.554
3/1	89.066	15.320	20.613	67.575	5.149
6/1	85.282	15.663	29.016	24.707	9.392
w/o O_2	94.464	8.404	23.885	5.251	10.288

Table B4 Effect of HCs/O_2 feed molar ratio on product molar ratios for the combined steam reforming and partial oxidation of natural gas (3 stages number of plasma reactors; steam content, 10 mol%; total feed flow rate, 100 cm3/min; input voltage, 14.5 kV; input frequency, 300 Hz; and electrode gap distance, 6 mm)

HCs/O_2 feed molar ratio	Molar ratio			
	H_2/CO	H_2/C_2H_2	H_2/C_2H_4	C_2H_4/C_2H_2
2/1	1.621	25.323	18.156	1.395
3/1	2.336	20.603	15.313	1.346
6/1	5.810	18.329	9.894	1.853
w/o O_2	28.247	35.300	12.420	2.842

Table B5 Effect of HCs/O_2 feed molar ratio on power consumptions and coke formation for the combined steam reforming and partial oxidation of natural gas (3 stages of plasma reactors; steam content, 10 mol%; total feed flow rate, 100 cm^3/min; input voltage, 14.5 kV; input frequency, 300 Hz; and electrode gap distance, 6 mm)

HCs/O_2 feed molar ratio	Power consumption ($\times 10^{-17}$ Ws/molecule)	
	per reactant converted	per H_2 produced
2/1	3.485	2.043
3/1	4.520	2.234
6/1	7.744	4.020
w/o O_2	4.539	1.923

Appendix C Experimental Data of Effect of Input voltage

Table C1 Effect of input voltage on reactant conversions and product yields for the combined steam reforming and partial oxidation of natural gas (3 stages of plasma reactors; steam content, 10 mol%; HCs/O_2 feed molar ratio of 2/1; total feed flow rate, 100 cm^3/min; input frequency, 300 Hz; and electrode gap distance, 6 mm)

Input voltage (kV)	Reactant conversion (%)					Product yield (%)		
	CH_4	C_2H_6	C_3H_8	CO_2	O_2	H_2	C_2	CO
13.5	41.215	46.064	67.703	7.676	40.082	135.003	41.523	133.732
14.5	39.585	45.596	68.952	7.775	36.788	120.756	41.351	134.845
15.0	38.375	44.693	67.987	23.400	33.180	121.117	43.291	153.583
16.0	38.038	45.125	67.827	22.279	37.499	120.110	44.139	149.014
16.8	38.196	46.382	70.306	21.554	39.005	134.224	48.683	147.953

Table C2 Effect of input voltage on concentrations of outlet gas for the combined steam reforming and partial oxidation of natural gas (3 stages of plasma reactors; steam content, 10 mol%; HCs/O_2 feed molar ratio of 2/1; total feed flow rate, 100 cm^3/min; input frequency, 300 Hz; and electrode gap distance, 6 mm)

Input voltage (kV)	Concentration of outlet gas (mol%)									
	H_2	O_2	CO	CH_4	CO_2	C_2H_2	C_2H_4	C_2H_6	C_3H_8	C_4H_{10}
13.5	39.87	19.56	22.20	28.66	12.09	1.501	1.945	1.346	0.744	0.229
14.5	39.75	19.53	24.51	28.17	11.83	1.570	2.189	1.822	1.039	0.262
15.0	41.13	19.42	28.04	29.99	10.16	1.640	2.312	1.906	1.098	0.281
16.0	39.79	19.34	26.67	29.42	10.18	1.621	2.330	1.871	1.100	0.274
16.8	41.90	18.37	25.07	28.17	9.88	1.735	2.389	1.741	0.952	0.262

Table C3 Effect of input voltage on product selectivities for the combined steam reforming and partial oxidation of natural gas (3 stages of plasma reactors; steam content, 10 mol%; HCs/O_2 feed molar ratio of 2/1; total feed flow rate, 100 cm^3/min; input frequency, 300 Hz; and electrode gap distance, 6 mm)

Input voltage (kV)	Product selectivity (%)				
	H_2	C_2H_2	C_2H_4	CO	C_4H_{10}
13.5	77.316	9.923	12.856	73.363	3.031
14.5	78.345	10.665	14.875	83.285	3.554
15.0	80.181	10.298	14.517	88.036	3.534
16.0	79.548	10.451	15.024	86.002	3.538
16.8	86.661	11.610	15.982	83.855	3.500

Table C4 Effect of input voltage on product molar ratios for the combined steam reforming and partial oxidation of natural gas (3 stages of plasma reactors; steam content, 10 mol%; HCs/O_2 feed molar ratio of 2/1; total feed flow rate, 100 cm^3/min; input frequency, 300 Hz; and electrode gap distance, 6 mm)

Input voltage (kV)	Molar ratio			
	H_2/CO	H_2/C_2H_2	H_2/C_2H_4	C_2H_4/C_2H_2
13.5	1.796	26.559	20.500	1.296
14.5	1.621	25.323	18.156	1.395
15.0	1.467	25.078	17.790	1.410
16.0	1.492	24.552	17.078	1.438
16.8	1.671	24.144	17.539	1.377

Table C5 Effect of input voltage on power consumptions and coke formation for the combined steam reforming and partial oxidation of natural gas (3 stages of plasma reactors; steam content, 10 mol%; HCs/O_2 feed molar ratio of 2/1; total feed flow rate, 100 cm^3/min; input frequency, 300 Hz; and electrode gap distance, 6 mm)

Input voltage (kV)	Power consumption ($\times 10^{-17}$ Ws/molecule)	
	per reactant converted	per H_2 produced
13.5	6.896	4.034
14.5	3.485	2.043
15.0	3.195	1.993
16.0	3.771	2.354
16.8	3.777	2.153

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