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APPENDICES

Appendix A

1. Proximate analysis of biomass

1.1 Moisture analysis: ASTM D3173

Moisture is determined by establishing the loss in weight of the sample when heated under rigidly controlled conditions of temperature, time and atmosphere, sample weight, and equipment specifications.

Procedure

1. Dry sample container for 30 min at 103 ± 1 °C in the oven, then cool in desiccator to room temperature. Weigh to the nearest 0.02 g and record as container weight, W_c Place a minimum of 1 g of sample in the container, weigh the sample and container to the nearest 0.01 g and record as initial weight, W_i.
2. Place the sample and container in the oven for 16 h at 103 ± 1 °C.
3. Remove the sample and the container from the oven and cool in the desiccator to room temperature. Remove the sample and container from the desiccator, weigh immediately to the nearest 0.01 g, and record the weight.
4. Return the sample and container to the oven at 103 ± 1 °C.for 2 h. Repeat.
5. Continue 4 until the total weight change between weighing varies less than 0.02 % and record as the final weight, W_f

Calculation

Moisture in analysis sample, (%) = $[(W_i - W_f) / (W_i - W_c)] \times 100$

Where : W_c = container weight, g.

W_i = initial weight, g. and

W_f = final weight, g.

1.2 Volatile matter analysis: ASTM D3175

Volatile matter is determined by establishing the loss in weight resulting from heating wood under rigidly controlled conditions.

Procedure

1. Weigh the crucible and cover to the nearest 0.01 g and record as crucible weight, W_c. Place approximately 1 g of sample in the crucible, cover, weigh the crucible, cover, weigh the crucible, cover, and sample to the nearest 0.01 g, and record as initial weight, W_i.
2. Place the covered crucible with sample on platinum or nickel-chromium wire supports and insert directly into the furnace chamber, which shall be maintained at a temperature of 950°C, and lower immediately to the 950°C.
3. Raising the crucible to the top of the furnace chamber, then lower immediately back to the 950°C. After heating for a total of exactly 7 min, remove the crucible from the furnace, cool in a descicator.
4. Weigh the covered crucible with sample as soon as cold to the nearest 0.1 mg and record as final weight, W_f

Calculation

1. Calculate the weight loss percent as follows :

   Weight loss, % = $100x(W_i - W_f)/(W_i - W_c) = A$ (1)

   Where: W_c = weight of crucible and cover, g,

   W_i = initial weight, g, and

   W_f = final weight, g.

2. Calculate the volatile matter percent in the analysis samples as follows:

   Volatile matter in analysis sample, % = A-B (2)

   Where: A = weight loss %, and

   B = moisture, %.

1.3 Ash analysis: ASTM D3174

The ash content is an approximate measure of the mineral content and other inorganic matter in wood.

Procedure

1. Ignite the empty crucible and cover over a burner or in the muffle at 600, cool in a desiccator, and weigh to the nearest 0.1 mg. Place the 2-g test specimen in the crucible, determine the weight of crucible plus specimen, and place in the drying over at 100 to 105 with the crucible cover removed. After 1 h, replace the cover on the cover on the crucible, cool in a desiccator, and weigh. Repeat the drying and weighing until the weight is constant.

2. Place the crucible and contents, with the cover removed, in the muffle furnace and ignite until all the carbon is eliminated. Heat slowly at the start to avoid flaming and protect the crucible from strong drafts at all times to avoid mechanical loss of test specimen. The recommended temperature of final ignition is 580 to 600 oC. Avoid heating above this maximum.

3. Remove the crucible with its contents to a desiccator, replace the cover loosely, cool, and weigh accurately. Repeat the heating for 30-min periods until the weigh after cooling is constant to within 0.2 mg.

Calculation

Calculate the percentage of ash, based on the weight of the moisture-free wood, as follows:

$$\text{Ash, \%} = (W_1 / W_2) \times 100$$

Where:

W_1 = weight of ash, and

W_2 = weight of oven-dry sample.

Appendix B

Calculation of gas composition

Peak area of standard gas from gas chromatography

std	No. 1 area	No. 2 area	Average area	% balance in He
H_2	838257.8	881719.7	859988.8	75
CO	274.4	167.2	220.8	10
CH_4	53899.1	51486	52692.55	10
CO_2	20304.7	23021.4	21663.05	5

Calculation of gas products from experiment;

1. Calculation gas composition (%)

$$\%\ H_2 = \frac{(75/100) \times [\text{Peak area of } H_2 \text{ from experiment}]}{[\text{Peak area of } H_2 \text{ Standard gas}]}$$

$$\%\ CO = \frac{(10/100) \times [\text{Peak area of CO from experiment}]}{[\text{Peak area of CO Standard gas}]}$$

$$\%\ CH_4 = \frac{(10/100) \times [\text{Peak area of } CH_4 \text{ from experiment}]}{[\text{Peak area of } CH_4 \text{ Standard gas}]}$$

$$\%\ CO_2 = \frac{(5/100) \times [\text{Peak area } CO_2 \text{ from experiment}]}{[\text{Peak area of } CO_2 \text{ Standard gas}]}$$

2. Carbon in feed

$$\text{Carbon in coconut} = \frac{\text{Carbon from elemental analysis (\%) x biomass feed rate}}{12}$$

3. Calculation carbon of gas product

$$CO = \frac{\text{flow out (ml/min) x (\%CO)x 298}}{273 \times 22.4} \text{ mmol/min}$$

$$CH_4 = \frac{\text{flow out (ml/min) x (\%CO)x 298}}{273 \times 22.4} \text{ mmol/min}$$

$$CO_2 = \frac{\text{flow out (ml/min) x (\%CO)x 298}}{273 \times 22.4} \text{ mmol/min}$$

4. $$\text{Carbon conversion (\%)} = \frac{CO + CH_4 + CO_2}{\text{Carbon total in feed}} \times 100$$

$$\text{Carbon char (\%)} = \frac{\text{carbon from elemental analysis (\%) x char weight (g)}}{\text{Carbon total in feed}} \times 100$$

$$\text{Tar (\%)} = 100 - \text{gas(\%)} - \text{char (\%)}$$

5. $$\text{Steam to carbon ratio (S/C)} = \frac{\text{steam feed rate (g/min)}}{\text{Carbon total in feed x 18}}$$

Appendix C

Experimental Data

Data		Gas composition (%)			
		H_2	CO	CH_4	CO_2
Calcination	500	35.39	21.12	17.02	26.22
temperature	750	38.42	22.70	10.84	18.01
	950	22.99	15.21	25.83	35.96
coconut	noncat	22.67	32.31	15.11	29.90
	catalyst	30.31	37.71	4.74	27.22
plam	noncat	22.42	32.70	16.85	28.02
	catalyst	33.94	34.02	6.91	5.11
temperature	650	30.89	35.56	13.37	20.15
coconut	700	35.68	29.82	12.80	21.65
	750	42.34	29.52	10.84	17.30
	800	45.00	32.00	8.01	15.09
plam	650	11.74	48.87	18.50	20.89
	700	30.89	35.59	13.37	20.15
	750	35.68	29.82	12.85	21.65
	800	42.34	29.52	10.84	17.30
Steam/carbon	0.24	41.67	27.36	15.33	15.40
coconut	0.44	42.94	20.17	15.22	17.65
	0.95	46.11	20.34	11.52	22.02
plam	0.24	41.67	27.36	15.33	15.63
	0.44	40.94	26.17	15.22	17.65
	0.95	49.11	17.34	11.52	22.02
oxygen	10	34.73	64.76	0.01	0.49
plam	20	17.88	79.82	0.06	2.22
	30	17.47	77.36	0.01	5.15
	40	9.93	78.86	0.01	11.18
oxygen	10	30.42	60.66	0.71	8.20
plam	20	28.13	70.81	77.36	78.86
	30	17.47	77.36	0.02	5.15
	40	10.00	78.86	0.01	11.18

Appendix D

Data from gas chromatography

Condition	Gas composition	No 1 (area)	No. 2 (area)	Avg (area)
palm shell non catalyst	H_2	145401.6	145401.6	145401.6
700°C (S/C) 0.24	CO	150.8	150.8	150.8
	CH_4	81128.4	81128.4	81128.4
	CO_2	57827.9	57827.9	57827.9
coconut shell non catalyst	H_2	90968.8	89696.9	90332.85
700°C (S/C) 0.24	CO	348.6	364.2	356.4
	CH_4	57089.7	56153.5	56621.6
	CO_2	51610.3	51761.4	51685.85
palm shell	H_2	86354.5	88866.1	87610.3
700°C (S/C) 0.24	CO	691.7	399.9	545.8
Ni/dolomite 10 g.	CH_4	57858.1	51396.5	54627.3
	CO_2	57858.1	56091.5	56974.8
coconut shell	H_2	88996.4	87207.3	88101.85
700°C (S/C) 0.24	CO	1428.8	1321.3	1375.05
Ni/dolomite 10 g.	CH_4	51904.4	51033.8	51469.1
	CO_2	51904.4	60529	56216.7
palm shell	H_2	54458	34985.3	44721.65
650°C (S/C) 0.24	CO	186	2570.3	1378.15
Ni/dolomite 10 g.	CH_4	59056.2	59056.2	59056.2
	CO_2	35798	35798	35798
palm shell	H_2	178669.5	122094.2	150381.9
700°C (S/C) 0.24	CO	75.5	2489.6	1282.55
Ni/dolomite 10 g.	CH_4	63627.9	45527.5	54577.7
	CO_2	46137.6	42117.7	44127.65
palm shell	H_2	20117.89	19948.19	20033.04
750°C (S/C) 0.24	CO	6283.67	6653.50	6468.59
Ni/dolomite 10 g.	CH_4	14790.18	14690.71	14740.45
	CO_2	13733.36	13764.83	13749.10
palm shell	H_2	297069.1	262341.5	279705.3
800°C (S/C) 0.24	CO	1444	1444	1444
Ni/dolomite 10 g.	CH_4	51352	68746.4	60049.2
	CO_2	51352.8	51506.9	51429.85

Condition	Gas composition	No. 1 (area)	No 2 (area)	Avg (area)
coconut shell	H_2	56587.5	26534.3	41560.9
650°C (S/C) 0.24	CO	1771.1	4311.9	3041.5
Ni/dolomite 10 g.	CH_4	21245.7	11050.8	16148.25
	CO_2	38337.9	24589.3	31463.6
coconut shell	H_2	50374.9	11169.8	30772.35
700°C (S/C) 0.24	CO	955	6464.6	3709.8
Ni/dolomite 10 g.	CH_4	31826.4	3493.7	17660.05
	CO_2	43297.5	5461.3	24379.4
coconut shell	H_2	54906	54906	54906
750°C (S/C) 0.24	CO	1558.1	1558.1	1558.1
Ni/dolomite 10 g.	CH_4	36496	36496	36496
	CO_2	36570.8	36570.8	36570.8
coconut shell	H_2	83960.8	52753.1	68356.95
800°C (S/C) 0.24	CO	1309	2808.8	2058.9
Ni/dolomite 10 g.	CH_4	46799.5	34572	40685.75
	CO_2	48046.9	36732.6	42389.75
palm shell	H_2	180210.6	101421.8	140816.2
800°C (S/C) 0.24	CO	1706	1406	1556
Ni/dolomite 10 g.	CH_4	37125.4	37125.4	37125.4
	CO_2	54249	37146.4	45697.7
palm shell	H_2	203737.9	68482.6	136110.3
800°C (S/C) 0.44	CO	878	4682.5	2780.25
Ni/dolomite 10 g.	CH_4	64825.4	27203.8	46014.6
	CO_2	46340	25799.2	36069.6
palm shell	H_2	303225.6	273096.5	288161.1
800°C (S/C) 0.95	CO	645.1	609.1	627.1
Ni/dolomite 10 g.	CH_4	69171.9	65088.3	67130.1
	CO_2	50642.2	50642.2	50642.2
coconut shell	H_2	64982.9	31109.2	48046.05
800°C (S/C) 0.24	CO	2132	5490.6	3811.3
Ni/dolomite 10 g.	CH_4	50423.2	13106.4	31764.8
	CO_2	46440.7	12816.2	29628.45
coconut shell	H_2	48833.3	46620.4	47726.85
800°C (S/C) 0.44	CO	2495	1450.9	1972.95
Ni/dolomite 10 g.	CH_4	43631.7	44343.8	43987.75
	CO_2	48059.8	40067.9	44063.85
coconut shell	H_2	106866.1	103504.1	105185.1
800°C (S/C) 0.95	CO	1184	1754	1754
	CH_4	64982.9	31109.2	48046.05
	CO_2	56587.5	26534.3	41560.9

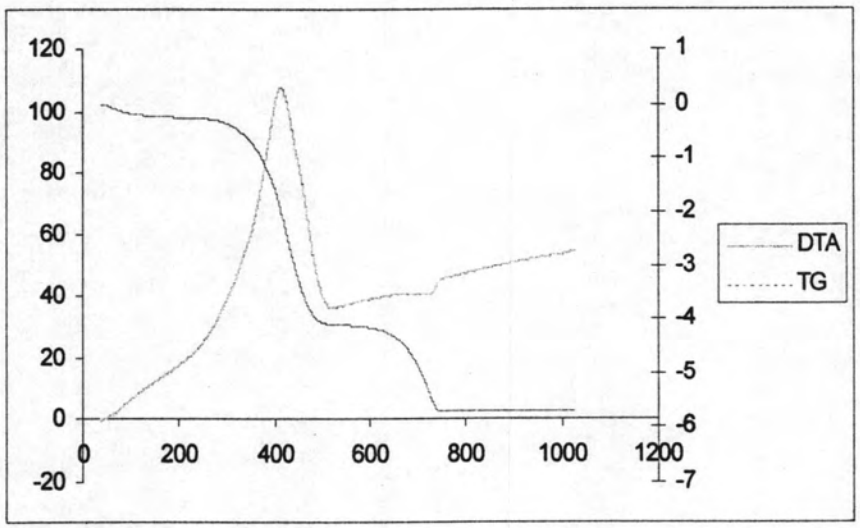
Condition	Gas composition	No. 1 (area)	No 2 (area)	Avg (area)
palm shell	H2	6322	6322	6322
800°C (S/C) 0.95	CO	5005	5005	5005
O_2 10 ml	CH4	481	481	481
	CO2	11020	11020	11020
palm shell	H2	655	655	655
800°C (S/C) 0.95	CO	1241	1241	1241
O_2 20 ml	CH4	481	481	481
	CO2	10063	10063	10063
palm shell	H2	359	359	359
800°C (S/C) 0.95	CO	675	675	675
O_2 30 ml	CH4	58	58	58
	CO2	13069	13069	13069
palm shell	H2	135	135	135
800°C (S/C) 0.95	CO	455	455	455
O_2 40 ml	CH4	48	48	48
	CO2	18766	18766	18766
coconut shell	H2	1062	1062	1062
800°C (S/C) 0.95	CO	899	899	899
O_2 10 ml	CH4	5040	5040	5040
	CO2	35347	35347	35347
coconut shell	H2	477	477	477
800°C (S/C) 0.95	CO	620	620	620
O_2 20 ml	CH4	3100	3100	3100
	CO2	13508	13508	13508
coconut shell	H2	359	359	359
800°C (S/C) 0.95	CO	675	675	675
O_2 30 ml	CH4	58	58	58
	CO2	13069	13069	13069
coconut shell	H2	135	135	135
800°C (S/C) 0.95	CO	455	455	455
O_2 40 ml	CH4	48	48	48
	CO2	18766	18766	18766
coconut shell	H2	185758.8	61153.6	123456.2
800°C (S/C) 0.95	CO	615.5	4781.6	2698.55
Ni/Pt/Dolomite	CH4	36148.4	16603.3	26375.85
	CO2	32136.5	15768.2	23952.35
coconut shell	H2	96245.2	96245.2	96245.2
800°C (S/C) 0.95	CO	753	753	753
Ni/Fe/Dolomite	CH4	54249.9	54249.9	54249.9
	CO2	52588.1	52588.1	52588.1

Condition	Gas composition	No. 1 (area)	No 2 (area)	Avg (area)
coconut shell	H2	1307.4	1220.2	17185.3
800°C (S/C) 0.95	CO	4204.1	4269.2	4236.65
Ni/Co/Dolomite	CH4	7128.7	70329.4	38729.05
	CO2	17185.3	7128.7	12157

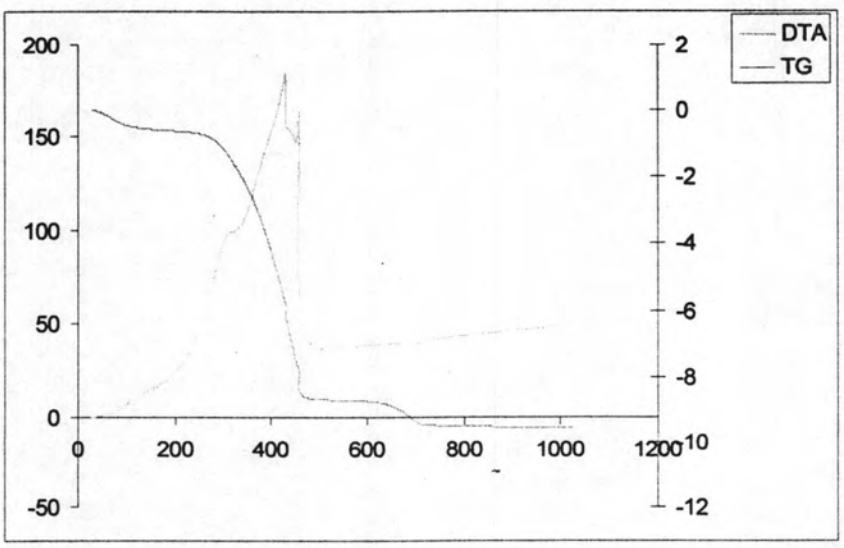
Appendix E

Data from coke formation by thermogravimetric analysis of various catalysts after reaction

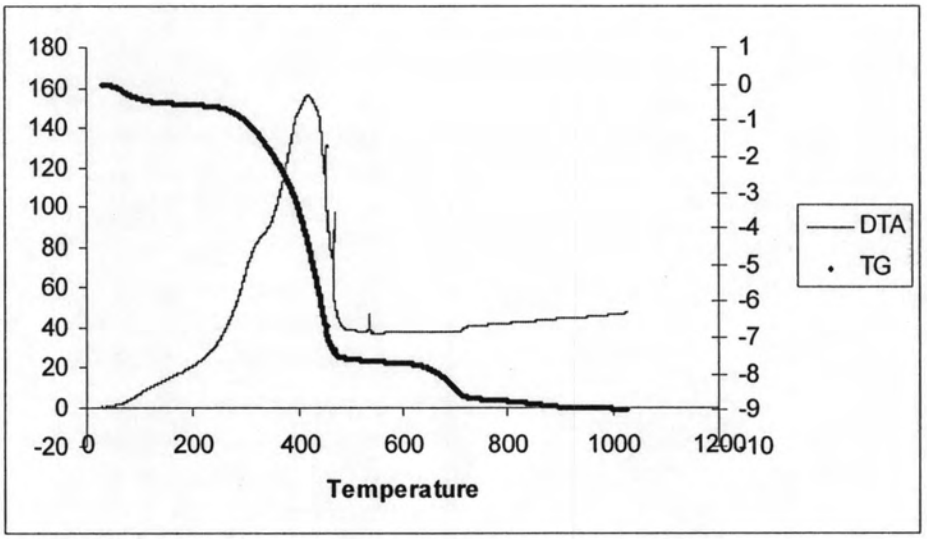
1. Used Ni



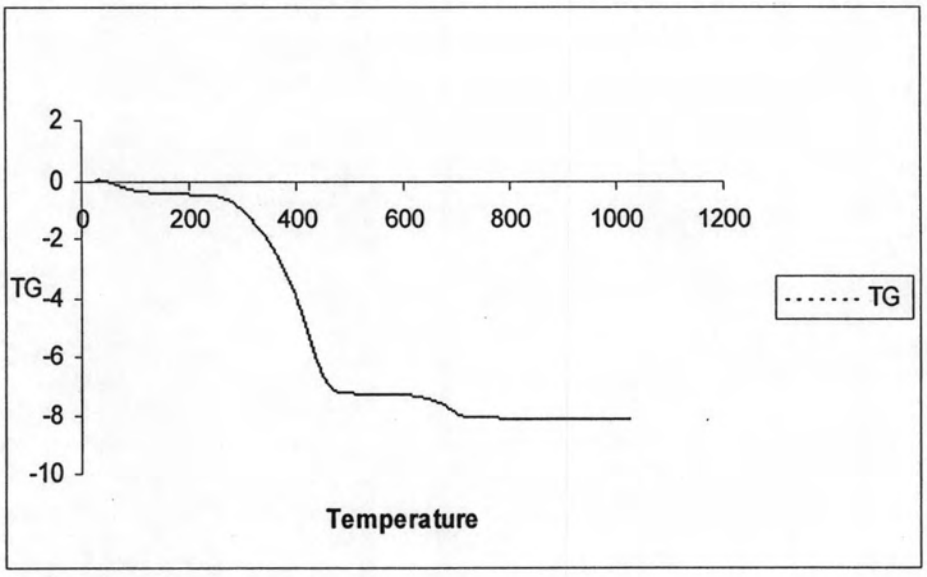
2. Used Ni/Pt/DM



3. Used Ni/Co/DM



4.Used Ni/Fe/DM



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