CHAPTER V

DISCUSSION OF RESULTS

The operation of the batch gas producer was aimed at studying the technical possibility of gasifying several kinds of biomass shredds in a simple manner. The main questions of interest are whether the gas producer can be ignited, once ignited whether it convert the fuel into a producer gas, what the efficiency of conversion of the batch of solid fuel into a gas is, what the problems of mechanical flow of low density fuels are, then what is the influence of water content of both air and fuel. One question left out of this study was the quantitative amount of tars and particulates in the exit gas, a point of importance in the study of gas cleanliness, but a point of less importance in the study of gas calorific value and the general operation of the gas producer itself.

5.1 Ignition of the gas producer

As mentionned in the previous section the ignition of the batch gasifier was based on starting combustion at the bottom of the empty open top gasifier with air flowing using a few handfull of diesel soaked biomass shreds. It was found in this study that ignition was successful for some fuels but not successful for other fuels. Some fuels would ignite to some extent but the fire would not propagate in a radial direction or vertically into the fuel batch placed on top of the ignition zone. The fuels for which ignition was successful and those for which ignition was not

successful are listed in the table 5.1.

It is to be noted that the biomass fuels mentionned in table 5.1 which were unsuccessfully ignited in the bottom of the gasifier had two related characteristics in common. The first characteristic was the presence of excessive amounts of fines in each fuel including the carbonized round rice hull pellets which disintegrated into fines. The second characteristic was the high pressure drop caused by the presence of fines in such fuels, however the high pressure drops could be remedied by increasing the speed of the suction fan.

The main problem related to unsuccessful ignitions was the inability of the flame to propagate itself into unburned fuel. As such fuels were made up of high percentage of fines it is believed that the presence of fines do hamper flame propagation. However no additional investigations of this phenomena were made.

It should be noted that the results as presented in table 5.1 are with an open-top condition for which ignition temperatures are expected to be lowest. The other extreme could be to seal the open-top and let air come in through a smaller ignition port thereby increasing markedly the ignition temperature, however this experiment was not performed as the gasifier was not desiged for a tuyered operation.

Biomass fuels successfully ignited in the bottom of the gasifier	Biomass fuels unsuccessfully ignited in the bottom of the gasifier
Rice hulls Corn cob pieces Wood shaving Bagasse as received : fiber & fines (ignition was possible but difficult) Bagasse fiber Water hyacinth stems	Shredded rice hulls[*] Corn cob fines[*] Sawdust[*] Bagasse fines[*] Carbonized round rice hull pellets

* : it is to be noted that if the gasifier is ignited successfully using proper fuels and these four fuels are added on top later, only shredded rice hulls will gasify successfully, the other three materials will cause the fire zone to die out.

Table 5.1 Ignition test results on biomass fuel.

5.2 Producer gas calorific content

The most important question surrounding the utilisation of this batch gasifier was whether the equipment could satisfactorily convert biomass shreds into a producer gas of comparable calorific value as a traditional charcoal gasifer gas, which normally claims a high calorific content.

From selected data of various biomass tested the compositions and calorific contents of gas produced are presented in the table 5.2 for comparison with other charcoal gasification data.

The overall results between producer gas from biomass shredds using our design and producer gas obtained from conventional downdraft charcoal gasifier indicate the following main points.

5.2.1 Overall gas calorific content : the producer gas calorific contents of all shredded biomass tests were generally lower than the calorific content of a good producer gas converted from charcoal in a traditional downdraft unit. For the best runs using shredded biomass the calorific contents obtained compared to a charcoal gasifier run made by I.E. Cruz (9) are of the order of 60 percent up to the gas calorific content of the above mentioned experiment with charcoal. On some runs with shredded biomass the gas calorific content sometimes exceeded the above mentionned charcoal data due to a significant contribution of methane present.

5.2.2 Methane content : the gas obtained from the various biomass shreds are particularly richer in methane than gas from charcoal . One would tend to assume that the methane is produced by pyrolysis reaction above the combustion zone and pass through both the combustion zone and the reduction zone and a significant amount

Biomass	H_2	CH_4	Volume % CO	CO_2	N_2	O_2	A	CO/CO_2
Rice hulls(1)	8.06	1.59	13.86	6.42	61	9.07	815.77	2.16
Shredded rice hulls(2)	9.78	1.77	9.4	10.11	62.85	6.09	750.67	0.93
Corn cobs (size 1)(3)	12.64	2.47	12.41	8.17	56.55	7.76	995.45	1.52
Corn cobs (size 2)(4)	11.1	3	12.7	11.5	59.2	2.5	1007.69	1.1
Corn cobs (size 3)(5)	9.3	1.7	10.4	13.2	60.6	4.8	759.57	0.79
Corn cobs (size 3)(6)	9.3	1.7	10.4	13.2	60.6	4.8	759.57	0.79
Corn cobs (size 4)(7)	8.9	2.9	9.8	14.8	61.4	2.2	843.49	0.66
Bagasse fiber (8)	9.32	3.46	12.45	17.23	52.23	5.31	989.64	0.72
Wood shaving (9)	5.18	7.73	15.54	10.6	52.75	8.2	1363.19	1.45
Water hyacinth stems(10)	10	2.68	9.03	10.95	58.95	8.39	832.84	0.82
Charcoal(11)	13.86	0.1	27.36	7.17	51.51	0	1258.52	3.82
Charcoal(12)	12.54	1.02	23	12.12	51.32	0	1174.17	1.9
Rice hulls(13)	11.3	2.6	19	12.7	54.4	0.2	1165.97	1.5
Rice hulls(14)	14.8	3.3	15.4	13.3	53	0.2	1230.64	1.16

Note : A -Calorific   content (KCAL/SCM)

Gross heating value   of H2 =   3050   KCAL/SCM
CH4 =   9520   KCAL/SCM
CO =   3020   KCAL/SCM

(1) – moisture 6.2% wt., air flow rate 19.5 Nm^3/h, 75% R.H. at $T_{air}=30$ C

(2) – moisture 5.2% wt., air flow rate 19.63 Nm^3/h, 94% R.H. at $T_{air}=30$ C

(3) – moisture 5.94%wt., air flow rate 26.45 Nm^3/h, 72%R.H. at $T_{air}=30$ C

(4) – moisture 5.14%wt., air flow rate 32.9 Nm^3/h, 69.5%R.H.at $T_{air}=29$ C

(5) – moisture 7.03%wt., air flow rate 31.4 Nm^3/h 72%R.H. at $T_{air}=30$ C

(6) – moisture 5.14%wt., air flow rate 31.5 Nm^3/h, 74.5%R.H.at $T_{air}=29$ C

(7) – moisture 6.8 %wt., air flow rate 17.41 Nm^3/h 69% R.H. at $T_{air}=28$ C

(8) – moisture 6.01%wt., air flow rate 17.67 Nm^3/h, 72.5%R.H.at $T_{air}=30$ C

(9) – moisture 5.8 %wt. , air flow rate 17.38 Nm^3/h, 67%R.H. at $T_{air}=29$ C

(10)– moisture 5.25%wt., air flow rate 17.53 Nm^3/h, 71.5%R.H.at $T_{air}=28$ C

(11)– from Dr. Cruz (11) experiment using downdraft gasifier with throat.

(12)– from Dr. Woraphat experiment using 1 Hp downdraft gasifier with throat

(13)– from Dr. Kaupp(2) experiment using 15 cm. diameter stratified open top gasifier.

(14)–experimental data from 1 meter diameter Chinese gasifier(4).

TABLE 5.2   SELECTED DATA OF VARIOUS BIOMASS COMPARED WITH OTHER

CHARCOAL AND RICE HULLS GASIFICATION DATA.

is left unreacted in the exiting producer gas. Another assumption is that the methanization reaction between carbon and hydrogen which produces methane is especially high for uncarbonized fuel that this reaction is the main cause for methane. In addition to this assumption a small part of methane produced could come from reaction between carbon monoxide and hydrogen yielding methane and water, however this reaction is highest at temperatures around 1200 C and this reaction is negligible at temperature of about 800 C in this reduction zone as can be seen from the equilibrium constant of this last reaction at 800 C shown in annex 3. It is of course also possible that both mechanisms play a role in the production of methane.

In connection with methane contents in the producer gas it is noted that the producer gas obtained in this study contained some oxygen, while producer gas from conventional charcoal gasifiers contains none. Although the presence of oxygen will be the object of a subsequent section, we can initially assume that we have a constant amount of oxygen passing through both combustion and reduction zones unreacted. If this hypothesis is valid then the chances are high that the presence of methane is in part due to unreacted passages of volatiles through the reactor.

It must noted that methane has a calorific content which is three times that of either carbon monoxide or hydrogen and increases significantly gas calorific content. On the other hand if we assume that most of the methane present in the producer gas is pyrolysis produced methane which has survived passage through the combustion zone and the reduction zone, then this would mean that the producer gas obtained also contains other volatiles which have also survived

the reaction zones. This last prospect of having a producer gas which contains volatiles which eventually condense into tars is an undesired prospect in most gasifier applications, particularly for internal combustion engine applications. In this study however no quantitative analysis of tar content was made.

5.2.3 Carbon monoxide content

The data presented in table 5.2 indicates a carbon monoxide concentration ranging from 9 to 15.5 percent which is well below the 27 percent concentration in ordinary charcoal gasifiers as obtained from Cruz (9). For two other studies dealing with open top gasifiers using rice hull (3,8) the carbon monoxide concentration was also low in the range of 15 to 19 percent. There are two possible causes of this low concentration in our system : the physical characteristics of the fuel being unfavorable to gasification, and the operation of gasifier with an open top which diffuses the air blast and lower oxidation temperatures.

Data of carbon monoxide concentration in ordinary gasifiers equipped with tuyeres and using wood and charcoal , indicates that carbon monoxide levels in the producer gas are high for both biomass fuels. Thus the level of carbonization is not a single factor contributing to low carbon monoxide concentrations.

The physical characteristics of the fuel does play a role in the transfer of heat. Shredded biomass must transfer heat to other shredded biomass which propagate combustion. This propagation happens with varying difficulty in the following order (by order of increasing difficulty of combustion propagation : type I biomass which includes bagasse fibers, cut water hyacinth stems; type II biomass consist of four sizes of hammer milled corn cobs, wood sha-

vings; type III biomass consists of rice hulls; type IV biomass in which it is very difficult to propagate combustion and consist of powdered rice hulls, sawdust, bagasse fines. The data presented in the table 5.2 does not however correlate carbon monoxide concentration and hydrogen concentration with difficuly of combustion. Such concentrations probably relate to the physical characteristics of the fuel and may also relate to other phenomena such as temperature levels in the bed. However the results to be presented later indicate that maximum temperature levels in the gas producer do not show strong differences between one fuel to another.

The operation of a gasifier with an open top is the second possible cause of low carbon monoxide concentration. During the course of this study tests were being conducted by the other researchers on an ordinary tuyered charcoal gasifier used to produce electricity. It was found during tests with the top hatch open and closed that operation with the hatch open resulted in loss of power in the range of 20 percent. Thus the operation of a gasifier with an open top does seem to result in a different operating condition. There are at least two effects that may result from the operation of a gasifier with an open top. The first effect could be an increase in oxygen through the top of the gasifier. The second effect could be a lowering in the temperature of combustion due to unconcentrated combustion flame in the oxidation zone.

The first effect of increased oxygen availability due to the open top perhaps exists in the region above the combustion zone. As the gas flow rate through the oxidation and reduction zones is controlled by a suction fan regulator additional oxygen cannot pass

through. At this stage there is no reason to feel that increased oxygen availability due to the open top is the primary reason for low CO content in the gases.

The second effect of the open top being responsible for a decrease in CO content when compared to an ordinary gasifier with tuyeres is more plausible. It is to be noted that if a welding apparatus is properly tuned with the right amount of acetylene and oxygen the flame temperature will be highest. When no oxygen is supplied the flame will rely on outside air and the flame temperature will be lowest. Likewise in a gasifier, for a given air flow rate the size of the tuyere will determine temperatures in the combustion zone. The smaller the tuyere diameter the higher the temperature. The temperatures obtained in our open-top system as will be presented later are of the order of only 500 C in the combustion zone. However temperatures obtained in gasifiers equipped with tuyeres are generally reported to be several hundred degrees higher. The heat generated in the combustion zone is the radiant energy source for the reduction zone and intensity of such radiant energy should inevitably effect the production of CO.

5.2.4 Oxygen content

The data presented in table 5.2 indicates that the producer gas contains abnormaly high O_2 content ranging up to 9 percent by volume percentages. Initially this was thought of as a leak between the gas producer and the gas sampling port downstream from the water scrubber but leak tests on the downstream piping from the gas producer by applying soap water along the piping system proved negative. Thus it had to be concluded that the presence of O_2 was indeed due to

unreacted passage of O_2 through the gasifier.

Reines (16) did gasification work using an open top gasifier also and a range of air flux of equivalent to 4.78 - 6.62 Ncu.m./h for a 15 cm diameter pipe) with a short fuel height above the combustion zone. Personal communications with Dr. Reines indicated that he did also find O_2 in his producer gas. One explanation also shared by Reines was that some oxygen passed through the reaction zones without being reacted itself. Reines cited the possibility that air may flow down in the space between the tubular reactor and the slightly contracted biomass shredds and thus exit without having contacted the reaction zones.

Another factor which may play an important role in the concentration of oxygen in the producer gas, if we assume the reason being a lack of reactivity in both reaction zones, is the flow rate of gas. Kaupp (2) also worked on an open top continuous gasifier using rice hulls as fuel in a system that included a wide open hopper fitted on top of the open core. In the experiments conducted Kaupp (2) does not mention the presence of O_2. However the flow rate ranges used were between 2 and 10 Ncu.m./h for a 15 cm diameter reactor, whereas flow rates used in this study were between 15 to 35 Ncu.m./h also for a 15 cm diameter reactor. It is very possible that the high flow rates used in this study, and thus the small oxygen residence times in the reaction zones contributed to excess of O_2 in the exit gases.

In ordinary tuyered downdraft charcoal gasifiers all the data known including data performed in this laboratory indicated absolutely no oxygen present in the producer gas.
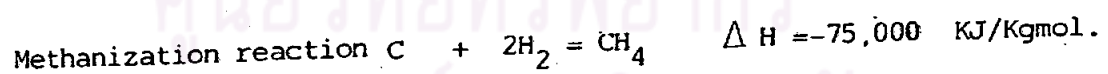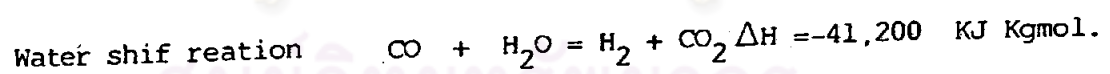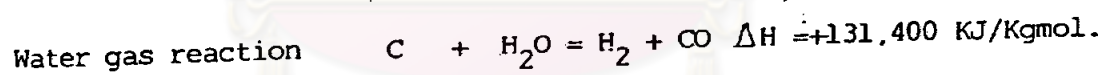
If the presentce of oxygen is to be a permanent feature of the

open top batch gasifer this should cause no great problems during utilization of the producer gas either as a fuel for internal combustion engine or direct combustion in a burner as additional oxygen must eventually be added to the gas. However this is not a desired outcome as the presence of the oxygen somehow indicates inefficient combusion.

5.2.5 Hydrogen content

The hydrogen content of the gas produced by the batch gasifier during the experiments varies between 5 percent to a maximum of 12.64 percent, whereas the hydrogen content of three sets of data using traditional downdraft gasifiers as mentionned in table 5.2 varies between 12.54 - 13.86 percent. Thus the hydrogen is somewhat below expected figures from traditional drowdraft gasifier gas quality.

The significance of lower than expected hydrogen contents is probably difficult to assume from these sets of experiments. Hydrogen formation can be explained by the following reaction.

Water gas reaction $C + H_2O = H_2 + CO$ $\Delta H = +131,400$ KJ/Kgmol.

Water shif reation $CO + H_2O = H_2 + CO_2$ $\Delta H = -41,200$ KJ Kgmol.

Methanization reaction $C + 2H_2 = CH_4$ $\Delta H = -75,000$ KJ/Kgmol.

For reaction in the reduction zone at about 800 C the methanization reaction strongly favors the reverse reaction (8,9,17). For hydrogen to be formed the presence of water is necessary as shown in the water gas reaction and water shift reaction equations. During the experiments conducted a typical run had 5 percent moisture content by weight of fuel (2.5kg batch)or 0.125 kg of water plus 65 percent relative humidity air (at 20 Ncu.m./h for half an hour) at

25C or 0.0215 kg of water/kg dry air = 0.278 kg of water. Thus in a typical run conducted the moisture of air was twice as important as the fuel moisture. It is to be noted that for some runs air moistures up to 98 percent relative humidity were recorded.

As variations of both biomass and humidity were not studied it is difficult to explain the above mentionned hydrogen content of fuel.

5.2.6 Carbon dioxide content

The carbon dioxide content of the gas produced for the selected experiments presented in table 5.2 varied between about 6.5 to 17 percent. In particular the CO/CO_2 ratio varied between a low of 0.66 for corn using charcoal in a traditional tuyered, close top gasifier Cruz (11) obtains a CO/CO_2 rdatio of 3.82.

It is to be noted that the CO/CO_2 gives a measure of CO conversion efficiency. The higher the CO level with respect to CO_2 the better. It is to be noted that Desrosiers (9) simulating the equilibrium concentrations as a function of equivalance ratio (Fig. 5.1) for bone dry wood at 1 atmosphere and indicated that at an equivalance ratio (ER) of 0.25 , in (gasification zone) the CO/CO_2 ratio is above 9.0, and will come down to 1.0 at ER. = 0.7 . Although the simulation does not duplicate the exact conditions of the experiments conducted in this study it would appear that based on CO/CO_2 ratio information the open top gasifier operates at ER values outside the gasification rage. This agree with measured ER values.

5.2.7 Producer gas water content

The water content ofthe producer gas was not determined in this study. The main reason being that we felt that at worst the producer gas would be saturated with moisture and thus the cooling system of

the apparatus used was a gas – water direct contactor. No experimental measurements of moisture contents have been reported in the literature. However based on the assumption that water content in air and in ordinary producer gas is equivalent, and assuming that for one typical run conducted in our apparatus (flow rate of 25 Nm3/h) relative air humidity of 80 % Tair in = 30 C, Tproducer gas out = 50 C wood humidity of 6 % based on dry weight, equivalence ratio equal to one neglecting also the water gas reaction) we obtain an outgoing gas humidity of 100 %. One reported experimental evidence observed of the operation of a wood gasifier in Songkhla Province indicated that water does condense in the cooling tubes which points to the fact that at least wood producer gas can produce water saturated producer gas.

No work has been undertaken to quantitatively measure the water content of producer gas but estimations could be done by assuming additivity of water contents of mixtures if the data for individual gases are available. No work has also be undertaken on engine corrosing due to water saturated producer gas.

5.2.8 Producer gas tar content

The aim of the study did not include a study of tar content in the producer gas. It is to be noted however that tar concentration are known to be higher in open top and gasifiers without throats as against a traditional downdraft close top gasifier with a throat. The study of tar concentrations would have required special equipment which did not exist at the time of this work.

However based on the observations made during this study the following comments may be made on tar content.

1. It was generally observed that whenever the temperature levels in the gasifier were high the tar contents as observed by visual inspection of the cooling water and the rotameter cleanlinesss were low.

2. During gasification of rice hulls on one hand and corn cobs, water hycinth stems, bagasse, and wood shavings on the other hand the tar content was much higher for rice hulls at equivalent temperature levels in the gasifier.

3. During gasification of corn cobs on one hand and water hyacinth stems, bagasse, and wood shavings on the other hand the tar content was higher for corn cobs at equivalent temperature levels in the gasifier.

Whenever temperature levels, that is temperatures in both oxidation and reduction zones are low the biomass volatiles are known from the general understanding of the gasification process of downdraft gasifiers to be able to bypass both reaction zones with more case. Thus one way to reduce tar contents would be to increase general temperature levels in the gasifier. Incrasing bulk densities of the biomass could be one way, adding tuyeres inside the column in addition to the open top could be ways to increase temperature levels.

Another factor related indirectly to tar contents is the particulate content of producer gas. In this work particulate content study was also not an aim. Thus no quantitative study was made. However the batch gasifier design inherently contains a particulate filter at the bottom of the gasifier since the reduction has a tendency to lengthen as reaction proceed and should produce lass particulates. However no data as well as no observations are available to subtantiate this point.

5.3   The   effect of temperatures

In   the experiments conducted temperature profiles along the length of the reactor (actually the temperature at 1 inch from the wall) were recorded systematically as a function of time.   The original   idea   was to   delineate   the various reaction zones   and how they progressed with time up the column, and what their respective local temperatures were.

The temperature data for each run has been reported in annex 1 . A selected number of temperature profiles were drawn and presented in figure 5.1, 5.2, 5.3 .

The effect of biomass moisture levels was studied only in one set of data involving rice hulls as shown in figure 4.2 . However the data was too in conclusive to determine a trend between moisture content and reduction zone temperatures.   It is to be noted that the moles of water coming into the gasifier as air moisture in all experiments in this study is greater than the mole of water contained in the biomass, and thus a control of biomass moisture content also may not be sufficient.

In   most experimental runs performed as shown in figures 5.1, 5.2, 5.3 the temperature profile along the gasifier shows an increase at the grate. The answer could be explained by channeling of oxygen in the annular space between the gasifier outer core and the outer layer of solid fuel which sometimes shrink due to heat. This is an explanation given by Dr. T. Reines (personnal communication with Dr. Worahat).   If this were the case it would mean the existence of secondary combustion at the grate.

The overall comment to be made on the temperature data obtained is that the temperature levels in the gasifier are lower than expected and seem to relate to CO production. Higher reduction zone
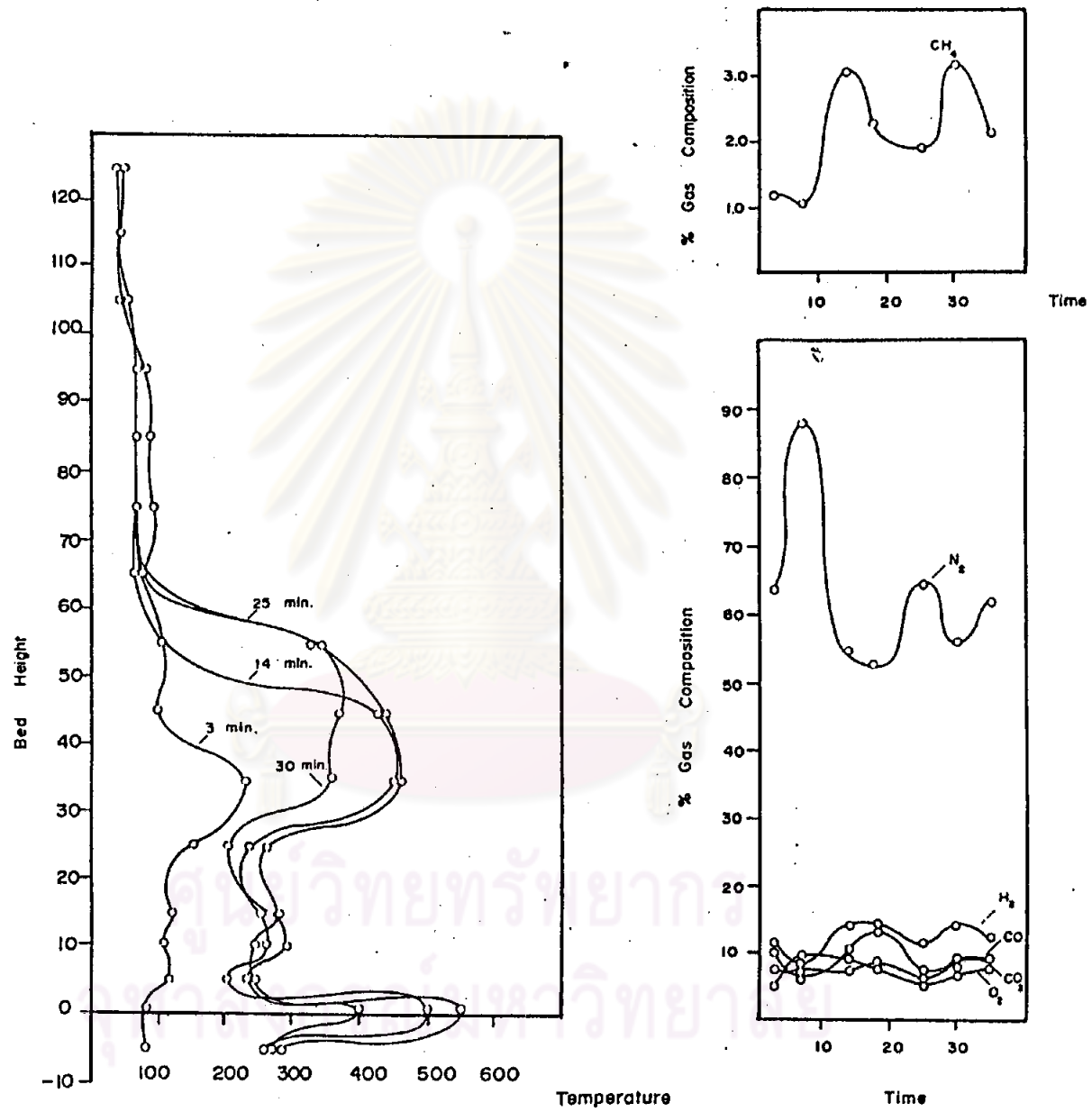
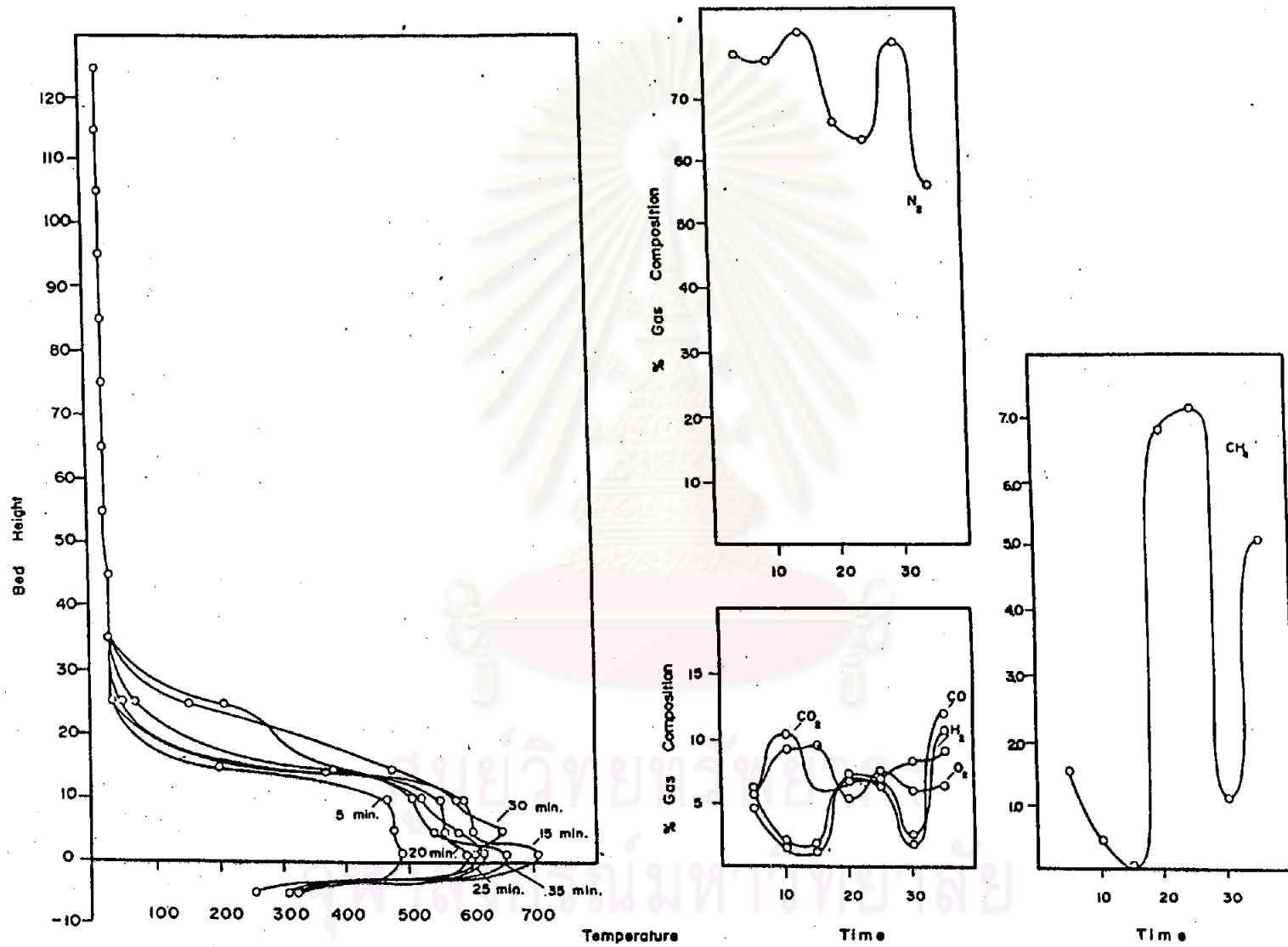FIGURE 5.1   TEMPERATURE vs. BED HEIGHT FOR RICE HULLS (RUN No. RH 4)

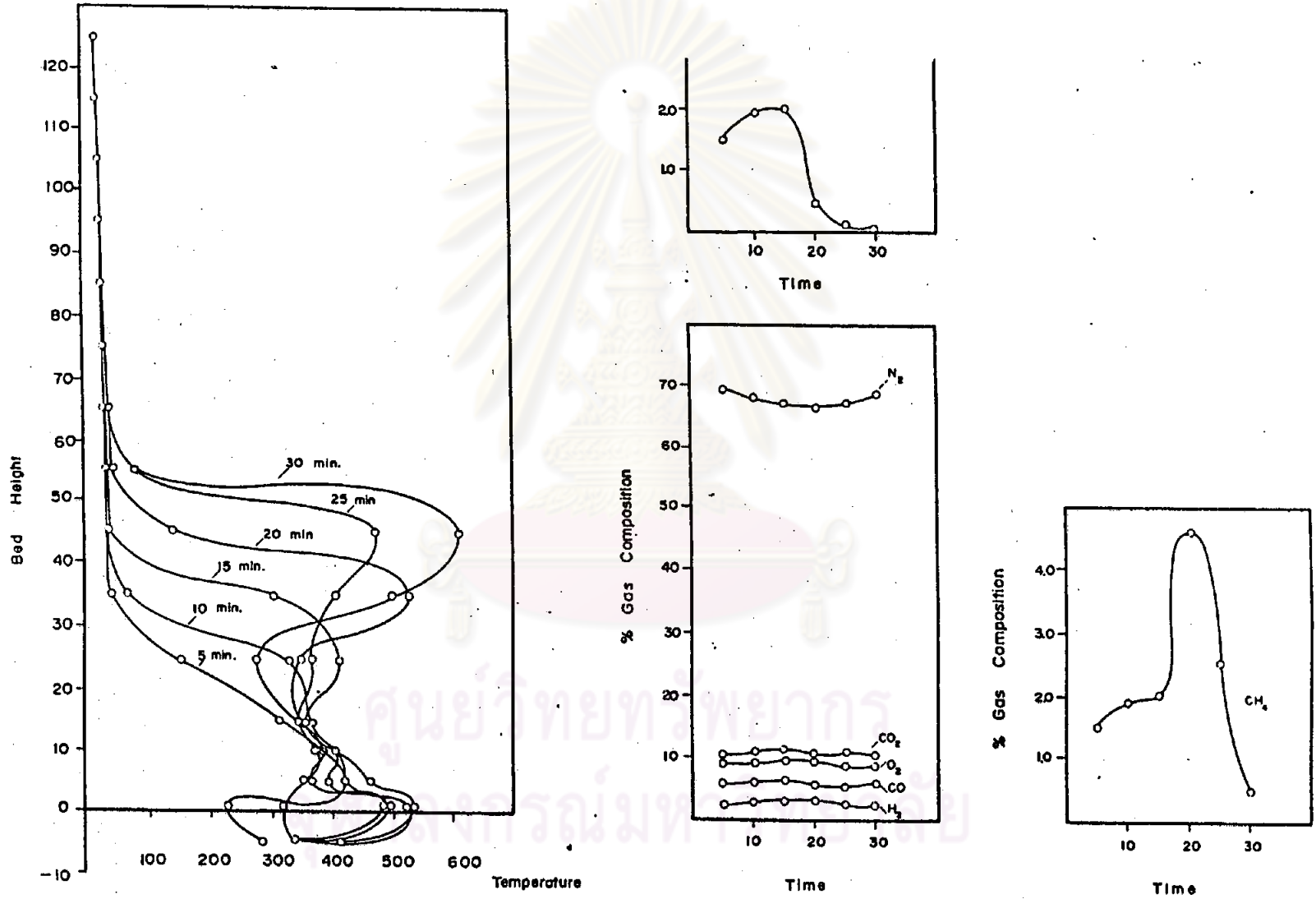FIGURE 5.2   TEMPERATURE vs. BED HEIGHT FOR CORN COBS (RUN No. CN 2)

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FIGURE 5.3   TEMPERATURE vs. BED HEIGHT FOR WOOD SHAVINGS (RUN No.WD 4)

temperatures yield higher CO production, a trend which agrees with all equilibrium models.

5.3 Discussion of mathematic models for gasification process

From the literatures we found that several researchers such as Gumz (6),Schlapfer (17), Groeneveld (17), Buekens(16), Cruz (11), and Reed (20) etc.. who used mathematical methods to explained the various gasification process to either predict gas composition or predict reaction zone depths in a gasifiers.

In this study we were interested and in using the Gumz and the Reed model to predict producer gas composition , and to predict time and length required for the pyrolysis and combustion zones.

A computer program in BASIC was written using the Gumz model (see annex 3) to predict producer gas compositions knowing reduction temperatures. In this model Gumz made element balances (carbon, oxygen, hydrogen and nitrogen) and assumed that the Boudouard reaction, the heterogeneous water shift reaction and the methanization reaction were in equilibrium with the producer gas being assumed ideal. Thus there are eight equation and eight unknowns with following input variables :

- the composition (based on the ultimate analysis) of the fuel and the gasifying agent

- the equilibrium temperature and operating pressure

and the following output variables :

- the composition of the product gas (CO, CO_2, H_2, H_2O, N_2,

CH_4)

_ the amount of fuel and gasifying medium used per Ncu.m of gas

The computer flow digram and program listing are shown in the annex .

In order to predict passage times and length required for the flaming pyrolysis and gasification zones, the Reed model (see annex) was used based on the following equations

time for pyrolysis : $t_p = (h_p + F_w * h_w) * F_d * V / A * q$

fuel velocity : $V_f = m/A_g * F_d * (1-F_v)$

flaming pyrolysis zone length : $l_p = V_f * t_p$

time for char reaction zone : t_c = constant

$= 100$ sec

char zone length $= t_c * V_f$

$= 100 * V_f$

Table 5.3 presents a gasification simulation using the Gumz model with the reduction zone temperature as parameter. The information fed into the Gumz model was reduction zone temperature and the C,H,O,N, value in the biomass feed and in the gasifying medium and the information returned are compositions from which as number of ralated values can be obtained. Figure 5.3 represents a simulation of ordinary rice hull gasification reacting the biomass with a blast of air with the model making its own calculation of the ratio of biomass to air to use as in an actual gasifier. The main result from this excercise indicates that reduction temperature

TEMPERATURE (K)	773	873	973	1073	1173	1273
% VOL. OF CO	2.7	10.35	21.2	26.63	27.91	28.15
% VOL. OF H_2	12.25	22.57	34.56	41.3	43.33	44.22
% VOL. OF CO_2	14.59	10.4	4.02	0.91	0.2	0.05
% VOL. OF CH_4	2.91	2.17	1.51	0.79	0.37	0.18
% VOL. OF N_2	67.1	54.5	38.72	30.37	28.18	27.38
M	0.18	0.63	0.47	0.38	0.36	0.35
F	0.48	0.21	0.26	0.28	0.29	0.29
CO/CO_2	0.185	0.9951	5.27	29.26	139.55	563
ER	3.2	25.63	15.45	11.6	10.61	10.314259
HEAT CONTENT (KCAL/SCM)	732.2	1207.54	1838.07	2139.08	2199.67	221597.6

TABLE 5.3   GASIFICATION SIMULATION (FOR WOOD SHAVINGS) USING THE GUMZ

MODEL WITH REDUCTION ZONE TEMPERATURE AS PARAMETER.

affects gas quality quite a bit. This agrees with the general findings of this study that both the recorded temperature levels in the reduction zones and the gas calorific content were low. However the experiments conducted in this study were of the batch type and the data could not be compared meaningfully with the equilibrium Gumz model, as an example Table 5.4 shows a comparison between 4 experiments on rice hulls and Gumz model which indicates that at the temperature levels measured in the reduction zone the concentrations of CO and H_2 are negligible.

Table 5.5 presents a gasification simulation using the Reed Model for various biomass. The aim of the excersise is to calculate flaming pyrolysis zone length lp and reduction zone length for several biomass. It was originally thought that direct measurements of reaction zones could be made using the temperature probes but this was not experimentally possible. Thus direct comparisons between experiment and predictions could not be made. However the results of Table 5.5 at least give indications of relative lengths of reaction zones between biomass of various sizes. It would be more interesting to observe at least the depth of the flaming pyrolysis zone in a glass see-through reactor.

RUN NUMBER	RN 1	RN 2	RN 3	RN 4
GAS FLOW RATE (Ncu.m./h)	12	18	25	30
AIR FLOW RATE (Ncu.m./h)	9.54	14.84	19.66	22.93
AIR TEMPERATURE (C)	28.00	30.50	30.00	28.00
AIR RELATIVE HUMIDITY (%)	72.50	75.00	97.00	56.00
FUEL MOISTURE (% wt.)	4.81	5.40	4.52	5.20
AVERAGE TEMPERATURE (C)*	300	240	290	410
GRATE TEMPERATURE (C)	500	160	500	230

GAS COMPOSITION (% vol.)

	(1)	(2)	(1)	(2)	(1)	(2)	(1)	(2)
CO	7.41	0.01	5.90	0.01	9.93	0.04	9.00	0.51
H_2	5.86	0.01	6.29	0.01	11.93	0.07	12.09	3.44
CO_2	7.00	38.88	10.05	30.57	6.86	29.34	8.88	21.19
CH_4	1.00	0.90	0.79	0.25	6.24	0.08	2.11	1.58
N_2	68.82	70.19	67.15	68.96	58.44	70.47	60.40	73.28
O_2	8.01	0.00	9.85	0.00	6.60	0.00	7.52	0.00
GAS CALORIFIC CONTENT(3)	497.71	86.28	445.23	24.40	1257.80	10.97	841.42	134.85
CO/CO_2	1.06	$2.57*10^{-3}$	0.56	$3.27*10^{-3}$	1.40	$1.36*10^{-3}$	1.01	0.02

NOTE   * - ASSUME AVERAGE TEMPERATURE = REDUCTION ZONE TEMPERATURE

(1) EXPERIMENTAL DATA

(2) CALCULATED FROM GUMZ THERMODYNAMIC MODEL

(3) Kcal/Ncu.m.

TABLE 5.4 COMPARISON BETWEEN EXPERIMENTS AND THE GUMZ MODEL FOR

THE GASIFICATION OF RICE HULLS.

	A	RICE HULLS	BAGASSE	WATER HYACINTH	WOOD SHAVING	CORN COB
VOLATILE	0.9	0.5923	0.5882	0.6775	0.70105	0.7031
CHAR	0.1	0.19015	0.13125	0.157	0.21105	0.2046
ASH	0.01	0.16415	0.0205	0.1008	0.0099	0.02475
WATER	0.2	0.0534	0.2605	0.0647	0.7	0.06755
DENSITY F_d g/cm^3	0.4	0.433	0.05	0.0866	0.178	0.316
BULK DENSITY g/cm^3	0.2	0.26	0.02984	0.05196	0.107	0.19
VOID FR. F_v	0.5	0.3995381	0.4032	0.4	0.3988764	0.3987342
LENGHT cm	1	1	1	1	1	1
WIDTH cm	1	0.2	0.1	1	1	1
HEIGHT cm	0.2	0.2	0.1	2	0.1	1
AVG. DIAM. d cm						
VOLUME V cm^3	0.2	0.04	0.01	2	0.1	1
AREA A cm^2	2.8	0.88	0.6	10	2.4	6
DIAM. GASIFIER D_g m	0.15	0.15	0.15	0.15	0.15	0.15
HT. TRANSFER q w/cm^2	2	2	2	2	2	2
FEED RATE M kg/hr	10	10	10	10	10	10
SPEC. RATE m kg/m^{2}hr.	566	566	566	566	566	566
PYROL. TIME T_p sec	40.197143	22.40438	1.26478	20.074407	17.228175	61.317251
FUEL VELOCITY V_f cm/sec	0.0785634	0.0604334	0.5265644	0.3023996	0.1468475	0.0826983
PYROL. LENGTH L_p cm	3.1580247	1.3539727	0.6659882	6.0704922	2.5299144	5.0708341
CHAR RX. TIME t_c sec	100	100	100	100	100	100
CHAR ZONE l_c cm	7.8563412	6.0433394	52.656442	30.239958	14.68475	8.2698328

TABLE 5.5 GASIFICATION SIMULATION USING THE REED MODEL FOR VARIOUS BIOMASS IN ORDER TO CALCULATE FLAMING PYROLYSIS LENGTH l_p AND REDUCTION ZONE LENGTH l_c. (BIOMASS A REFERS TO WOOD CUBES)