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ANNEX 1

EXPERIMENTAL DATA



ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

Table A-1 Data using rice hulls (gas flow rate
12 Ncu.m./hr)

Date	Run No.	RH1
Room temperature (°C)		32
Air moisture (% relative humidity)		72.50
Air flow rate (Ncu.m./hr)		9.54
Gas flow rate (Ncu.m/hr)		12.00
Fuel weight (kgs.)		2.3
Fuel moisture content (% wt)		4.81
Experimental time (min.)		40
Weight of char and ash (kgs.)		0.70
% fixed carbon in char and ash		

Gas Composition vs. Time

Time	CO	H ₂	CH ₄	CO ₂	O ₂	N ₂
5	2.34	2.41	0.75	10.45	5.21	76.84
10	4.56	5.21	0.72	8.51	9.22	69.78
15	8.02	6.23	1.12	8.25	8.05	68.33
25	9.29	6.80	1.07	7.08	8.08	67.68
35	8.21	5.75	1.05	6.01	7.95	70.03
Avg.	7.41	5.89	1.00	7.9	8.01	69.82

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

TABLE A-1 (CONT.)

BED HEIGHT TIME	TEMPERATURE VS. TIME																			
	125	115	105	95	85	75	65	55	45	35	25	15	10	5	1	-5	A	B	C	
1	47	47	47	83	88	97	109	108	93	130	140	145	132	116	87	85	26	24	24	
2	47	47	47	83	88	97	109	108	93	130	140	145	132	116	87	85	26	24	24	
3	47	47	47	83	88	97	80	108	98	232	155	124	112	116	87	87	71	24	24	
4	47	47	52	63	64	64	74	111	103	218	178	152	148	118	87	87	69	24	24	
5	47	47	52	63	64	64	74	113	108	244	200	166	209	132	99	87	68	24	25	
6	46	47	52	63	64	64	74	113	108	300	200	207	216	174	120	111	67	24	25	
7	45	48	52	63	64	64	74	113	107	567	142	195	217	173	443	158	63	24	25	
8	45	48	52	63	64	64	72	112	106	593	123	196	208	172	449	176	63	24	25	
9	43	48	52	63	64	64	72	109	106	573	197	200	206	173	450	200	62	24	25	
10	42	48	53	63	64	64	68	105	107	552	180	205	209	171	450	210	63	24	25	
11	42	48	54	63	64	67	68	100	112	526	166	213	217	176	455	231	62	24	25	
13	42	48	54	63	64	67	68	100	112	526	166	213	217	176	455	231	62	24	25	
14	42	48	54	63	66	67	68	101	101	429	453	399	243	259	199	490	255	65	24	25
15	42	48	54	63	66	67	68	101	101	429	453	399	243	259	199	490	255	65	24	25
16	42	48	54	63	66	67	68	101	101	453	460	229	253	269	206	516	261	64	24	25
18	42	48	54	63	66	67	70	98	459	472	337	257	272	210	537	267	64	24	25	
19	42	48	54	63	66	67	70	98	440	493	237	260	272	212	542	271	64	24	25	
20	42	48	54	63	66	67	70	98	455	524	378	263	273	214	545	274	64	25	25	
21	42	48	54	63	66	67	70	98	502	538	240	266	275	215	540	275	63	25	26	
22	42	48	54	63	66	67	70	98	495	508	176	269	279	219	543	276	63	25	26	
23	42	48	54	63	66	67	70	169	408	426	168	276	286	227	544	276	66	25	25	
24	42	48	54	63	66	67	71	240	400	400	158	276	286	228	550	276	69	25	25	
25	42	48	54	63	66	67	71	282	383	385	253	273	285	231	556	280	71	25	25	
26	42	48	54	63	66	67	71	250	374	360	209	275	289	234	557	280	71	25	25	
27	42	48	54	63	66	67	71	389	378	353	125	267	285	238	533	281	70	25	25	
28	42	48	54	63	66	67	73	430	378	354	120	267	285	238	500	280	70	25	25	
29	42	48	54	63	66	67	75	400	428	375	116	262	273	238	418	280	70	25	25	
30	42	48	54	63	66	67	78	355	427	372	213	264	277	241	401	275	70	25	25	
31	42	48	54	63	66	67	78	333	436	370	266	279	241	241	403	275	70	25	25	
32	42	48	54	63	66	67	78	345	440	376	173	273	291	249	435	275	68	25	25	
33	42	48	54	63	66	67	77	340	453	371	328	275	297	253	457	276	66	25	25	
34	42	48	54	63	66	67	73	333	466	372	177	279	304	258	486	278	66	25	25	
35	42	48	54	63	66	67	70	354	465	376	313	276	304	264	517	280	68	25	25	
36	42	50	57	73	80	88	70	348	466	377	119	275	304	264	520	282	68	25	25	
37	44	50	57	76	84	99	129	444	405	357	257	268	286	258	469	287	68	25	25	

Note : A = T prior to water scrubber B = T after water scrubber C = T at rotameter D = actual height of fuel

ศูนย์วิจัยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

Table A-2 Data using rice hulls (gas flow rate
20 Ncu.m./hr)

Date	Run No. RH2
Room temperature (°C)	30.5
Air moisture (% relative humidity)	75
Air flow rate (Ncu.m./hr)	14.84
Gas flow rate (Ncu.m/hr)	18
Fuel weight (kgs.)	2.5
Fuel moisture content (% wt)	5.4
Experimental time (min.)	35
Weight of char and ash (kgs.)	0.82
% fixed carbon in char and ash	

Gas composition vs. Time

Time	CO	H ₂	CH ₄	CO ₂	O ₂	N ₂
5	7.48	7.35	0.77	9.94	11.46	62.99
15	4.33	5.18	0.79	10.17	12.24	67.29
25	5.90	6.26	0.78	10.06	11.85	65.14
30	8.10	7.20	0.75	10.04	8.20	65.53
Avg	5.90	6.26	0.787	10.06	11.34	65.66

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย



TABLE A / (CONT.)

PEO HEIGHT LINE	TEMPERATURE VS TIME															a	b	c	
	125	115	105	95	85	75	65	55	45	35	25	15	10	5	1				-5
2	34	39	40	43	45	47	45	56	50	63	412	134	94	80	60	69	55	27	20
5	34	36	37	39	38	46	46	56	36	70	331	201	208	152	78	90	57	28	20
7	34	36	38	40	41	41	47	57	37	98	316	224	230	171	87	124	56	28	28
8	35	37	38	40	42	40	48	57	35	153	292	271	295	179	99	139	57	28	28
9	33	36	38	40	41	43	47	56	35	227	320	237	232	185	152	108	55	28	29
15	34	36	38	40	42	44	49	57	85	272	302	234	222	175	139	131	55	28	28
17	35	36	38	40	42	44	49	57	114	353	309	227	217	175	162	120	55	28	28
20	34	38	39	40	42	47	47	56	232	381	321	223	212	175	167	110	50	28	29
21	34	39	41	43	44	49	49	58	232	271	303	223	199	193	150	118	54	28	29
22	34	36	38	40	40	41	47	57	464	430	338	237	225	185	118	130	57	30	29
24	34	36	38	40	42	42	46	57	329	350	314	225	217	183	171	106	50	29	29
25	35	36	38	40	42	43	48	59	503	350	350	245	220	199	102	168	60	29	28
26	34	35	37	39	40	46	59	531	366	347	236	227	200	142	131	56	29	29	
27	34	36	38	40	41	42	47	63	518	334	331	231	225	191	120	154	55	28	29
29	34	36	38	40	41	43	47	82	464	348	324	234	226	190	134	140	60	29	29
34	34	35	38	40	41	45	47	112	669	273	269	332	245	222	129	169	60	30	29

Note : A = T prior to water scrubber B = T after water scrubber C = T at rotameter D = actual height of fuel

จุฬาลงกรณ์มหาวิทยาลัย

Table A-3 Data using rice hulls (gas flow rate
25 Ncu.m./hr)

Date	Run No. RH3
Room temperature (°C)	30
Air moisture (% relative humidity)	97.50
Air flow rate (Ncu.m./hr)	19.66
Gas flow rate (Ncu.m/hr)	25
Fuel weight (kgs.)	2.3
Fuel moisture content (% wt)	4.53
Experimental time (min.)	25
Weight of char and ash (kgs.)	0.90
% fixed carbon in char and ash	

Gas composition vs. Time

Time	CO	H ₂	CH ₄	CO ₂	O ₂	N ₂
5	8.10	4.92	3.23	4.56	9.48	69.74
10	10.95	8.93	3.26	7.86	6.83	62.16
15	11.33	10.79	4.55	7.48	6.14	59.70
20	10.68	8.80	4.14	7.10	7.20	62.08
25	10.51	4.38	3.79	6.95	6.95	67.20
30	10.50	10.62	6.49	8.31	7.03	57.05
35	10.8	10.46	5.47	6.60	7.29	59.33
Avg	9.93	11.93	6.24	6.86	6.66	58.37

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

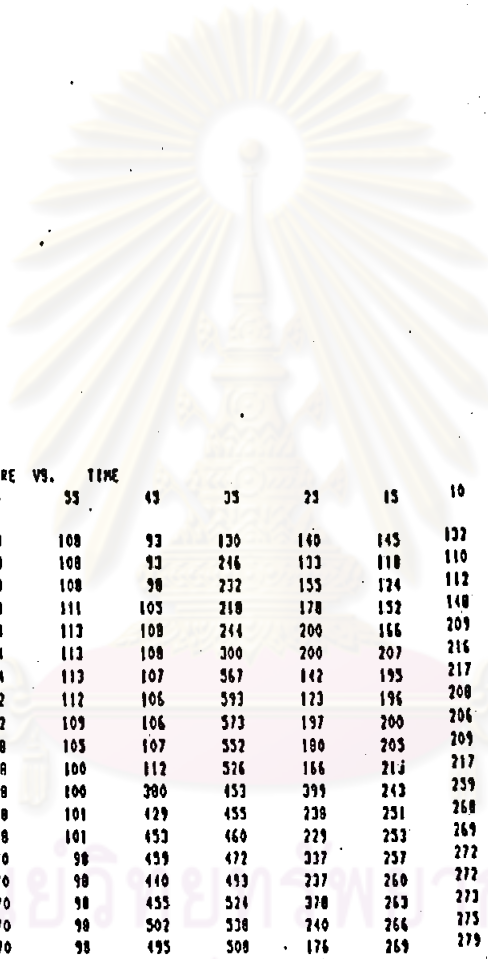


TABLE A 3 (CONT.)

HEIGHT	TEMPERATURE VS. TIME										5	1	-5	a	b	c			
	175	115	105	95	85	75	65	55	45	35							25	15	10
1	47	47	47	83	88	97	109	108	93	130	140	145	132	116	87	85	26	24	24
2	47	47	47	83	88	97	109	108	93	146	133	118	110	114	87	85	67	24	24
3	47	47	47	83	88	97	80	108	98	232	155	124	112	116	87	87	71	24	25
4	47	47	52	63	64	64	74	111	105	218	178	152	148	118	87	87	69	24	24
5	47	47	52	63	64	64	74	113	108	244	200	166	209	132	99	87	68	24	25
6	46	47	52	63	64	64	74	113	108	300	200	207	216	174	420	111	67	24	25
7	45	48	52	63	64	64	74	113	107	567	142	195	217	173	443	158	63	24	25
8	45	48	52	63	64	64	72	112	106	593	123	196	208	172	449	176	63	24	25
9	43	48	52	63	64	64	72	109	106	573	197	200	206	173	450	200	62	24	25
10	42	48	53	63	64	64	68	105	107	552	180	205	209	171	450	210	63	24	25
11	42	48	54	63	64	67	68	100	112	526	166	214	217	176	455	231	62	24	25
13	42	48	54	63	64	67	68	100	380	453	399	243	259	199	490	255	65	24	25
14	42	48	54	63	66	67	68	101	429	455	238	251	268	204	505	260	67	24	25
15	42	48	54	63	66	67	68	101	453	460	229	253	269	206	516	261	64	24	25
16	42	48	54	63	66	67	70	98	459	472	337	257	272	210	537	267	64	24	25
18	42	48	54	63	66	67	70	98	440	493	237	260	272	212	542	271	64	24	25
19	42	48	54	63	66	67	70	98	455	524	370	263	273	214	545	271	64	25	25
20	42	48	54	63	66	67	70	98	502	538	240	266	275	215	540	275	63	25	26
21	42	48	54	63	66	67	70	98	495	508	176	269	279	219	543	276	63	25	26

Note : A = T prior to water scrubber B = T after water scrubber C = T at rotaneter D = actual height of fuel

Table A-4 Data using rice hulls (gas flow rate
30 Ncu.m./hr)

Date	Run No.	RH4
Room temperature (°C)		30
Air moisture (% relative humidity)		56
Air flow rate (Ncu.m./hr)		22.93
Gas flow rate (Ncu.m/hr)		30
Fuel weight (kgs.)		2.2
Fuel moisture content (% wt)		5.2
Experimental time (min.)		32
Weight of char and ash (kgs.)		0.75
% fixed carbon in char and ash		

Gas composition vs. Time

Time	CO	H ₂	CH ₄	CO ₂	O ₂	N ₂
3	10.25	11.82	1.17	7.54	5.42	63.81
7	6.48	8.76	1.04	7.89	9.83	87.73
14	10.58	14.47	3.42	7.56	9.14	54.89
18	13.94	14.80	2.25	8.76	7.52	52.79
25	7.80	11.90	1.90	6.99	6.73	64.76
30	9.17	14.62	3.20	9.34	7.31	56.36
35	9.29	12.48	2.18	9.17	7.76	62.32
Avg	9.00	12.09	2.11	8.88	7.52	60.39

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

TABLE A 4 (CONT.)

FACE MILL RED HEIGHT TIME	TEMPERATURE -VS- TIME																			
	125	115	105	95	85	75	65	55	45	35	25	15	10	5	t	-S	a	b	c	
1	45	53	58	64	66	72	82	95	66	412	157	215	142	67	111	77	78	27	28	
5	42	49	50	59	62	71	80	94	90	585	417	210	238	187	148	266	82	27	29	
6	41	48	50	58	63	70	78	312	539	306	327	213	235	181	148	335	89	28	30	
7	41	48	50	58	66	72	82	314	532	394	332	214	228	199	187	281	97	29	30	
8	41	47	50	60	66	73	82	694	573	393	338	222	221	181	120	247	92	29	30	
9	41	47	50	57	68	69	84	582	544	312	341	227	229	198	247	245	93	29	30	
10	41	47	50	59	65	74	86	563	528	307	345	232	232	215	210	252	90	31	30	
11	41	47	50	57	61	74	82	330	502	295	315	242	253	211	122	247	84	33	30	
13	41	47	50	54	58	72	83	500	487	285	338	245	248	217	150	265	91	37	30	
14	41	47	50	48	62	67	85	493	479	231	336	246	248	235	225	272	93	32	30	
15	41	47	50	52	62	67	55	724	457	469	314	235	249	254	235	132	279	91	32	30
16	41	47	50	52	62	67	723	451	463	266	338	248	254	235	134	279	91	32	30	
20	41	47	50	52	62	63	674	463	476	521	315	241	273	273	154	271	92	32	30	
22	41	47	50	52	62	63	600	471	512	316	310	259	276	276	241	264	89	32	30	
23	43	48	52	66	83	83	594	460	510	322	283	261	279	279	259	265	88	32	30	
24	43	52	52	71	95	94	612	467	508	297	242	268	283	283	261	265	88	32	30	
25	47	53	55	72	98	99	867	465	508	290	240	260	282	280	265	267	85	32	30	
28	47	55	60	85	107	121	364	466	467	287	200	251	260	278	260	262	72	32	30	
29	50	57	69	87	116	132	321	480	459	259	169	246	259	269	248	259	63	32	30	

Note : A = T prior to water scrubber

B = T after water scrubber

C = T at rotaneter

D = actual height of fuel

Table A-5 Data using rice hull milled (gas flow rate
15 Ncu.m./hr)

Date	Run No.	RHMI
Room temperature (°C)		29
Air moisture (% relative humidity)		65
Air flow rate (Ncu.m./hr)		13.33
Gas flow rate (Ncu.m./hr)		15
Fuel weight (kgs.)		1.70
Fuel moisture content (% wt)		5.01
Experimental time (min.)		35
Weight of char and ash (kgs.)		0.80
% fixed carbon in char and ash		

Gas composition vs. Time

Time	CO	H2	CH4	CO2	O2	N2
5	1.22	2.78	0.52	9.73	5.43	80.32
10	2.10	4.35	0.68	9.05	5.72	78.1
15	2.31	4.2	0.83	8.51	5.23	78.92
20	2.77	1.67	0.66	8.01	5.03	81.86
25	2.56	5.01	0.75	8.94	4.24	78.5
30	2.15	4.78	0.72	8.60	5.94	77.81
Avg.	2.50	4.28	0.78	8.69	5.43	77.12

ศูนย์วิทยทรัพยากร
จุฬาลงกรณ์มหาวิทยาลัย

TABLE A 5 (CONT)

FIRE MULL RED HEIGHT TIME	TEMPERATURE VS. TIME															a	b	c	
	125	105	105	95	85	75	65	55	45	35	25	15	10	5	1				-5
1	45	53	58	64	66	72	82	95	66	412	157	215	142	67	111	77	78	27	28
5	42	49	50	59	62	71	80	94	90	585	417	210	238	187	148	266	82	27	29
6	41	48	50	58	63	70	78	312	539	306	327	213	239	181	148	335	89	28	30
7	41	48	50	58	66	72	82	314	532	394	332	214	228	199	107	281	97	29	30
8	41	47	50	60	66	73	82	694	573	393	338	222	221	181	120	247	92	29	30
9	41	47	50	57	68	69	84	582	544	392	341	227	229	198	247	245	93	29	30
10	41	47	50	59	65	74	86	563	528	307	345	232	232	215	210	252	90	31	30
11	41	47	50	57	61	74	82	530	502	295	345	242	253	211	122	247	84	33	30
12	41	47	50	54	58	72	83	500	487	285	318	245	248	217	150	265	91	32	30
14	41	47	50	48	62	67	85	493	479	231	336	246	248	235	225	272	93	32	30
15	41	47	50	52	62	55	774	457	469	314	335	249	254	235	132	279	91	32	30
16	41	47	50	52	62	67	723	451	463	266	338	248	254	235	134	279	91	32	30
20	41	47	50	52	62	69	674	463	476	521	315	241	273	273	154	271	92	32	30
22	41	47	50	52	62	63	600	471	512	316	310	259	276	276	241	264	89	32	30
23	43	48	52	66	83	83	594	460	510	322	282	261	279	279	259	265	88	32	30
24	43	52	52	71	95	94	612	467	508	297	242	265	283	283	261	265	88	32	30
25	47	53	55	72	98	99	867	465	508	290	240	260	282	280	265	267	85	32	30
28	47	55	60	85	107	121	364	466	467	287	200	251	260	270	260	262	72	32	36
29	50	57	69	87	116	132	371	480	459	259	169	246	259	269	248	259	63	32	36

Note : A = T prior to water scrubber

B = T after water scrubber

C = T at rotameter

D = actual height of fuel



Table A-6 Data using Rice hull milled. (gas flow rate 15Ncu.m./hr)

Date	Run No. RHM2
Room temperature (°C)	28
Air moisture (% relative humidity)	63
Air flow rate (Ncu.m./hr)	17.09
Gas flow rate (Ncu.m/hr)	20
Fuel weight (kgs.)	1.8
Fuel moisture content (% wt)	5.22
Experimental time (min.)	40
Weight of char and ash (kgs.)	0.65
% fixed carbon in char and ash	

Gas composition vs. Time

Time	CO	H ₂	CH ₄	CO ₂	O ₂	N ₂
5	6.02	6.92	1.24	9.8	10.37	66.27
10	6.21	7.92	1.12	9.68	8.28	66.79
15	6.8	8.2	1.10	10.35	5.59	67.24
25	6.5	8.7	1.17	10.28	5.14	68.21
30	8.32	8.15	1.02	9.76	3.43	69.52
Avg	6.72	8.1	1.25	10.2	6.23	67.5

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TABLE A-6 (CONT.)

NO WEIGHT TIME	TEMPERATURE °C																	
	125	115	105	95	85	75	65	55	45	35	25	15	10	5	1	-5	b	c
0	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
1	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
2	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
3	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
4	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
5	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
7	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
8	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
9	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
10	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
12	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
13	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
14	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
15	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
16	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
17	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
18	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
19	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
20	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
22	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
24	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
25	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
27	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
29	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
30	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
32	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
34	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
35	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
36	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
38	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
40	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28

Note : A = T prior to water scrubber B = T after water scrubber C = T at rotameter D = actual height of fuel

Table A-8 Data using rice hull milled. (gas flow rate
25Ncu.m./hr)

Date	Run No. RHM4	
Room temperature ($^{\circ}\text{C}$)		25
Air moisture (% relative humidity)		94
Air flow rate (Ncu.m./hr)		19.63
Gas flow rate (Ncu.m/hr)		25
Fuel weight (kgs.)		2.50
Fuel moisture content (% wt)		5.20
Experimental time (min.)		45
Weight of char and ash (kgs.)		0.95
% fixed carbon in char and ash		

Gas composition vs. Time

Time	CO	H ₂	CH ₄	CO ₂	O ₂	N ₂
5	12.4	10.42	1.29	10.39	7.03	59.43
10	15.15	10.78	2.32	9.05	7.08	55.61
15	5.96	5.67	1.20	9.74	6.50	70.95
20	7.87	14.49	2.83	10.48	7.64	56.69
25	6.26	8.70	0.88	11.27	7.89	65.98
30	11.19	8.17	1.96	9.66	5.71	65.98
Avg.	9.4	9.78	1.77	10.11	6.5	64.69

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TABLE A 8 (CONT.)

RICE MILL BED WEIGHT TIME	TEMPERATURE VS. TIME																			
	125	115	105	95	85	75	65	55	45	35	25	15	10	5	1	-5	a	b	c	
0	23	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	24	25
1	25	25	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	25
2	25	25	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	25
3	25	25	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	25
4	25	25	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	25
5	25	25	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	25
8	25	25	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	25
9	25	25	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	25
10	25	25	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	25
11	25	25	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	25
12	25	25	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	25
13	25	25	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	25
14	25	25	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	25
15	25	25	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	25
16	25	25	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	25
18	25	25	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	25
20	25	25	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	25
22	26	26	26	27	28	28	28	29	29	29	29	29	29	29	29	29	29	29	29	28
23	26	26	26	27	28	29	29	29	29	29	29	29	29	29	29	29	29	29	29	28
24	26	26	26	27	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	28
25	26	26	26	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	28
26	27	27	28	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	28
27	27	27	28	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	28
30	27	27	28	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	28
31	28	28	28	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	28
32	28	28	28	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	28
33	28	28	28	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	28
34	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	28
35	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	28
37	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	28
40	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	28
41	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	28
43	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	29	28

Note : A = T prior to water scrubber B = T after water scrubber C = T at rotameter D = actual height of fuel

Table A-9 Data using rice hull milled. (gas flow rate
30Ncu.m./hr)

	Run No. RHMS
Date	30
Room temperature (°C)	72
Air moisture (% relative humidity)	24.54
Air flow rate (Ncu.m./hr)	30
Gas flow rate (Ncu.m/hr)	2.0
Fuel weight (kgs.)	5.21
Fuel moisture content (% wt)	40
Experimental time (min.)	0.80
Weight of char and ash (kgs.)	
% fixed carbon in char and ash	

Gas composition vs. Time

Time	CO	H ₂	CH ₄	CO ₂	O ₂	N ₂
5	5.4	6.54	1.08	10.28	9.25	67.45
10	6.78	7.38	1.12	10.45	9.45	64.82
15	6.34	8.42	1.63	10.15	8.52	63.55
20	6.34	8.56	1.24	10.21	9.34	64.23
25	7.05	10.46	1.09	10.45	8.23	62.72
30	6.52	8.02	1.02	11.60	8.40	65.46
Avg.	6.51	8.42	1.22	10.45	8.08	64.69

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TABLE A-9 (CONT.)

BED HEIGHT TIME	TEMPERATURE VS. TIME																	
	125	115	105	95	85	75	65	55	45	35	25	15	10	5	1	-5	a	c
0	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	a	c
1	30	30	31	31	32	34	35	45	45	45	66	150	30	30	30	30	30	30
3	30	30	31	31	32	34	35	45	45	45	66	163	117	96	93	30	30	30
5	31	31	31	31	32	34	31	31	45	45	66	238	130	98	101	65	30	30
8	31	31	31	31	32	34	35	45	45	46	66	244	220	98	148	65	30	30
10	31	31	32	32	33	35	36	46	46	46	67	248	222	160	141	65	30	30
11	31	31	32	32	33	35	36	46	46	47	67	246	215	165	178	65	30	30
13	31	32	32	32	33	35	36	46	46	47	67	246	223	200	216	65	30	30
15	31	32	32	32	33	35	37	47	47	47	70	250	225	236	203	65	30	30
17	31	32	33	33	34	35	37	47	47	47	74	252	220	243	206	65	30	30
19	32	32	33	33	34	36	37	47	47	47	77	250	219	250	495	68	30	30
20	32	32	33	33	34	36	37	47	47	47	80	248	225	253	515	68	30	30
23	32	32	33	33	34	36	38	47	47	47	91	250	233	254	518	68	30	30
24	32	32	33	33	34	36	38	47	47	47	104	257	255	261	519	67	30	30
26	32	32	33	33	34	36	38	47	47	47	300	267	251	264	517	67	30	30
28	32	32	33	33	34	36	38	47	47	47	353	282	260	267	515	67	30	30
29	32	32	33	33	34	36	38	47	47	47	363	280	260	270	500	65	31	30
30	32	32	33	33	34	36	38	47	47	47	621	360	261	275	501	65	31	30
31	32	32	33	33	34	36	38	47	47	47	610	364	261	280	502	65	31	30
32	32	32	33	33	34	36	38	47	47	47	554	354	260	287	501	61	31	30
33	32	32	33	33	34	36	38	47	47	47	916	351	261	289	500	61	31	30
34	32	32	33	33	34	36	38	47	47	47	460	257	259	294	498	61	31	30
35	32	32	33	33	34	36	38	47	47	47	448	253	260	295	495	61	31	30
36	32	32	33	33	34	36	38	47	47	50	410	253	265	290	490	61	31	30
37	32	32	33	33	34	36	38	47	47	50	408	253	265	254	491	61	31	30
38	32	32	33	33	34	36	38	47	47	50	401	253	260	257	492	61	31	30
												373	254	490	61	31	30	

Note : A = T prior to water scrubber B = T after water scrubber C = T at rotameter D = actual height of fuel

Table A-10 Data using rice hull milled. (gas flow rate
35Ncu.m./hr)

Date	Run No. RHM5
Room temperature (°C)	30
Air moisture (% relative humidity)	68
Air flow rate (Ncu.m./hr)	30.92
Gas flow rate (Ncu.m/hr)	35
Fuel weight (kgs.)	2.9
Fuel moisture content (% wt)	5.12
Experimental time (min.)	40
Weight of char and ash (kgs.)	0.87
% fixed carbon in char and ash	

Gas composition vs. Time

Time	CO	H ₂	CH ₄	CO ₂	O ₂	N ₂
6	1.03	2.9	0	8.94	12.03	75.02
10	3.80	6.48	0.45	11.4	9.59	68.62
15	2.59	5.35	0.66	9.44	11.46	70.53
25	4.88	5.64	2.69	8.56	10.06	68.61
31	3.13	6.36	1.87	8.35	10.52	69.74
Avg	3.47	5.53	1.4	9.30	10.55	69.78

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TABLE A-10 (CONT)

HEIGHT ft	TEMPERATURE vs. TIME																	
	125	115	105	95	85	75	65	55	45	35	25	15	10	5	1	-5	b	c
0	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
1	30	30	31	31	32	34	35	45	45	45	66	179	117	96	93	58	30	30
4	30	30	31	31	32	34	35	45	45	45	66	236	131	98	109	66	30	30
6	30	31	31	31	32	34	35	45	45	45	66	258	213	98	148	66	30	30
9	30	31	31	31	32	34	35	45	45	46	66	244	222	116	156	66	30	30
10	31	31	32	32	33	35	36	46	46	46	67	228	205	128	178	66	30	30
12	31	31	32	32	33	35	36	46	46	47	67	226	223	139	216	66	30	30
13	31	32	32	32	33	35	36	46	46	47	67	235	223	136	283	66	30	30
15	31	32	32	32	33	35	37	47	47	47	70	250	226	143	386	67	30	30
18	31	32	33	33	34	35	37	47	47	47	74	252	227	150	500	70	30	30
19	32	32	33	33	34	36	37	47	47	47	77	248	229	153	503	71	30	30
21	32	32	33	33	34	36	37	47	47	47	88	248	243	157	518	68	30	30
23	32	32	33	33	34	36	38	47	47	47	101	257	255	162	525	67	30	30
25	32	32	33	33	34	36	38	47	47	47	238	257	255	164	513	67	30	30
26	32	32	33	33	34	36	38	47	47	47	523	258	260	168	482	67	30	30
28	32	32	33	33	34	36	38	47	47	47	595	264	262	179	508	65	31	30
29	32	32	33	33	34	36	38	47	47	47	775	262	261	179	511	65	31	30
30	32	32	33	33	34	36	38	47	47	47	683	257	258	181	502	65	31	30
31	32	32	33	33	34	36	38	47	47	47	606	262	260	187	508	64	31	30
32	32	32	33	33	34	36	38	47	47	47	587	254	256	189	495	64	31	30
33	32	32	33	33	34	36	38	47	47	47	526	258	259	192	498	64	31	30
34	32	32	33	33	34	36	38	47	47	47	490	257	260	199	484	64	31	30
35	32	32	33	33	34	36	38	47	47	47	418	255	268	198	473	64	31	30
37	32	32	33	33	34	36	38	47	47	50	429	260	265	204	424	64	31	30
38	32	32	33	33	34	36	38	47	47	50	418	263	271	207	495	64	31	30
39	32	32	33	33	34	36	38	47	47	50	404	263	273	207	490	64	31	30

Note : A = T prior to water scrubber B = T after water scrubber C = T at rotaneter D = actual height of fuel

Table A-11 Data using rice hull (gas flow rate 25Ncu.m./hr)

Date	Run No.	R1
Room temperature ($^{\circ}\text{C}$)		30
Air moisture (% relative humidity)		75
Air flow rate (Ncu.m./hr)		20.91
Gas flow rate (Ncu.m/hr)		25
Fuel weight (kgs.)		2.1
Fuel moisture content (% wt)		7.2
Experimental time (min.)		40
Weight of char and ash (kgs.)		0.80
% fixed carbon in char and ash		

Gas composition vs. Time

Time	CO	H ₂	CH ₄	CO ₂	O ₂	N ₂
5	4.67	3.2	0.87	10.98	8.34	71.94
10	5.29	3.15	0.95	15.32	8.20	68.23
15	5.00	3.87	1.85	17.34	8.27	63.67
20	6.52	4.56	1.44	16.52	8.95	60.96
25	5.12	4.50	1.47	14.35	7.57	66.99
30	5.67	4.23	0.92	12.34	7.68	69.16
Avg	5.42	3.96	1.32	15.02	8.20	66.08

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TABLE A-11 (CONT.)

BED HEIGHT TIME	TEMPERATURE VS. TIME																A	B	C	D							
	125	115	105	95	85	75	65	55	45	35	25	15	10	5	1	-5											
0	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27				
1	27	27	27	28	28	29	29	29	30	319	168	61	67	59	81	80	47	31	31	106							
2	27	27	27	28	28	29	29	29	33	305	122	71	71	65	81	81	54	31	31	86							
4	27	27	28	28	28	29	29	31	32	320	195	77	76	73	81	84	58	31	31								
5	27	27	28	28	28	29	29	31	66	309	230	88	84	76	158	97	62	31	31								
6	27	27	28	28	29	30	31	31	207	251	103	93	92	76	199	103	67	31	31								
7	28	28	28	28	29	30	31	31	241	243	109	94	97	74	228	106	65	31	31								
8	28	28	28	28	29	30	31	31	248	226	130	99	103	74	265	110	66	31	31								
10	28	28	28	28	30	30	31	105	348	233	139	108	123	72	309	113	66	31	31								
11	28	28	28	29	30	30	31	153	353	241	104	111	126	73	306	115	66	31	31								
12	28	29	29	29	30	30	31	243	355	243	102	113	128	73	301	118	66	31	31								
13	28	29	29	29	30	30	31	257	371	246	102	117	130	76	296	123	66	31	31								
14	28	29	29	29	30	30	31	225	489	265	168	119	131	77	288	125	66	31	31								
15	28	29	29	29	30	30	31	150	587	273	191	124	131	84	277	138	66	31	31								
16	28	29	29	30	30	30	31	116	569	285	228	125	131	88	272	139	66	31	31								
18	28	29	29	30	30	30	31	130	600	285	234	132	135	95	259	140	66	31	31								
19	28	29	29	30	30	30	31	110	571	292	237	133	136	97	255	142	66	31	31								
20	29	29	29	30	30	30	32	204	490	303	111	135	138	100	251	147	66	31	31								
21	29	29	29	30	32	30	35	280	455	308	111	138	143	103	250	148	66	31	31								
23	29	29	29	30	32	32	36	378	456	307	111	143	144	106	251	150	66	31	31								
24	29	32	32	32	32	32	42	416	448	303	180	144	147	107	251	148	66	31	31								
25	30	32	32	32	32	32	50	411	438	297	156	147	149	110	254	157	66	31	31								
26	30	32	32	32	32	32	54	383	423	296	186	149	151	115	257	154	66	31	31								
27	31	32	32	32	32	40	54	373	417	296	193	151	156	118	258	155	66	31	31								
28	31	32	32	37	49	44	58	387	409	297	187	156	154	121	259	157	66	31	31								
29	31	32	35	45	45	51	58	446	409	297	185	154	154	121	260	157	66	31	31								
30	32	32	38	48	48	55	58	477	458	297	185	154	154	125	260	157	66	31	31								

Note: A = T prior to water scrubber B = T after water scrubber C = T at retainer D = actual height of fuel

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Table A-12 Data using rice hull (gas flow rate 25Ncu.m./hr)

Date	Run No.	R1
Room temperature (°C)		32
Air moisture (% relative humidity)		75
Air flow rate (Ncu.m./hr)		21.71
Gas flow rate (Ncu.m/hr)		25
Fuel weight (kgs.)		2.1
Fuel moisture content (% wt)		10.25
Experimental time (min.)		40
Weight of char and ash (kgs.)		0.70
% fixed carbon in char and ash		

Gas composition vs. Time

Time	CO	H ₂	CH ₄	CO ₂	O ₂	N ₂
5	8.09	6.25	0	7.91	6.8	70.93
10	12.18	8.80	1.77	5.81	6.01	65.44
15	8.79	6.56	1.26	6.06	6.5	70.18
20	7.10	7.42	0	9.76	6.7	68.62
25	6.30	3.19	4.64	7.13	6.31	72.60
30	6.42	4.83	3.41	17.94	6.00	61.36
Avg	8.33	9.32	1.88	10.67	6.79	68.63

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TABLE A 12 (CONT'D)

INCH						TEMPERATURE		VS. TIME											
	125	115	105	95	85	75	65	55	45	35	25	15	10	5	1	-5	a	b	c
7	34	39	40	43	45	47	45	56	50	63	412	134	94	80	68	69	55	27	28
5	34	36	37	39	38	46	46	56	56	70	339	209	208	152	78	90	57	28	28
7	34	36	38	40	41	41	47	57	37	98	316	224	230	171	87	124	56	28	28
8	35	37	38	40	42	40	48	57	35	153	192	271	230	171	99	131	57	28	28
9	33	36	38	40	41	43	47	56	35	227	320	237	232	185	152	108	55	28	28
15	34	36	38	40	42	44	49	57	85	272	302	234	272	175	139	131	55	28	28
17	35	36	38	40	42	44	49	57	114	353	309	227	217	175	162	120	55	28	28
29	34	38	39	40	42	47	47	56	232	381	321	223	212	175	167	110	50	28	29
21	34	39	41	43	44	49	49	58	232	271	303	223	217	175	167	110	50	28	29
22	34	36	38	40	40	41	47	57	464	430	328	237	225	183	150	118	54	28	29
24	34	36	38	40	42	42	46	57	329	350	314	225	217	183	118	138	57	30	29
25	35	36	38	40	42	43	48	59	505	350	350	245	217	183	171	106	50	29	29
26	34	35	37	39	40	40	46	59	531	366	347	236	228	199	102	168	60	29	29
27	34	36	38	40	41	42	47	63	518	334	331	231	225	200	142	131	56	29	29
29	34	36	38	40	41	43	47	82	464	348	324	234	226	191	120	154	58	28	29
14	34	35	38	40	41	45	47	112	669	273	269	332	245	232	129	169	60	29	29

Note: A - T prior to water scrubber
 B = T after water scrubber
 C = T at rotameter
 D = actual height of fuel



Table A-13 Data using rice hull (gas flow rate 25Ncu.m./hr)

Date	Run No.	R4
Room temperature ($^{\circ}\text{C}$)		28
Air moisture (% relative humidity)		75
Air flow rate (Ncu.m./hr)		19.30
Gas flow rate (Ncu.m/hr)		25
Fuel weight (kgs.)		2.2
Fuel moisture content (% wt)		6.2
Experimental time (min.)		53
Weight of char and ash (kgs.)		0.65
% fixed carbon in char and ash		

Gas composition vs. Time

Time	CO	H ₂	CH ₄	CO ₂	O ₂	N ₂
14	12.81	7.19	2.42	8.66	7.36	61.43
22	13.58	7.72	1.00	6.55	9.70	61.44
29	14.31	7.49	1.13	7.34	10.72	60.99
37	15.01	7.34	1.38	7.18	5.66	63.41
44	13.70	7.68	1.66	6.39	12.67	57.89
53	1.15	7.70	0.16	0.14	20.59	70.24
Avg	13.06	7.59	1.49	7.05	12.05	58.34

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TABLE A-13 (CONT.)

FRO HEIGHT TIME	TEMPERATURE VS. TIME																	
	125	115	105	95	85	75	65	55	45	35	25	15	10	5	1	-5	b	c
0	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28
1	30	30	31	31	32	34	35	45	45	45	66	170	117	96	93	58	30	30
4	30	30	31	31	32	34	35	45	45	45	66	236	131	98	109	66	30	30
6	30	31	31	31	32	34	35	45	45	45	66	238	213	98	148	66	30	30
9	30	31	31	31	32	34	35	45	45	46	66	244	222	110	150	66	30	30
10	31	31	32	32	33	35	36	46	46	46	67	270	205	120	170	66	30	30
12	31	31	32	32	33	35	36	46	46	47	67	226	223	120	216	66	30	30
13	31	32	32	32	33	35	36	46	46	47	67	235	223	136	203	66	30	30
15	31	32	32	32	33	35	37	47	47	47	70	250	226	143	206	67	30	30
18	31	32	32	33	34	35	37	47	47	47	74	252	227	150	300	70	30	30
19	32	32	33	33	34	36	37	47	47	47	77	248	229	153	303	71	30	30
21	32	32	33	33	34	36	37	47	47	47	80	248	243	157	318	68	30	30
23	32	32	33	33	34	36	38	47	47	47	101	257	255	162	325	67	30	30
25	32	32	33	33	34	36	38	47	47	47	230	257	259	164	313	67	30	30
26	32	32	33	33	34	36	38	47	47	47	323	258	260	168	482	67	30	30
28	32	32	33	33	34	36	38	47	47	47	595	264	262	179	308	65	31	30
29	32	32	33	33	34	36	38	47	47	47	775	262	264	179	311	65	31	30
30	32	32	33	33	34	36	38	47	47	47	683	257	258	181	302	65	31	30
31	32	32	33	33	34	36	38	47	47	47	606	262	260	187	308	64	31	30
32	32	32	33	33	34	36	38	47	47	47	387	254	256	189	499	64	31	30
33	32	32	33	33	34	36	38	47	47	47	526	258	259	192	498	64	31	30
34	32	32	33	33	34	36	38	47	47	47	490	257	260	195	484	64	31	30
35	32	32	33	33	34	36	38	47	47	47	448	255	268	198	473	64	31	30
37	32	32	33	33	34	36	38	47	47	50	439	260	265	204	431	64	31	30
38	32	32	33	33	34	36	38	47	47	50	418	263	271	207	455	64	31	30
39	32	32	33	33	34	36	38	47	47	50	404	263	273	207	490	64	31	30

Note : A = T prior to water scrubber

B = T after water scrubber

C = T at rotameter

D = actual height of fuel

Table A-14 Data using rice hull (gas flow rate 25Ncu.m./hr)

Date	Run No.	R5
Room temperature ($^{\circ}\text{C}$)		27
Air moisture (% relative humidity)		65
Air flow rate (Ncu.m./hr)		19.04
Gas flow rate (Ncu.m/hr)		25
Fuel weight (kgs.)		2.7
Fuel moisture content (% wt)		13.42
Experimental time (min.)		35
Weight of char and ash (kgs.)		0.85
% fixed carbon in char and ash		

Gas composition vs. Time

Time	CO	H ₂	CH ₄	CO ₂	O ₂	N ₂
5	9.9	10.2	1.77	10.47	6.99	60.66
10	8.49	12.64	1.62	14.96	5.67	55.37
15	7.27	11.17	1.85	12.68	7.44	58.11
20	4.24	6.00	0.57	15.16	9.02	64.09
30	4.84	5.33	0.64	15.08	7.80	65.57
Avg	7.84	9.39	1.31	13.89	7.38	60.17

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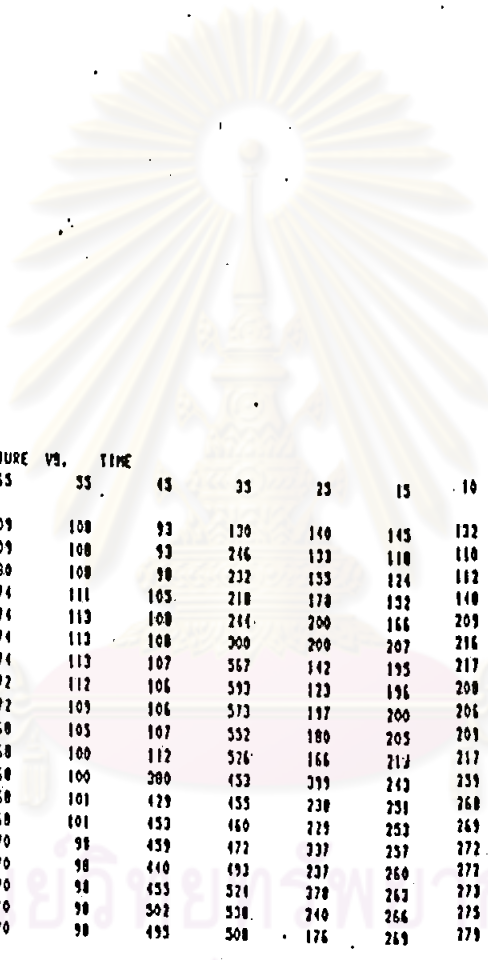


TABLE A-14 (CONT)

HEIGHT	TEMPERATURE VS. TIME																		
	125	115	105	95	85	75	65	55	45	35	25	15	10	5	1	-5	a	b	c
1	47	47	47	83	88	97	109	108	93	170	140	145	132	116	87	85	76	74	74
2	47	47	47	83	88	97	109	108	93	246	133	110	110	114	87	85	67	24	24
3	47	47	47	83	89	97	80	108	90	232	153	124	112	116	87	87	71	24	24
4	47	47	52	63	64	64	74	111	105	218	178	152	140	110	87	87	69	24	24
5	47	47	52	63	64	64	74	113	108	244	200	166	209	132	99	87	68	24	25
6	46	47	52	63	64	64	74	113	108	300	200	207	216	174	420	111	67	24	25
7	45	48	52	63	64	64	74	113	107	367	142	195	217	173	443	158	63	24	25
8	45	48	52	63	64	64	72	112	106	593	123	196	208	172	449	176	63	24	25
9	43	48	52	63	64	64	72	109	106	573	197	200	206	173	456	200	62	24	25
10	42	48	53	63	64	64	68	105	107	552	180	205	201	171	450	210	63	24	25
11	42	48	54	63	64	67	68	100	112	526	166	217	217	176	455	231	62	24	25
12	42	48	54	63	64	67	68	100	380	453	399	243	259	199	490	255	65	24	25
13	42	48	54	63	66	67	68	101	429	455	238	251	268	204	505	260	67	24	25
14	42	48	54	63	66	67	68	101	453	460	229	253	269	206	516	261	64	24	25
15	42	48	54	63	66	67	70	98	459	472	337	257	272	210	537	267	64	24	25
16	42	48	54	63	66	67	70	98	440	493	237	260	277	212	542	271	64	24	25
17	42	48	54	63	66	67	70	98	455	521	378	263	273	214	545	274	64	24	25
18	42	48	54	63	66	67	70	98	502	538	240	266	275	215	546	275	63	25	25
19	42	48	54	63	66	67	70	98	495	508	176	269	279	219	543	276	63	25	26

Note : A = T prior to water scrubber B = T after water scrubber C = T at rotaneter D = actual height of fuel

Table A-15 Data using woodshavings (gas flow rate 15Ncu.m./hr)

Date	Run No.	WS1
Room temperature (°C)		30
Air moisture (% relative humidity)		71
Air flow rate (Ncu.m./hr)		11.41
Gas flow rate (Ncu.m/hr)		15
Fuel weight (kgs.)		2.3
Fuel moisture content (% wt)		6.2
Experimental time (min.)		30
Weight of char and ash (kgs.)		0.80
% fixed carbon in char and ash		

Gas composition vs. Time

Time	CO	H ₂	CH ₄	CO ₂	O ₂	N ₂
5	7.6	2.92	3.46	8.35	11.28	66.37
10	10.24	3.36	6.00	12.39	9.90	58.09
15	12.82	2.50	3.94	10.11	10.24	69.26
20	6.47	3.05	3.57	7.67	9.98	64.92
25	10.30	9.33	1.36	6.06	8.00	64.92
30	7.49	7.43	1.16	13.57	6.28	64.06
35	6.32	5.07	0.67	9.48	7.35	71.13
Avg	9.46	5.15	3.15	10.20	8.95	63.08

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TABLE A-15 (CONT)

BED HEIGHT TIME	TEMPERATURE															TIME				
	125	115	105	95	85	75	65	55	45	35	25	15	10	5	1	-5	A	B	C	D
1	38	45	47	57	61	68	74	83	87	95	78	92	99	99	86	85	28	28	28	
2	38	45	47	57	59	68	72	73	66	75	47	204	233	130	179	126	51	28	28	
3	38	45	47	56	59	65	69	73	68	79	49	272	245	149	235	189	68	28	29	75
4	38	45	47	55	57	59	68	73	66	79	67	281	249	155	314	189	61	28	29	
5	38	44	44	53	54	57	66	74	68	80	63	259	264	164	399	215	62	28	29	
6	38	44	44	53	54	57	66	74	67	81	65	249	279	179	447	252	63	28	29	
7	38	43	44	52	54	58	66	74	70	82	88	217	271	186	465	271	68	28	29	
8	38	43	44	52	54	57	65	74	71	83	130	224	255	181	449	282	68	28	29	
9	38	43	44	52	54	57	65	74	71	104	116	247	260	181	402	281	71	28	29	
10	38	43	44	52	54	57	65	74	72	151	104	255	272	186	372	271	67	28	29	
11	38	43	41	52	54	57	65	74	75	182	125	248	288	194	377	257	78	28	29	
12	38	43	41	52	54	57	65	86	88	180	128	229	288	203	397	252	71	28	29	78
13	38	43	41	52	54	57	65	84	155	160	132	208	263	220	447	285	73	28	29	68
14	38	43	41	52	54	57	65	81	166	350	190	208	245	218	448	293	75	28	29	
15	38	40	40	51	52	57	64	80	153	384	153	201	232	214	437	297	77	28	29	
16	38	40	40	51	52	58	64	79	154	352	158	203	232	213	364	285	77	28	29	
17	37	40	40	51	52	58	62	83	353	300	178	201	231	212	344	274	77	28	29	
18	37	40	40	51	52	58	63	83	322	308	157	203	236	214	330	265	77	28	29	
19	37	40	40	51	52	58	65	95	284	297	122	208	254	223	341	258	77	28	29	
20	37	40	40	51	52	58	72	90	195	346	116	203	251	226	358	262	77	28	29	
21	37	40	40	51	52	59	76	87	168	711	163	200	250	223	371	258	77	28	29	
22	37	40	40	51	52	60	79	87	168	472	178	197	236	223	369	252	77	28	29	
23	37	40	40	51	52	60	79	87	168	404	209	197	234	223	369	250	77	28	29	40
24	37	40	40	51	52	60	81	87	168	403	236	201	234	223	367	248	77	28	29	31

Note : A = T prior to water scrubber B = T after water scrubber C = T at rotameter D = actual height of fuel

Table A-16 Data using woodshavings (gas flow rate
20 Ncu.m./hr)

Date	Run No.	WS2
Room temperature (°C)		25
Air moisture (% relative humidity)		67
Air flow rate (Ncu.m./hr)		13.38
Gas flow rate (Ncu.m/hr)		20
Fuel weight (kgs.)		2.0
Fuel moisture content (% wt)		5.8
Experimental time (min.)		32
Weight of char and ash (kgs.)		0.80
% fixed carbon in char and ash		

Gas composition vs. Time

Time	CO	H ₂	CH ₄	CO ₂	O ₂	N ₂
5	16.56	5.95	8.18	11.35	7.97	49.99
10	13.67	2.82	6.16	16.07	8.24	53.04
15	17.05	4.27	3.17	9.80	8.76	56.94
20	16.77	6.65	13.53	6.86	8.40	48.30
25	17.80	5.29	11.02	5.41	7.89	52.59
30	8.22	7.82	1.30	18.38	7.26	56.99
Avg	15.54	5.18	7.73	10.60	8.10	52.85

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TABLE A-16 (CONT.)

BED HEIGHT TIME	TEMPERATURE															TIME					
	125	115	105	95	85	75	65	55	45	35	25	15	10	5	1	-5	A	B	C	D	
0	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	27	
1	27	27	27	28	28	29	29	29	30	349	168	61	67	59	81	80	47	31	31	106	
2	27	27	27	28	28	29	29	29	33	305	122	71	71	65	81	81	54	31	31	86	
4	27	27	28	28	28	29	29	31	32	320	195	77	76	73	81	84	58	31	31		
5	27	27	28	28	28	29	29	31	66	309	230	88	84	76	158	97	62	31	31		
6	27	27	28	28	29	30	31	31	207	251	103	93	92	76	199	103	67	31	31		
7	28	28	28	28	29	30	31	31	241	243	109	94	97	74	228	106	65	31	31		
8	28	28	28	28	29	30	31	31	248	226	130	99	103	74	265	110	66	31	31		
10	28	28	28	28	30	30	31	105	348	233	139	108	123	72	309	113	66	31	31		
11	28	28	28	29	30	30	31	153	353	241	104	111	126	73	306	115	66	31	31		
12	28	29	29	29	30	30	31	243	355	243	102	113	128	73	301	118	66	31	31		
13	28	29	29	29	30	30	31	257	371	246	102	117	130	76	296	123	66	31	31		
14	28	29	29	29	30	30	31	225	489	265	168	119	131	77	288	125	66	31	31		
15	28	29	29	29	30	30	31	150	587	273	191	124	131	84	277	138	66	31	31		
16	28	29	29	30	30	30	31	116	569	285	228	125	131	88	272	139	66	31	31		
18	28	29	29	30	30	30	31	130	600	285	234	132	135	95	259	140	66	31	31	82	
19	28	29	29	30	30	30	31	110	571	292	237	133	136	97	255	142	66	31	31	58	
20	29	29	29	30	30	30	32	204	490	303	111	135	138	100	251	147	66	31	31		
21	29	29	29	30	32	30	35	280	455	308	111	138	142	103	250	148	66	31	31		
23	29	29	29	30	32	32	36	378	456	307	111	143	144	106	251	150	66	31	31		
24	29	32	32	32	32	32	42	416	448	303	180	144	147	107	251	148	66	31	31		
25	30	32	32	32	32	32	50	411	438	297	156	147	149	110	254	157	66	31	31		
26	30	32	32	32	32	32	54	383	423	296	186	149	151	115	257	154	66	31	31		
27	31	32	32	32	32	40	54	373	417	296	193	151	156	118	258	155	66	31	31		
28	31	32	32	37	49	44	58	387	409	297	187	156	154	121	259	157	66	31	31		
29	31	32	35	45	45	51	58	446	409	297	185	154	154	121	260	157	66	31	31		
30	32	32	38	48	48	55	58	477	458	297	185	154	154	125	260	157	66	31	31	43	

Note: A = T prior to water scrubber B = T after water scrubber C = T at rotameter D = actual height of fuel

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Table A-17 Data using woodshavings (gas flow rate
25 Ncu.m./hr)

Date	Run No. WS3
Room temperature (C)	29
Air moisture (% relative humidity)	65
Air flow rate (Ncu.m./hr)	21.44
Gas flow rate (Ncu.m/hr)	25
Fuel weight (kgs.)	2.4
Fuel moisture content (% wt)	6.5
Experimental time (min.)	45
Weight of char and ash (kgs.)	0.95
% fixed carbon in char and ash	

Gas composition vs. Time

Time	CO	H ₂	CH ₄	CO ₂	O ₂	N ₂
5	6.67	7.69	1.94	10.80	5.51	67.03
10	7.46	9.87	3.56	6.78	6.65	65.68
15	7.23	3.62	1.16	7.28	8.92	71.79
20	9.07	3.06	2.64	15.42	6.71	63.10
25	7.30	5.85	2.41	11.90	7.19	66.25
30	5.68	4.03	1.33	10.20	7.57	71.19
35	5.27	3.15	0.93	12.75	6.00	71.55
Avg	7.08	5.28	2.10	10.6	7.12	67.82

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TABLE A 17 (CONT.)

AVING :GHT	TEMPERATURE					TIME											a	b	c	
	125	115	105	95	85	75	65	55	45	35	25	15	10	5	1	-5				
1	28	29	29	29	29	29	29	29	29	32	47	310	360	236	678	211	68	30	30	
2	28	29	29	29	29	29	29	29	31	31	49	318	501	374	681	317	73	30	30	
3	28	29	29	29	29	29	29	31	31	31	59	408	356	237	684	325	78	30	30	
4	28	29	29	29	30	31	31	31	31	32	84	358	354	250	695	338	83	30	30	
5	28	29	29	30	30	31	31	31	31	32	129	362	366	256	691	342	84	30	30	
6	28	29	29	30	30	31	31	31	31	32	151	387	439	300	684	328	81	30	30	
7	28	29	30	30	30	31	31	31	32	32	151	430	430	300	695	364	104	31	30	
10	28	29	30	30	31	31	31	32	32	32	192	425	427	351	691	357	99	31	30	
12	28	29	30	31	31	31	31	32	32	33	182	389	411	344	680	370	99	31	30	
13	28	29	30	31	31	31	31	32	32	34	172	371	407	338	700	364	100	31	30	
14	29	31	31	31	31	31	31	32	32	35	301	362	394	331	730	342	99	31	30	
16	29	31	31	31	31	31	31	32	32	38	206	357	392	320	706	346	100	31	30	
17	31	31	31	31	31	31	31	32	32	194	237	343	388	320	650	342	98	31	30	
18	31	31	31	31	31	31	31	32	32	403	215	345	370	320	551	325	98	31	30	
19	31	31	31	31	31	31	31	32	32	334	220	332	362	320	539	311	94	31	30	
20	31	31	31	31	31	31	31	32	32	310	261	321	352	314	453	301	94	31	30	
22	32	32	32	33	33	33	33	34	34	35	354	249	314	349	314	446	301	92	31	30
23	32	32	32	33	33	35	35	36	48	457	142	304	341	313	470	297	91	32	30	
24	32	32	32	33	34	35	36	36	54	488	138	306	345	316	468	295	92	32	30	
25	32	32	32	33	34	35	36	37	47	536	131	304	350	318	492	293	93	32	30	
26	32	32	33	33	35	37	37	37	44	565	127	298	349	318	520	297	94	32	30	
27	31	32	33	33	36	37	37	37	56	512	209	302	357	328	565	309	97	32	30	
28	32	32	33	33	36	37	37	37	62	518	244	303	328	327	565	315	97	32	31	
29	32	32	33	33	36	37	37	37	72	518	205	298	344	323	555	317	97	32	31	
30	32	32	33	36	36	37	37	38	592	533	204	291	332	312	523	317	97	32	31	
33	32	32	33	36	37	37	37	38	566	541	287	290	331	312	520	317	97	32	31	
34	32	32	33	36	37	37	37	38	590	536	265	288	330	312	515	317	96	32	31	
35	32	32	33	36	37	37	37	38	592	562	226	288	330	312	500	315	94	32	31	
36	32	32	33	37	37	37	37	38	591	570	213	293	333	315	493	313	96	32	31	
37	32	32	33	37	37	37	37	38	655	520	277	286	324	309	483	306	95	32	31	
38	32	32	33	37	37	37	37	38	656	481	282	285	326	307	478	303	96	32	31	
39	32	32	36	37	37	37	37	38	587	505	287	285	305	305	456	291	90	32	31	
40	32	32	36	37	37	37	37	38	479	486	281	286	305	300	450	289	89	32	31	
42	32	32	36	37	37	37	37	38	337	465	214	285	305	300	436	287	89	32	31	
43	32	32	36	37	37	37	37	38	285	467	212	268	305	300	425	285	89	32	31	
45	32	32	36	37	37	37	37	38	290	472	218	239	305	300	420	280	89	32	31	

Note : A = T prior to water scrubber B = T after water scrubber C = T at rotameter D = actual height of fuel

Table A-18 Data using woodshavings (gas flow rate 30 Ncu.m./hr)

Date	Run No.	WS4
Room temperature (°C)		30
Air moisture (% relative humidity)		72
Air flow rate (Ncu.m./hr)		28.80
Gas flow rate (Ncu.m/hr)		30
Fuel weight (kgs.)		2.0
Fuel moisture content (% wt)		6.32
Experimental time (min.)		40
Weight of char and ash (kgs.)		0.80
% fixed carbon in char and ash		

Gas composition vs. Time

Time	CO	H ₂	CH ₄	CO ₂	O ₂	N ₂
5	5.92	3.85	1.50	11.28	9.35	68.10
10	6.01	4.12	1.93	12.45	9.12	66.37
15	6.25	4.36	2.01	13.36	9.22	64.80
20	6.14	5.18	4.66	11.15	9.72	63.16
25	5.98	4.32	2.56	12.80	8.67	65.67
30	6.52	4.70	0.48	11.60	8.79	67.91
Avg	6.12	4.45	2.43	12.24	8.86	65.90

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TABLE A-18 (CONT.)

BED HEIGHT TIME	TEMPERATURE VS. TIME																A	B	C	D
	125	115	105	95	85	75	65	55	45	35	25	15	10	5	1	-5				
1	30	30	30	30	31	37	43	47	43	40	65	213	370	382	256	218	65	28	27	
3	30	30	30	30	32	30	46	47	43	40	82	224	249	390	208	280	66	28	27	
4	30	30	30	30	33	38	44	47	43	41	156	323	394	433	236	292	63	28	27	
7	30	30	30	31	31	34	38	44	41	41	301	345	391	382	490	362	73	28	27	130
8	30	31	31	31	32	35	38	45	42	41	364	350	377	380	509	354	73	28	27	115
10	30	31	31	31	33	36	40	45	42	72	338	369	410	399	500	355	81	28	27	
11	31	31	31	31	30	33	37	44	42	95	313	365	402	411	519	340	76	28	27	104
14	31	31	31	31	32	36	39	44	42	181	325	366	408	431	534	357	82	28	27	
15	31	31	31	32	32	35	38	43	42	310	422	367	411	430	533	365	87	28	27	
16	31	32	32	32	32	35	38	43	42	325	365	364	405	431	531	360	87	28	27	
18	31	32	32	32	32	36	41	43	42	391	352	368	398	437	529	376	97	28	27	96
19	32	32	32	32	32	36	40	43	80	300	375	366	411	466	544	402	101	28	27	
20	32	32	32	32	33	36	40	43	148	533	351	359	411	466	544	402	101	28	27	
21	32	32	32	32	33	36	40	43	350	454	338	356	389	469	541	399	107	28	27	
22	32	32	32	32	33	36	40	43	583	360	296	355	393	461	479	369	103	28	27	96
23	32	32	32	32	33	36	40	44	610	455	294	354	391	461	434	362	105	28	27	83
24	32	32	32	32	32	36	40	89	587	407	352	352	377	364	323	348	109	28	27	
25	32	32	32	32	32	36	40	85	483	416	375	350	381	366	325	341	111	28	27	
27	32	32	32	32	33	37	40	86	510	397	354	358	394	374	333	339	111	28	27	
28	32	32	32	32	33	37	41	85	584	482	287	362	396	383	312	342	112	28	27	
29	32	32	32	32	33	37	41	86	597	513	265	361	397	378	385	340	114	28	27	
30	32	32	32	32	33	37	41	87	618	508	288	358	394	373	491	343	114	28	27	
31	32	32	32	32	33	37	41	105	620	506	273	359	403	380	492	345	115	28	27	
32	32	32	32	32	33	37	41	230	685	362	216	350	404	383	457	311	118	28	27	82
33	32	32	32	32	33	37	41	596	633	799	229	347	415	390	498	302	121	28	27	60
34	32	32	32	32	33	37	45	154	556	677	228	344	407	386	483	301	120	28	27	
35	32	32	32	32	34	37	48	168	618	636	242	341	407	384	360	299	125	28	27	
36	32	32	32	32	34	37	65	162	650	604	273	351	420	400	497	298	127	28	27	
37	32	32	32	32	34	37	76	643	589	603	348	416	395	399	401	297	127	28	27	59

Note: A = T prior to water scrubber B = T after water scrubber C = T at rotaneter D = actual height of fuel

Table A-19 Data using woodshavings (gas flow rate 35 Ncu.m./hr)

Date	Run No.	WS5
Room temperature (°C)		30
Air moisture (% relative humidity)		69
Air flow rate (Ncu.m./hr)		31.51
Gas flow rate (Ncu.m/hr)		35
Fuel weight (kgs.)		2.0
Fuel moisture content (% wt)		5.54
Experimental time (min.)		35
Weight of char and ash (kgs.)		0.80
% fixed carbon in char and ash		

Gas composition vs. Time

Time	CO	H ₂	CH ₄	CO ₂	O ₂	N ₂
5	5.42	4.29	0.45	9.98	7.62	72.24
10	5.95	5.07	0.97	9.75	7.45	70.81
15	6.21	4.36	0.76	9.23	7.15	72.29
20	6.90	5.58	0.64	9.54	7.60	69.75
25	6.57	5.62	0.52	9.02	7.02	71.25
30	6.52	5.15	0.48	9.74	7.15	70.96
Avg	6.32	5.07	0.67	9.48	7.32	71.14

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TABLE A-19 (CONT.)

FO HEIGHT INC	TEMPERATURE						TIME						5	1	-5	a	b	c	
	175	115	105	95	85	75	65	55	45	35	25	15							10
1	38	45	47	57	61	68	74	83	87	95	78	92	99	99	86	85	28	28	29
2	38	45	47	57	59	68	72	73	66	75	47	204	233	130	179	126	51	28	28
3	38	45	47	56	59	65	69	73	68	79	49	272	245	149	235	189	68	28	29
4	38	45	47	55	57	59	68	73	66	79	67	281	249	155	214	189	61	28	29
5	38	44	44	53	54	57	66	74	68	80	63	259	264	161	299	215	62	28	29
6	38	44	44	53	54	57	66	74	67	81	65	249	279	179	447	252	63	28	29
7	38	43	44	52	54	58	66	74	70	82	88	217	271	186	465	271	68	28	29
8	38	43	44	52	54	57	65	74	71	83	130	224	255	181	449	282	68	28	29
9	38	43	44	52	54	57	65	74	71	104	116	247	250	181	462	281	71	28	29
10	38	43	44	52	54	57	65	74	72	151	104	255	272	186	372	271	67	28	29
11	38	43	41	52	54	57	65	74	75	182	125	248	288	194	377	257	78	28	29
12	38	43	41	52	54	57	65	86	88	180	128	229	288	203	357	252	71	28	29
13	38	43	41	52	54	57	65	84	155	160	132	208	263	220	447	285	73	28	29
14	38	43	41	52	54	57	65	81	166	350	190	208	245	218	448	293	75	28	29
15	38	40	40	51	52	57	64	80	153	381	153	201	232	214	437	297	77	28	29
16	38	40	40	51	52	58	64	79	154	352	158	203	232	213	364	283	77	28	29
17	37	40	40	51	52	58	67	83	353	300	178	201	231	212	344	274	77	28	29
18	37	40	40	51	52	58	63	81	322	308	157	203	236	214	320	265	77	28	29
19	37	40	40	51	52	58	65	95	281	297	122	208	254	213	341	258	77	28	29
20	37	40	40	51	52	58	72	90	195	346	116	203	251	226	358	262	77	28	29
21	37	40	40	51	52	59	76	87	168	711	163	200	250	223	371	258	77	28	29
22	37	40	40	51	52	60	79	87	168	472	178	197	236	223	369	252	77	28	29
23	37	40	40	51	52	60	79	87	168	404	209	197	234	223	369	250	77	28	29
24	37	40	40	51	52	60	81	87	168	403	236	201	234	223	367	248	77	28	29

Note : A = T prior to water scrubber B = T after water scrubber C = T at rotameter D = actual height of fuel



Table A-20 Data using corn cobs (gas flow rate 20 Ncu.m./hr)

	Run No. CN1
Date	28
Room temperature ($^{\circ}\text{C}$)	72.50
Air moisture (% relative humidity)	17.87
Air flow rate (Ncu.m./hr)	20
Gas flow rate (Ncu.m/hr)	2.0
Fuel weight (kgs.)	6.12
Fuel moisture content (% wt)	40
Experimental time (min.)	0.80
Weight of char and ash (kgs.)	
% fixed carbon in char and ash	

Gas composition vs. Time

Time	CO	H ₂	CH ₄	CO ₂	O ₂	N ₂
5	1.23	4.03	1.70	7.56	9.23	76.25
10	3.20	5.07	3.89	8.75	9.46	69.63
15	4.27	5.13	4.30	8.34	9.15	68.81
20	4.50	5.29	4.05	7.46	9.39	69.32
25	4.15	5.97	2.13	8.72	8.76	70.27
30	4.02	5.15	1.57	8.01	7.76	73.49
Avg	3.75	5.21	3.20	8.21	9.05	70.58

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TABLE A 20 (CONT)

10 15HT	TEMPERATURE VS. TIME																			
	125	115	105	95	85	75	65	55	45	35	25	15	10	5	1	-5	a	b	c	
0	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	28	
1	28	28	28	28	28	28	28	28	29	30	30	67	259	165	262	192	73	28	28	
2	28	28	28	28	28	28	28	28	29	30	33	80	453	392	306	240	73	28	28	
3	28	28	28	28	28	28	28	28	29	30	33	172	466	452	472	256	73	28	28	
4	28	28	28	28	28	28	28	28	29	30	33	185	423	512	591	274	73	28	28	
5	28	28	28	28	28	28	28	28	29	30	34	193	401	492	604	286	73	28	28	
6	28	28	28	28	28	28	28	29	29	30	34	230	435	466	632	292	73	28	28	
7	28	28	28	28	28	28	28	29	29	30	36	320	440	521	654	295	73	28	28	
8	28	28	28	28	28	28	28	29	29	30	36	314	592	586	675	304	73	29	28	
9	28	28	28	28	28	28	28	29	29	30	36	318	612	600	611	320	73	29	28	
10	28	28	28	28	28	28	28	29	29	30	31	40	328	572	573	610	312	73	29	28
11	28	28	28	28	28	28	28	29	29	30	31	44	320	484	560	590	320	73	29	28
12	28	28	28	28	28	28	28	29	29	30	31	48	347	482	562	589	320	73	29	29
13	28	28	28	28	28	28	28	29	29	30	31	51	355	487	516	600	320	73	29	29
14	28	28	28	28	28	28	28	29	29	30	31	54	401	483	551	591	312	73	29	29
15	28	28	28	28	28	28	28	29	29	30	31	54	379	465	532	590	305	73	29	29
16	28	28	28	28	28	28	28	29	29	30	32	57	380	498	575	623	320	73	29	29
17	28	28	28	28	28	28	28	29	29	30	32	72	363	512	612	620	324	76	29	29
18	28	28	28	28	28	28	28	29	29	30	32	96	372	520	597	619	316	76	30	29
19	28	28	28	28	28	28	28	29	29	30	32	116	372	540	595	597	300	76	30	29
20	28	28	28	28	28	28	28	29	29	30	32	124	372	541	592	602	310	76	30	29
21	28	28	28	28	28	28	28	29	29	30	34	140	377	560	624	610	315	76	30	29
22	28	28	28	28	28	28	28	29	29	30	34	152	376	505	598	623	308	76	30	29
23	28	28	28	28	28	28	28	29	29	30	34	160	378	503	598	640	305	76	30	30
24	28	28	28	28	28	28	28	29	29	30	34	163	386	509	540	640	310	76	30	30
25	28	28	28	28	28	28	28	29	29	30	34	170	397	511	525	650	309	79	30	30
26	28	28	28	28	28	28	28	29	29	30	36	201	400	516	594	659	307	79	30	30
27	28	28	28	28	28	28	28	29	29	30	36	263	429	510	560	698	305	79	30	30
28	28	28	28	28	28	28	28	29	29	30	36	200	446	512	560	700	309	79	30	30
29	28	28	28	28	28	28	28	29	29	30	36	183	393	527	569	712	315	79	30	30
30	28	28	28	28	28	28	28	29	29	30	36	154	355	450	586	756	362	79	30	30
31	28	28	28	28	28	28	28	29	29	30	36	126	341	449	551	712	377	79	30	30
32	28	28	28	28	28	28	28	29	29	30	36	115	321	442	522	720	365	79	30	30

Note : A = T prior to water scrubber

B = T after water scrubber

C = T at rotameter

D = actual height of fuel

Table A-21 Data using corn cobs (gas flow rate
25 Ncu.m./hr)

Date	Run No. CN2
Room temperature (°C)	26
Air moisture (% relative humidity)	75
Air flow rate (Ncu.m./hr)	21.70
Gas flow rate (Ncu.m/hr)	25
Fuel weight (kgs.)	2.0
Fuel moisture content (% wt)	5.90
Experimental time (min.)	40
Weight of char and ash (kgs.)	0.80
% fixed carbon in char and ash	

Gas composition vs. Time

Time	CO	H ₂	CH ₄	CO ₂	O ₂	N ₂
5	4.78	6.38	1.57	5.49	5.68	77.89
10	1.33	2.08	0.46	10.53	9.36	76.23
15	1.07	1.71	0	6.05	9.96	81.20
20	7.15	7.24	6.86	6.84	5.49	66.42
25	6.88	7.11	7.18	7.30	7.62	63.91
30	1.76	2.46	1.14	8.56	6.11	79.96
35	12.08	10.59	5.11	9.46	6.54	56.21
Avg	4.93	5.22	3.60	8.21	7.49	70.56

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TABLE A-21 (CONT.)

COB HEIGHT	TEMPERATURE V.B. TIME																			
	125	115	105	95	85	75	65	55	45	35	25	15	10	5	1	-1	a	b	c	
0	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	26	
3	26	26	26	26	26	26	26	26	31	31	34	34	261	178	281	200	63	29	28	
4	26	26	26	26	26	26	26	26	31	31	32	32	464	409	326	256	72	28	28	
5	26	26	26	26	26	26	26	26	30	30	32	200	468	475	492	256	70	28	28	
6	26	26	26	26	26	26	26	26	30	30	33	215	418	518	631	294	62	28	28	
9	26	26	26	26	26	26	27	28	29	30	34	193	350	422	664	296	73	28	28	
10	26	26	26	26	27	27	27	28	29	30	34	303	395	464	597	292	73	28	28	
13	26	26	26	26	27	27	27	28	29	30	36	325	410	481	654	276	64	29	28	
15	26	26	27	27	27	27	27	28	29	30	36	304	392	600	711	304	73	21	28	
16	26	26	27	27	27	27	27	28	29	30	42	322	610	629	621	328	73	21	28	
18	26	26	27	27	27	27	27	28	29	30	45	348	529	554	616	312	74	29	28	
19	26	27	27	27	27	27	27	28	29	30	46	340	484	560	642	311	77	29	28	
20	26	27	27	27	27	27	27	28	29	30	48	372	557	562	598	323	82	29	29	
21	26	27	27	27	27	27	27	28	29	30	50	355	487	573	626	320	84	29	29	
22	26	27	27	27	27	27	27	28	29	30	51	406	541	570	605	312	82	29	29	
23	26	27	27	27	27	28	27	28	29	30	55	349	475	584	640	302	82	29	29	
24	26	27	27	27	27	28	28	28	29	30	57	380	541	602	638	332	82	29	29	
25	26	27	27	27	28	28	28	28	29	30	72	372	520	581	620	334	82	29	29	
26	26	27	27	27	28	28	28	28	29	30	96	378	524	567	626	311	82	30	29	
28	26	27	27	28	28	28	28	28	29	30	120	377	458	569	587	291	82	30	29	
29	26	27	27	28	28	28	28	28	29	32	130	372	541	592	586	305	82	30	29	
30	26	27	27	28	28	28	28	29	29	34	151	477	578	648	616	315	82	30	29	
31	26	27	27	28	28	28	28	29	29	34	166	376	471	582	636	298	82	30	29	
32	26	27	27	28	28	28	28	29	29	34	162	378	464	512	642	303	84	30	30	
33	26	27	27	28	28	28	28	29	29	34	164	386	486	540	651	315	84	30	30	
34	26	27	27	28	28	28	28	29	29	34	174	397	511	536	653	309	84	31	30	
35	26	27	27	28	28	28	28	29	29	30	219	377	516	544	659	301	84	31	30	
36	26	27	27	28	28	28	28	29	29	30	273	429	518	588	750	301	92	31	30	
37	26	27	27	28	28	28	28	29	29	30	37	189	522	580	756	309	92	31	30	
40	26	27	27	28	28	28	28	29	29	31	43	102	355	557	579	794	315	92	31	30
41	26	27	27	28	28	28	28	29	29	31	45	104	355	486	796	362	92	31	30	
43	26	27	27	28	28	28	28	29	29	31	48	126	341	488	512	811	377	102	31	30
45	26	27	27	28	28	28	28	29	29	31	56	115	334	442	513	812	365	101	32	30
46	26	27	27	28	28	28	28	29	29	31	71	121	332	453	510	851	368	101	32	30
48	26	27	27	28	28	28	28	29	29	31	72	121	332	450	510	854	367	102	32	30

Note : - T prior to water scrubber B = T after water scrubber C = T at rotameter D = actual height of fuel

Table A-22 Data using corn cobs (gas flow rate
30 Ncu.m./hr)

Date	Run No.	CN 3
Room temperature (C)		30
Air moisture (% relative humidity)		61.5
Air flow rate (Ncu.m./hr)		21.56
Gas flow rate (Ncu.m/hr)		30
Fuel weight (kgs.)		2.3
Fuel moisture content (% wt)		5.9
Experimental time (min.)		40
Weight of char and ash (kgs.)		0.75
% fixed carbon in char and ash		

Gas composition vs. Time

Time	CO	H ₂	CH ₄	CO ₂	O ₂	N ₂
10	6.14	7.18	1.51	5.45	5.21	74.51
15	10.11	11.42	3.01	8.71	7.45	59.3
25	13.45	14.11	3.08	8.72	7.18	53.46
30	14.21	14.28	2.45	8.51	8.10	52.45
35	15.79	13.62	1.98	7.64	8.80	52.17
40	12.11	12.11	1.00	8.01	7.22	59.55
Avg	12.41	12.64	2.47	8.17	7.51	56.8

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TABLE A 22 (CONT')

TEMPERATURE V.S. TIME

RED HEIGHT TIME	115	105	95	85	75	65	55	45	35	25	15	10	5	1	-5	a	b	c
0	23	23	23	23	23	23	24	24	24	24	24	24	24	24	24	24	25	25
1	23	23	23	23	23	23	31	40	420	87	77	98	91	150	143	77	27	27
2	23	23	23	23	23	23	29	35	353	84	74	113	95	92	210	77	26	27
3	26	23	22	24	27	28	29	35	630	160	72	110	100	241	222	77	26	27
4	26	25	25	32	33	30	29	35	467	327	71	96	92	126	197	81	28	28
5	27	26	25	30	32	30	39	39	981	275	120	87	85	318	238	80	27	28
6	26	27	27	27	31	34	31	55	557	427	155	100	108	357	226	82	27	28
8	26	27	27	27	31	34	31	79	521	407	220	139	108	357	226	81	29	29
9	26	27	27	27	31	34	32	134	557	300	246	167	86	357	222	83	28	29
10	26	27	27	27	31	34	32	290	509	457	248	170	84	357	218	86	29	29
11	26	27	27	27	31	34	32	395	503	462	282	178	96	357	212	88	29	29
12	26	27	27	27	31	34	32	583	474	420								
13	26	27	25	27	31	32	33	690	420	400	315	238	129	131	220	88	28	28
14	26	27	27	27	31	32	34	730	435	468	334	238	190	130	222	91	28	29
15	26	27	27	27	31	32	36	718	498	430	335	349	173	130	212	90	28	29
16	26	27	27	27	31	32	38	700	508	319	328	307	258	130	217	89	30	29
17	26	27	27	27	31	32	39	650	358	443	369	320	225	117	217	90	29	30
19	26	27	27	27	31	32	40	616	379	497	380	313	253	214	213	90	31	30
20	26	27	27	27	31	32	42	608	604	500	385	314	291	132	212	92	28	29
21	26	27	27	27	31	32	45	627	581	375	386	330	200	107	209	89	28	29
22	26	27	27	27	31	32	48	743	528	494	385	342	313	292	210	90	29	29
23	26	27	27	27	31	32	51	683	540	432	394	344	310	206	215	92	29	29
25	26	27	27	27	31	32	76	537	516	378	419	420	373	145	224	90	29	29
26	26	27	27	27	31	32	100	490	580	347	414	418	333	136	227	91	29	29
27	26	27	27	27	31	32	134	577	533	425	422	422	349	314	228	91	30	29
28	26	27	27	27	31	32	196	577	406	360	427	418	364	112	222	90	29	30
29	26	27	27	27	31	32	319	513	501	275	433	431	345	117	233	93	29	30
30	26	27	27	27	31	32	339	524	242	398	434							
31	26	27	27	27	31	32	391	506	366	240	441							
33	26	27	27	27	31	32	341	492	476	137	429	430	381	103	273	102	29	30
34	26	27	27	28	30	31	354	475	455	378	426	439	383	124	267	102	30	30
35	26	27	27	28	30	31	340	490	403	373	413	413	392	122	266	99	30	30
38	26	27	27	28	30	31	335	377	393	517	420	430	387	120	270	87	29	30
40	26	27	27	28	30	30	301	514	401	461	383	391	366	110	151	63	30	30

Note : A = T prior to water scrubber

B = T after water scrubber

C = T at rotameter

D = actual height of fuel

Table A-23 Data using corn cobs (gas flow rate
35 Ncu.m./hr)

Date	Run No. CN4
Room temperature (°C)	30
Air moisture (% relative humidity)	61
Air flow rate (Ncu.m./hr)	26.45
Gas flow rate (Ncu.m/hr)	35
Fuel weight (kgs.)	2.0
Fuel moisture content (% wt)	5.95
Experimental time (min.)	40
Weight of char and ash (kgs.)	0.80
% fixed carbon in char and ash	

Gas composition vs. Time

Time	CO	H ₂	CH ₄	CO ₂	O ₂	N ₂
5	9.2	10.5	1.89	7.86	6.12	64.43
10	9.32	11.36	3.25	8.25	6.13	61.69
15	9.72	11.67	3.47	9.05	6.12	59.97
20	11.98	13.48	2.59	9.45	6.35	57.00
25	12.51	13.87	2.02	8.85	6.53	56.22
30	8.54	12.43	2.15	7.95	6.02	62.91
Avg	10.48	12.37	2.67	8.70	6.24	59.71

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TABLE 23 (CONT.)

DRY COB ED HEIGHT LINE	TEMPERATURE V.S. TIME																		
	123	115	105	95	85	75	65	55	45	35	25	15	10	5	1	-3	a	b	c
0	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
1	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
2	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
3	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
4	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
5	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
6	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
7	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
8	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
9	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
10	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
11	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
12	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
13	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
14	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
15	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
16	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
17	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
18	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
19	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
20	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
21	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
22	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
23	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
24	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
25	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
26	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
27	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
28	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
29	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
31	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
32	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
33	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
34	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
35	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
36	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
37	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
38	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
39	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30
40	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30	30

Note : A = T prior to water scrubber

B = T after water scrubber

C = T at rotameter

D = actual height of fuel

ANNEX 2

A THERMODYNAMIC MODEL OF THE GASIFICATION OF CARBON

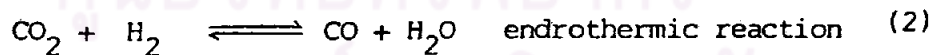
Gasification of carbon occurs when solid carbon particles subjected to heat come in direct contact with a "blast" of gas made up for example in the case of air gasification of oxygen, water, nitrogen and carbon dioxide. A set of reaction occurs between the carbon particles and the blast gases and the following additional gases are produced: carbon monoxide, hydrogen, methane and other hydrocarbons. In all practical cases this process of gasification will take place in a situation where there is excess of carbon, for example during cocurrent downdraft gasification of biomass where some unreacted carbon particles exit at the grate.

From previous theoretical work on coal gasification which are too numerous to mention, Gumz summarized the comprehension of the coal gasification process by indicating that the major chemical reactions could be summarized by

- (1) Combustion of carbon in oxidation zone:



- (2) Water shift reaction



- (3) Methane formation



This model takes into account the heterogeneous equilibria of CO_2 , H_2O , CH_4 , CO and H_2 with carbon present.

At equilibrium, the kinetic rate constants for equation (1),

(2), (3) are

$$K_{PB} = (v_{\text{CO}}^2 / v_{\text{CO}_2}) P \quad (4)$$

$$K_{PW} = (v_{\text{H}_2} * v_{\text{CO}}) / v_{\text{H}_2\text{O}} \quad (5)$$

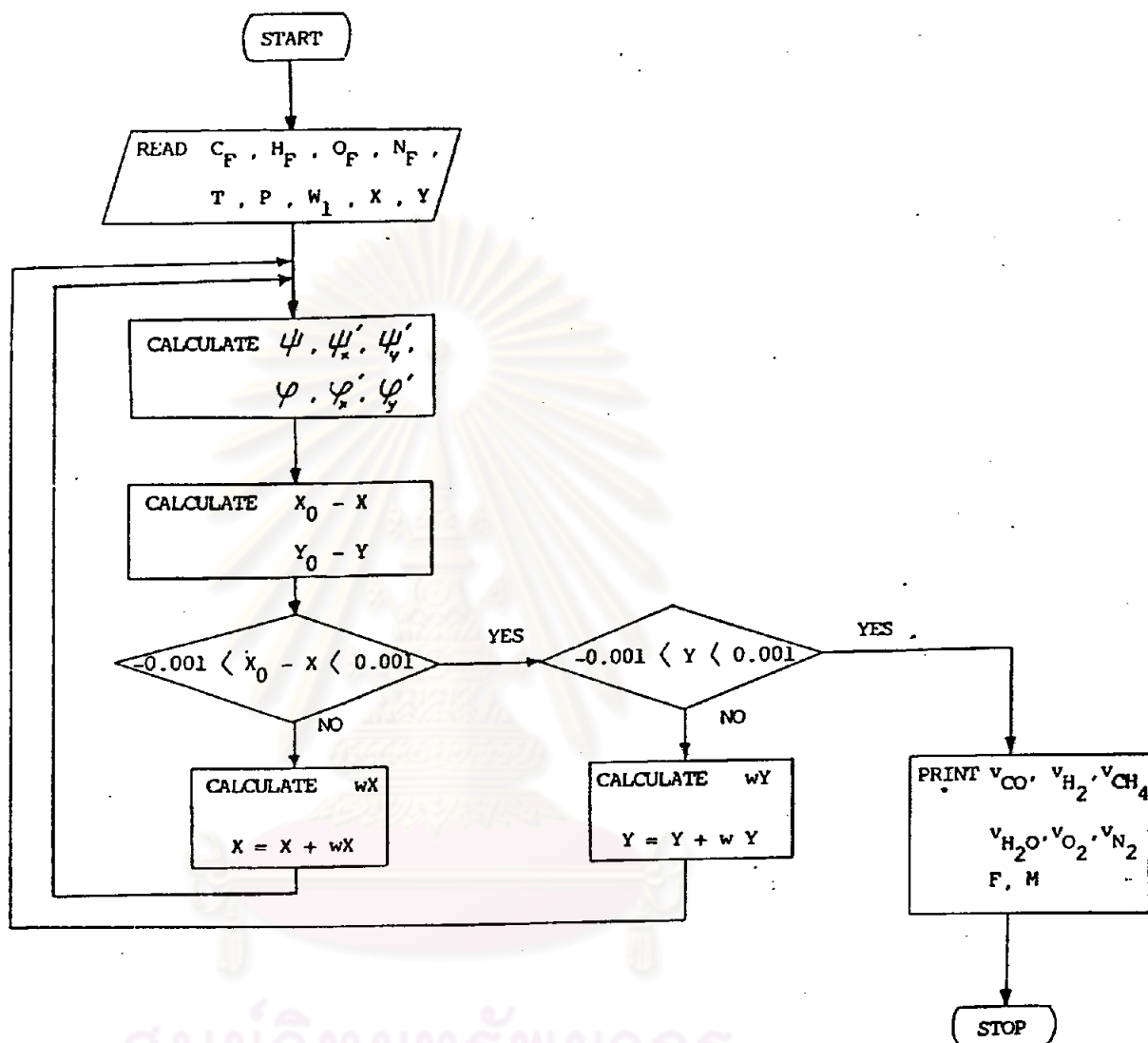


FIGURE A2-1 COMPUTER FLOW DIAGRAM FOR THERMODYNAMIC MODEL

$$K_{P_M} = V_{CH_4} / (V_{H_2}) \quad (6)$$

The product gases composition can be predicted from equations (4),(5),(6) with the help of elementary mass balance, e.g., carbon, oxygen, hydrogen and nitrogen balances as follows.

Carbon balance:

$$FC_F + MC_M = V_{CO} + V_{CO_2} + V_{CH_4} \quad (7)$$

$$\text{where } C_F = 22.416/12.01 = 1.866 \text{ C}$$

Hydrogen balance:

$$FH_F + MH_M = V_{H_2} + V_{H_2O} + 2V_{CH_4} \quad (8)$$

$$\begin{aligned} \text{where } H_F &= 22.416/2.016 \text{ h} + 22.416/18.016 * w \\ &= 18.121 \text{ h} + 1.244 \text{ w} \end{aligned}$$

Oxygen balance:

$$FO_F + MO_M = 0.5V_{CO} + V_{CO_2} + 0.5V_{H_2O} \quad (9)$$

$$\begin{aligned} \text{where } C_F &= 22.416/32.00 \text{ O} + 22.416/36.036 \text{ w} \\ &= 0.7005 \text{ O} + 0.6221 \text{ W} \end{aligned}$$

Nitrogen balance:

$$FN_F + MN_M = V_{N_2} \quad (10)$$

$$\text{where } N = 22.416/28.016 \text{ n} = 0.8001 \text{ n}$$

Overall elementary balance:

$$V_{CO} + V_{CO_2} + V_{H_2} + V_{H_2O} + V_{CH_4} + V_{N_2} = 1 \quad (11)$$

To solve equations (4) to (11) for the following unknowns first assume value for two unknowns, e.g., V_{CO} and V_{H_2} , then calculate V_{CO_2} , V_{H_2O} , V_{O_2} , V_{N_2} , M using a Newton approximation method

This procedure can be repeated until equation is satisfied. Figure A2-1 shows the flow diagram used.

This model can be simplified by assuming no methane formation in the reduction zone and methane can occur only in the distillation zone.

List of computer program for thremodynamic model.

DLIST

```

10 HOME
11 PRINT "-----"
12 PRINT
13 INPUT "RAW MATERAIL IS...";A$
15 PRINT "-----"
16 PRINT
81 PRINT
100 INPUT "CARBON CONTENT IN FUEL=?";CF
110 CF = CF * 1.866
200 INPUT "HYDROGEN CONTENT IN FUEL=?";H
210 H = H * 11.119
300 INPUT "OXYGEN CONTENT IN FUEL=?";O
310 O = O * .7005
400 INPUT "NITROGEN CONTENT IN FUEL=?";NF
410 NF = NF * .8001
500 INPUT "ESTIMATE EQUILIBRIU TEMPERATURE(K)=?";T
600 INPUT "OPERATE PRESSURE(ATM)=?";P
650 INPUT "MOISTURE CONTENT OF FUEL = ?";W1
660 INPUT "WATER CONTENT IN AIR(TOTAL KGH2O OR KGH2O/HR)=?";A
662 W1 = W1 * 1.244
665 W2 = A * 1.244
680 PRINT "-----"
681 PRINT
685 PRINT "ESTIMATE VCO,VH2"
690 PRINT "-----"
691 PRINT
700 INPUT "ESTIMATE VCO=?";X
800 INPUT "ESTIMATE VH2=?";Y
900 KB = 1 / 10 ^ (3.26730 - 8820.69 / T - .001208714 * T + .153734 * 10 ^ (- 6
) * T ^ 2 + 2.295483 * LOG (T) / LOG (10))
1100 KW = 1 / 10 ^ (- 33.45778 - 4825.986 / T - .00567112 * T + .8255484 * 10 ^
(- 6) * T ^ 2 + 14.51576 * LOG (T) / LOG (10))
1300 KM = 10 ^ (- 13.06361 + 4662.8 / T - 2.09594 * 10 ^ (- 3) * T + .3862 * 1
0 ^ (- 6) * T ^ 2 + 3.034338 * LOG (T) / LOG (10))
1512 PRINT "-----"
1513 PRINT
1514 PRINT "COMPOSITION OF GASIFYING MEDIUM"
1515 PRINT "-----"
1690 PRINT
1691 INPUT "PARTIAL VOLUME OF H2 =?";H2
1692 INPUT "PARTIAL VOLUME OF O2 =?";O1
1693 INPUT "PARTIAL VOLUME OF N2 =?";NM
1694 INPUT "PARTIAL VOLUME OF CO =";G1
1695 INPUT "PARTIAL VOLUME OF CO2 =";G2
1696 INPUT "PARTIAL VOLUME OF H2O =";G3
1697 INPUT "PRATIAL VOLUME OF CH4 =";G4
1698 CM = G1 + G2 + G4
1699 W2 = W2 + G3
1700 PRINT "PLEASE WAIT"
2000 I = 0
2010 I = I + 1
2015 X = X
2020 Y = Y
2060 IF I > 50 THEN GOTO 5100
2100 C1 = X
2200 C2 = P * KB * X ^ 2
2300 C3 = P * KM * Y ^ 2
2320 C4 = P * KW * X * Y
2380 C5 = Y
2390 C6 = C1 + C2 + C3
2500 HF = H + W1
2600 HG = Y + C4 + 2 * C3
2800 HM = H2 + W2
2900 OF = O + .5 * W1

```

```

3000 DM = D1 + .5 * W2
3100 OG = .5 * X + C2 + .5 * C4
3110 N = ((CG * OM - CM * OG) * NF) + ((CF * OG - CG * OF) * NM) / (CF * OM -
CM * OF)
3120 F = (CG * OM - CM * OG) / (CF * OM - CM * OF)
3130 M = (CF * OG - CG * OF) / (CF * OM - CM * OF)
3200 A2 = 1 + 1 * (OM * NF - .5 * CM * NF + .5 * CF * NM - OF * NM) / (CF * OM -
CM * OF)
3300 B2 = 1 + 1 * (OM * NF - CM * NF + CF * NM - OF * NM) / (CF * OM - CM * OF)
3400 D2 = 1 - 1 * (.5 * CM * NF - .5 * CF * NM) / (CF * OM - CM * OF)
3500 E2 = 1 + 1 * (CM * NF - OF * NM) / (CF * OM - CM * OF)
3600 S = A2 * X + B2 * C2 + Y + D2 * C4 + E2 * C3 - 1
3700 SX = A2 + 2 * B2 * C2 / X + D2 * C4 / X
3800 SY = 1 + D2 * C4 / Y + 2 * E2 * C3 / Y
3900 A3 = 1 * (OM * HF - .5 * CM * HF + .5 * CF * HM - OF * HM) / (CF * OM - CM
* OF)
4000 B3 = 1 * (OM * HF - CM * HF + CF * HM - OF * HM) / (CF * OM - CM * OF)
4100 D3 = 1 + 1 * (.5 * CM * HF - .5 * CF * HM) / (CF * OM - CM * OF)
4200 E3 = 2 - 1 * (OM * HF - OF * HM) / (CF * OM - CM * OF)
4400 R = Y + D3 * C4 + E3 * C3 - A3 * X - B3 * C2
4500 RX = D3 * C4 / X - A3 - 2 * B3 * C2 / X
4600 RY = 1 + D3 * C4 / Y + 2 * E3 * C3 / Y
4700 DX = (R * SY - S * RY) / (SX * RY - SY * RX)
4800 DY = (S * RX - R * SX) / (SX * RY - SY * RX)
4915 IF ABS (DX) > .001 THEN X = X + DX: GOTO 2010
5018 IF ABS (DY) > .001 THEN Y = Y + DY: GOTO 2010
5100 HOME
5102 PRINT " THE COMPOSITION OF PRODUCER GAS."
5110 PRINT "-----"
5115 PRINT "I=";I
5120 PRINT "          VCO = ";X
5130 PRINT "          VH2 = ";Y
5140 PRINT "          VCO2 = ";C2
5150 PRINT "          VCH4 = ";C3
5160 PRINT "          VH2O = ";C4
5170 PRINT "          VN2 = ";N
5180 PRINT "          M = ";M
5190 PRINT "          F = ";F
5200 PRINT "-----"
5300 END

```

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IRON

RAW MATERIAL IS...?1

CARBON CONTENT IN FUEL=?? .525
HYDROGEN CONTENT IN FUEL=?? .1375
OXYGEN CONTENT IN FUEL=?? .3375
NITROGEN CONTENT IN FUEL=??0
ESTIMATE EQUILIBRIUM TEMPERATURE(K)=??973
OPERATE PRESSURE(ATM)=??1
MOISTURE CONTENT OF FUEL = ??0
WATER CONTENT IN AIR(TOTAL KGH2O OR K6H2O/HR)=??0

ESTIMATE VCD, VH2

ESTIMATE VH2=?? .3
ESTIMATE VH2=?? .3

COMPOSITION OF GASIFYING MEDIUM

PARTIAL VOLUME OF H2 =??0
PARTIAL VOLUME OF O2 =?? .21
PARTIAL VOLUME OF N2 =?? .79
PARTIAL VOLUME OF CO =?0
PARTIAL VOLUME OF CO2 =?0
PARTIAL VOLUME OF H2O =?0
PARTIAL VOLUME OF CH4 =?0
PLEASE WAIT
THE COMPOSITION OF PRODUCER GAS.

I=4

VCD = .203598186
VH2 = .331153873
VCO2 = .0386435676
VCH4 = .014516444
VH2O = .0405683593
VN2 = .371538628
M = .470302061
F = .262091765

Example calculation use wood at reduction temperature =973 K
1 atm.

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ANNEX 3

STRATIFIED DOWNDRAFT BIOMASS GASIFIER MODEL

This model was developed to determine the time and distance required for flaming pyrolysis (a term used by T.B. Reed to denote the oxidation zone of a gasifier) and char/gas reaction that occurs in cocurrent downdraft gasifiers.

In a typical cocurrent downdraft gasifiers the two significant reaction zones are shown in figure.1

From figure.1 air and biomass enter the reactor together at the top and travel together to the "flaming pyrolysis" zone where the pyrolysis gases and tars are oxidized as they emerge from each particle. At the end of this zone 90 % of the biomass is believed to be consumed. The gases at temperatures of 900-1000 C react with remaining 10% of the biomass which has now been turned into char in an "adiabatic gas/char reaction" zone reducing the temperature to 700-800 C. It is to be noted that the temperature mentioned here were temperature reported for high density biomass such as wood.

T.B.Reed defines "Flaming Combustion" as the initial phase of biomass combustion during which the volatile matter released by heat burns in air thereby releasing more heat to continue the process until pyrolysis is complete. Thus after this process only charcoal remains. This charcoal may continue to burn in "glowing combustion" provided that there is sufficient heat flux or insulation to maintain the surface temperature high. On the other hand "Flaming Pyrolysis" indicates the process of air first passing over burning biomass causing very rapid pyrolysis, and the produced tars and oils

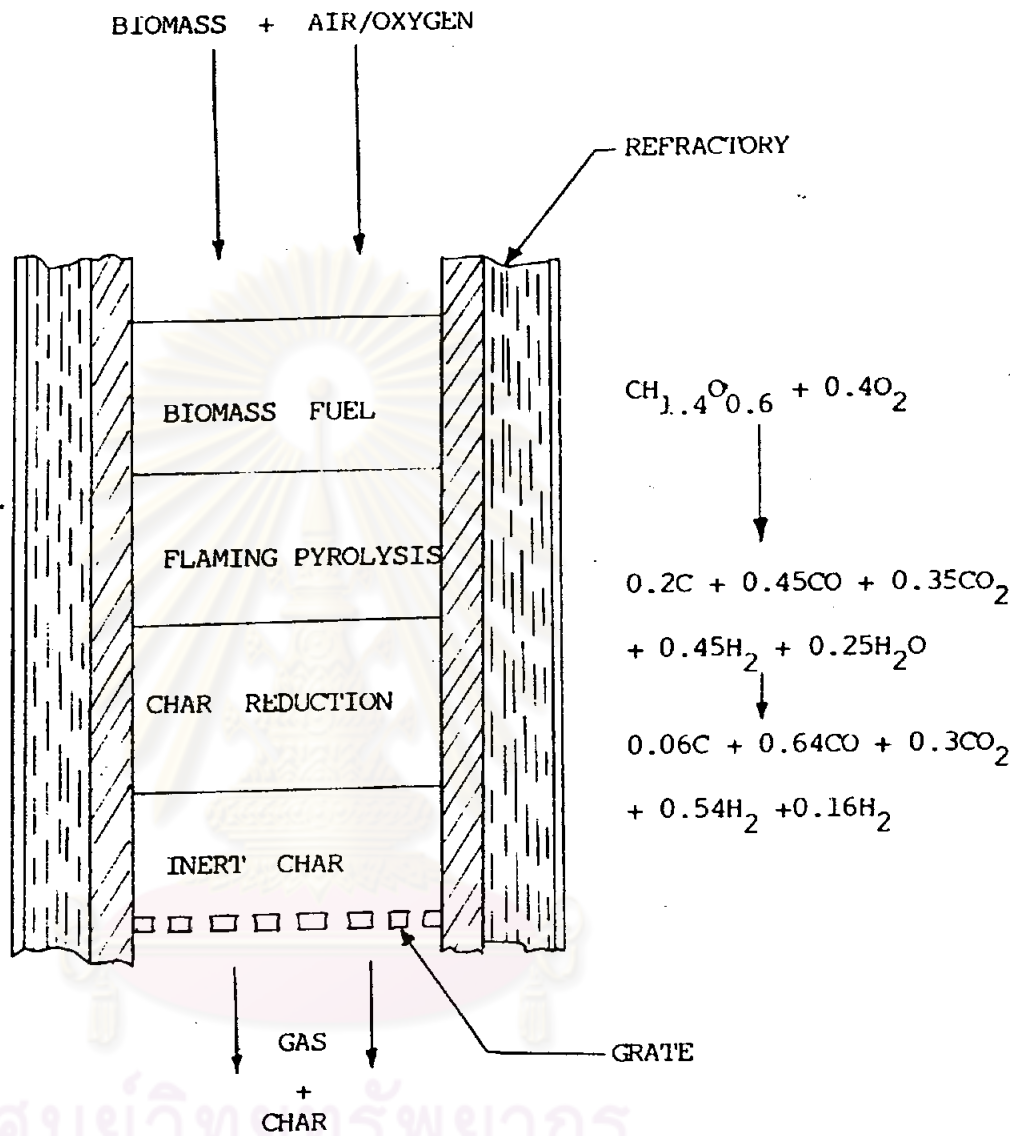
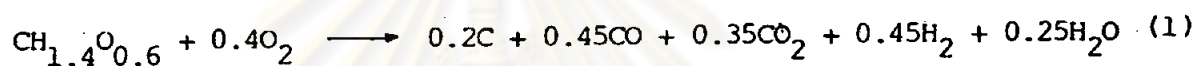


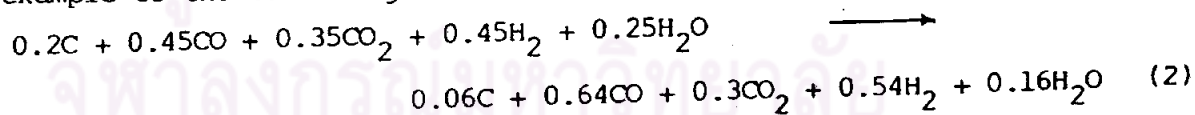
FIGURE 1 SCHEMATIC OF STRATIFIED DOWNDRAFT GASIFIER SHOWING CHEMICAL REACTION (1)

being consumed to provide the energy for further pyrolysis. An important aspect of flaming pyrolysis is that on one hand one has flow of pyrolysis gases radially out of the particle forming a boundary layer around the biomass pellet and on the other hand heat transfer by conduction and radiation from outside into the pellet. These two phenomena being interrelated we thus have a flaming pyrolysis zone "buffered" around 800-900 C

When air and biomass enter the tube together and biomass begins to react in the flaming pyrolysis zone the following equation may describe what happens there

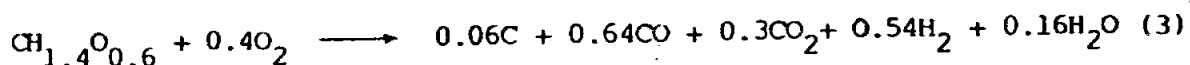


The gas composition varies through the flaming pyrolysis region from mostly air near interface 3 to a partially reduced gas at interface 2. The presence of excess oxygen in this zone relative to that required for complete gasification accounts for the almost total destruction of volatiles and the relatively high temperatures. After flaming combustion is complete there remain 0.2 moles (or about 10 % wt) of biomass as charcoal. This charcoal is now free to react with the flaming pyrolysis gases in the char reduction zone according for example to the following reaction



The final gas composition leaving the char reduction zone is quite close to that found in air stratified downdraft gasifiers (by assuming 1-3 % CH₄ and N₂).

Finally the gases enter the inert char zone where there are no further reactions with the char because of equilibrium. Equations (1) and (2) can be added to give the over all gasification equations:



During flaming combustion there are complex heat and mass transfer phenomena occurring as the thermal wave moves from the biomass surface of the center of the particles. An equation was developed to calculate the time, t_{fc} , required to complete flaming combustion of a particle in a furnace maintained at constant temperature. The data obtained was correlated with the size, shape, density, temperature and moisture content. The equation obtained is as follows :

$$t_{fc} \text{ (min)} = 0.12F_d A(1+0.61A)F_s (1+1.76F_m) \exp(2200/T) \quad (4)$$

Where F_d = density of particle

F_s = sphericity of the particle given by
 $= (4.836(v^2/S^3))^{1/3}$

S = surface area of the particle calculated from its dimensions

F_m = moisture fraction (dry basis)

T = temperature of the furnace around the particle

A = characteristic size and $A = (V)^{1/3}$

The time required for flaming combustion is expected to be close to that required for flaming pyrolysis under the same conditions but a major difference is that no oxygen is available for combustion during the latter half of the flaming pyrolysis time. Reed (1) modified the Huff equation (equation 4) to include the oxygen effect giving:

$$t_{fp} \text{ (min)} = 0.21F_d A(1+0.61A)F_s (1+1.76F_m) \exp(477/rt)/(1+3.4F_o) \quad (5)$$

And the pyrolysis length can be calculated from

$$\text{pyrolysis length } (l_p) = v_f * t_{fp}$$

where

$$v_f = m/F_d(1-F_v)$$

F_d = void fraction

m = feed rate $\text{ton} / \text{m}^2 \text{-hr}$ or a power

rate of $P \text{ kW/m}^2$ on a fuel of $H \text{ kJ/kg}$

V_f = velocity of bed move m/hr

Reed (4) developed a method to calculate t_{fp} by using a concept of heat of pyrolysis at T_s and used water as thermal tracer giving the following result

Time for pyrolysis = Energy Required for pyrolysis / Heat Supply

$$V = \frac{\text{rate } m}{F_d(1-F_v)} \quad \text{m/hr} \quad (6)$$

V = volume of the biomass particle

A = the surface area of biomass

q = heat transfer per unit area and its in the ranges from 3 -13 W / cm^2 ()

$$h_w = h_w(T) = C_p(d)(100 - T_o) + C_p(g)(T_s - 100)$$

where $C_p(1)$ = average heat capacity for steam at between 100 C and the temperature T_s

Reed suggested that the char conversion be considered effectively complete when the temperature drops to 850 C at the end of 100 sec.

e.g. Effectiveness for Char Conversion = Constant

$$t_c = 100$$

At this temperature the reaction rate has dropped to a very low value. The gasification zone length l_g will then be

$$l_g = t_c * V_f \quad (8)$$

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ANNEX 4

Producer Gas Analysis Methods

1. Analysis of CO, H₂, CH₄, N₂, O₂ by gas chromatography

For the experiments conducted a Variant 3400 gas chromatograph was used with the following conditions to analyse CO, H₂, CH₄, N₂ and O₂

column used	:	molecular sieve 5A
carrier gas	:	Argon
temperature of column	:	60 C
temperature of detector	:	60 C
filament temperature	:	90 C
current	:	104 mA
polarity	:	negative
attenuation for H ₂	:	64
O ₂	:	32
N ₂	:	64
CH ₄	:	4
CO	:	4
plotter sensitivity	:	0.05 %
offset	:	10 %
paper speed	:	1.0 cm / min.
volume of gas sample used	:	0.5 ml

2. Analysis of CO₂ by orsat apparatus

As the gas chromatograph used has only a single column filled

with molecular sieve 5A which absorb CO₂ and water, it could used to analyse CO₂.

An orsat analysis was used to determine CO₂ concentration in the producer gas. A 40 volume percent solution of Potassium Hydroxide was used to absorb CO₂ (absorbing power is 40 ml CO₂ per ml of liquid solution of KOH at the above concentration).



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ANNEX 5

Proximate Analysis Determination Procedure

The proximate analysis classified the fuels in terms of its moisture (M), volatile matter (VM), ash (A) and fixed carbon (by difference) using standard ASTM tests.

The moisture content is analyse by weight difference between the sample (100 g and 60 mesh size fuel) and the preheated sample (which is 100 g sample preheated at 105 ± 5 C for two hours).

Volatile matter (ASTM 3175 - 73) is determined by establishing the loss in weight resulting from heating 1 gm of 60 mesh dry fuel in nickel-chromium crucible in a muffle furnace at 950 ± 20 C for 3 min.

Ash (ASTM D 3174-73) is determine by weighing the residue remaining after burning the biomass (1 gm, 60 mesh) in a muffle furnace at 700-750 C for hr.

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BIOGRAPHY

Miss Onranong Nguanprasert was born on November 20, 1958 at Bangkok. She received a Bachelor Degree of Science from Chaingmai University in 1981.



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