# CHAPTER IV

## PRESENTATION OF RESULTS

### 4.1 The gasification of rice hulls

Three rice hulls fuels were tested in this study. They include ordinary rice hulls, shredded rice hulls, and partially carbonized round rice hull pellets. The second fuel was gasified less successfuly than the first fuel, and the third fuel did not gasify at all. The general results obtained will be reported in the following sections. The complete experimental details will be reported in the annex .

#### 4.1.1 Data with ordinary rice hulls

The proximate analysis of one representative sample of ordinary rice hulls is presented in table 4.1. The rice hulls utilized were obtained from a rice mill in Saraburi Province. The water content of rices hull vary according to sites but all the rice hull samples were oven dried down to about 5 percent water content by weight for each runs. The batch of rice hull to be used were dried and sealed in plastic bags prior to each run. On some of the runs where 10 percent humidity was required water was sprinkled into rice hull batches which had been previous dried to about 5 percent, then the batch of rice hull was left to stabilize for two days. The bulk density of the rice hull used in the experiments was measured to be between 100 to 150 kg/cubic meter depending on how good a packing one has in the gas producer. During operation of the gas producer,

| BIOMASS TYPES | % FIXED CARBON | % VOLATILE MATTER | % ASH CONTENT | % SULPHUR CONTENT | CALORIFIC CONTENT* |
|---|---|---|---|---|---|
| RICE HULLS | 20.07 | 62.51 | 17.32 | 0.09 | 3556.89 |
| CORN COBS | 21.94 | 75.4 | 2.65 | 0 | 4437.74 |
| WOOD SHAVINGS | 22.87 | 75.98 | 1.07 | 0.08 | 4123.2 |
| BAGASSE | 19.8 | 74.86 | 5.25 | 0.1 | 4455.28 |
| WATER HYACINTH | 16.68 | 72 | 10.71 | 0.6 | 3711.08 |

NOTE: 1. * : CAL/ gm. DRY BASIS.

2. DATA MADE BY NATIONAL ENERGY ADMINISTRATION

TABLE 4.1 PROXIMATE ANALYSIS OF RICE HULLS, CORN COBS, WOODSHAVINGS BAGASSE AND WATER HYACINTH.

| RUN NUMBER | RH1 | RH2 | RH3 | RH4 |
|---|---|---|---|---|
| GAS FLOW RATE (Ncu.m/h) | 12 | 18 | 25 | 30 |
| AIR FLOW RATE (Ncu.m/h) | 9.54 | 14.84 | 19.66 | 22.93 |
| EQUIVALENCE RATIO (ER) | 0.6 | 0.81 | 1.39 | 1.44 |
| AIR TEMPERATURE (°C) | 28 | 30.5 | 30 | 28 |
| RELATIVE HUMIDITY ( % ) | 72.5 | 75 | 97 | 56 |
| FUEL MOISTURE (% by wt.) | 4.81 | 5.4 | 4.53 | 5.2 |
| FUEL BULK DENSITY (g/cu.cm) | 0.16 | 0.14 | 0.11 | 0.12 |
| GAS COMPOSITION ( % vol.) | | | | |
| CO | 7.41 | 5.9 | 9.93 | 9 |
| $H_2$ | 5.86 | 6.26 | 11.93 | 12.09 |
| $CO_2$ | 7.9 | 10.06 | 6.86 | 8.88 |
| $CH_4$ | 1 | 0.78 | 6.24 | 2.11 |
| $N_2$ | 69.82 | 65.66 | 58.44 | 60.4 |
| $O_2$ | 8.01 | 10.06 | 6.6 | 7.52 |
| GAS CALORIFIC CONTENT (kcal/scm) | 497.71 | 443.37 | 1257.8 | 841.42 |
| $CO/CO_2$ | 0.94 | 0.59 | 1.45 | 1,01 |
| Tav | 300 | 240 | 290 | 410 |
| Tgrate | 500 | 160 | 500 | 230 |

TABLE 4.2 GASIFICATION OF RICE HULLS INFLUENCE OF AIR FLOW RATE

| RUN NUMBER | R1 | R2 | R3 | R4 | R5 |
|---|---|---|---|---|---|
| GAS FLOW RATE (Ncu.m/h) | 25 | 25 | 25 | 25 | 25 |
| AIR FLOW RATE (Ncu.m/h) | 19.66 | 19.3 | 21.71 | 19.04 | 20.91 |
| EQUIVALENCE RATIO (ER) | 1.08 | 2.1 | 1.54 | 0.7 | 1.02 |
| AIR TEMPERATURE ( C) | 30 | 30 | 29 | 28 | 29 |
| RELATIVE HUMIDITY ( % ) | 97.5 | 75 | 75 | 65 | 72 |
| FUEL MOISTURE (% by wt.) | 4.53 | 6.2 | 10.52 | 13.42 | 16.71 |
| FUEL BULK DENSITY (g/cu.cm) | 0.125 | 0.124 | 0.14 | 0.102 | 0.102 |
| GAS COMPOSITION ( % vol.) | | | | | |
| CO | 10.57 | 13.86 | 8.14 | 7.84 | 5.42 |
| $H_2$ | 12.7 | 8.06 | 6.3 | 9.39 | 9.36 |
| $CO_2$ | 7.3 | 6.42 | 10.42 | 13.86 | 15.02 |
| $CH_4$ | 4.22 | 1.59 | 1.88 | 1.31 | 1.32 |
| $N_2$ | 60.12 | 61 | 66.8 | 61.19 | 62.68 |
| $O_2$ | 5.09 | 9.07 | 6.46 | 6.38 | 6.2 |
| GAS CALORIFIC CONTENT(kcal/scm) | 981.712 | 768.07 | 560.55 | 608.58 | 535.23 |
| $CO/CO_2$ | 1.45 | 2.16 | 0.78 | 0.56 | 0.36 |
| Tav | 290 | 250 | 240 | 260 | 250 |
| Tgrate | 290 | 300 | 160 | 450 | 265 |

TABLE 4.3 GASIFICATION OF RICE HULLS, INFLUENCE OF RICE HULLS MOISTURE CONTENT.

rice hulls have some difficulties filling in the cavities formed during reaction. The higher the gas flow rate the more the problem of cavitation seems to become. Thus continuous poking into the open top gasifier was necessary. During start-up operation the introduction of rice hulls to ignite the gasifer resulted in a drop in air flow rate of about 10 percent. Upon addition of the entire batch the additional drop in air flow rate was another 5 percent. However this was compensated by increasing the power of the blower.

10 runs were performed with ordinary rice hulls for the following parameters

run 1 rice hulls at a air flow rate of 9.54 Ncu.m./h

run 2 rice hulls at a air flow rate of 14.84 Ncu.m./h

run 3 rice hulls at a air flow rate of 19.66 Ncu.m./h

run 4 rice hulls at a air flow rate of 22.93 Ncu.m./h

run 6 rice hulls with 4.72 % moisture content gas flow rate 25 Ncu.m./h

run 7 rice hulls with 6.20 % moisture content gas flow rate 25 Ncu.m./h

run 8 rice hulls with 10.25 % moisture content gas flow rate 25 Ncu.m./h

run 9 rice hulls with 13.24 % moisture content gas flow rate 25 Ncu.m./h

run 10 rice hulls with 17.30 % moisture content gas flow rate 25 Ncu.m./h

the results are presented in table 4.2 , table 4.3, figure4.1 and figure 4.2 and the details for each run are presented in the annex.

4.1.2 Data with shredded rice hulls

Shredded rice hull offers a greater density than ordinary rice hulls and was tested in the gasifier system. The shredded rice hulls sample used was obtained from a rice mill of Samut Prakarn

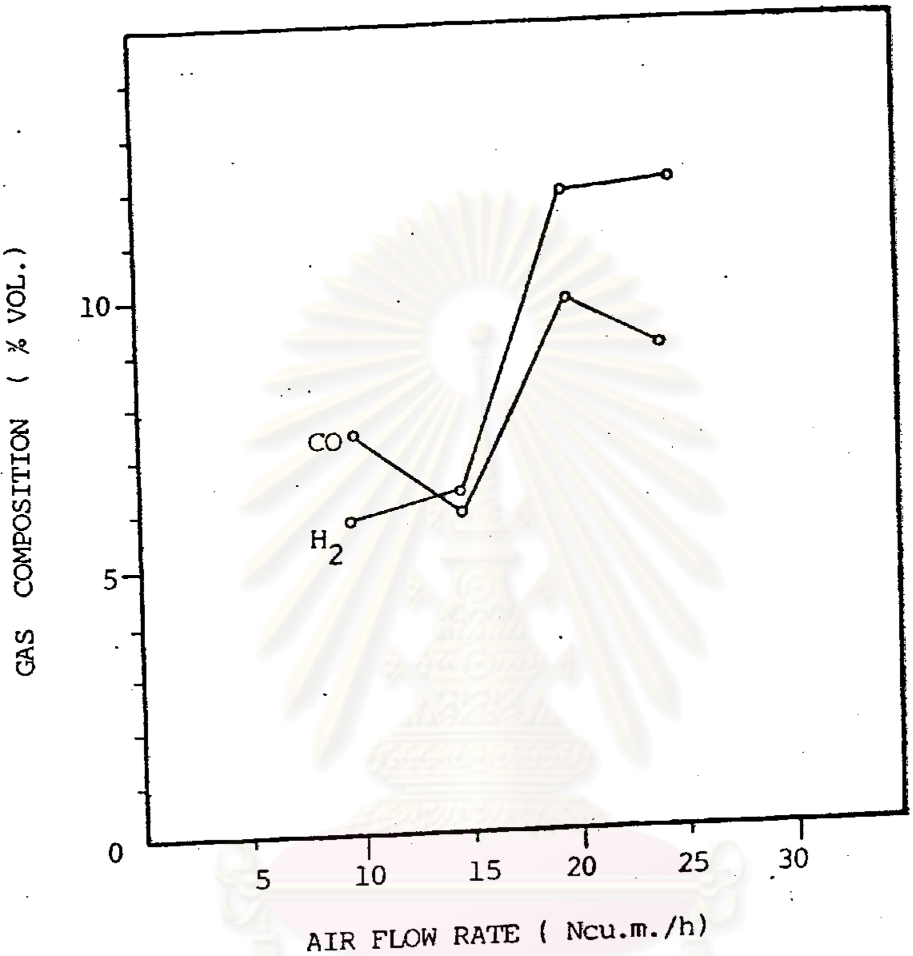


FIGURE 4.1 GAS COMPOSITION vs. AIR FLOW RATE FROM DATA TABLE 4.2 (RICE HULLS)

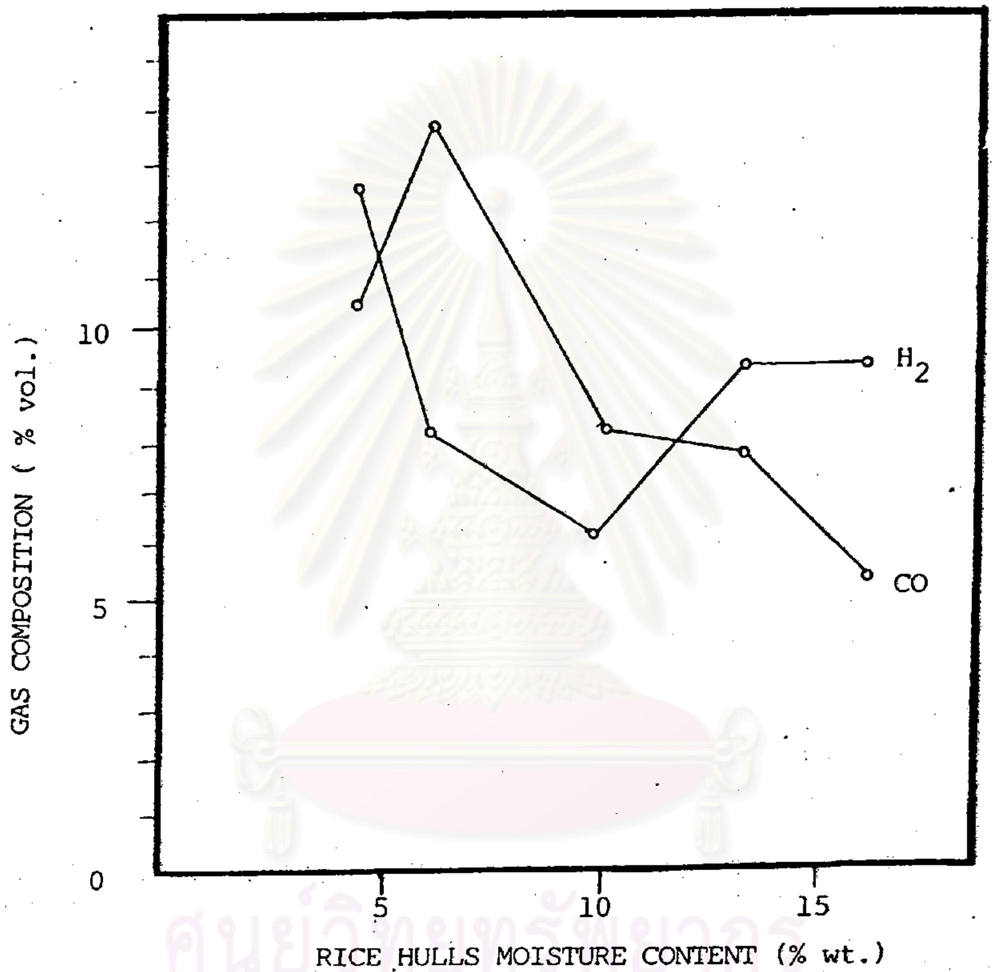


FIGURE 4.2 GAS COMPOSITION vs. RICE HULLS MOISTURE CONTENT

DATA FROM TABLE 4.3

Province where it was sold to duck farms as duck food additive. The bulk density of the shredded rice hull was 0.28

5 experiments using shredded rice hulls were conducted and the following results were obtained.

First of all it was found that the pressure drop caused by shredded rice hull was higher than with ordinary rice hulls resulting in a need to increase the speed of the variable speed suction fan. It was also found that the gas produced was difficult to ignite in the burner although the gas could be made to burn . However gas analysis indicated a CO and H2 content 5 percent less than during operation with ordinary rice hulls. Another problem perhaps responsible for difficulty of gas ignition was the unsteady nature of the gas quality as evidenced by the gas which stopped burning despite the presence of the pilot liquid propane gas flame.

The basic data for each of the five runs are as follows

run 1 shredded rice hulls at air flow rate 13.33 Ncu.m./h

run 2 shredded rice hulls at air flow rate 17.09 Ncu.m./h

run 3 shredded rice hulls at air flow rate 19.63 Ncu.m./h

run 4 shredded rice hulls at air flow rate 24.54 Ncu.m./h

run 5 shredded rice hulls at air flow rate 30.92 Ncu.m./h

is presented in details in the annex and the results are presented in table 4.4 and figure 4.3 .

4.1.3 <u>Data with carbonized rice hull round pellets</u>

The Thailand Institute for Scientific and Technological Research made available to us a by-product of a pyrolysis unit operating on rice hulls. The product was semi-carbonized rice hull

| RUN NUMBER | RHM 1 | RHM 2 | RHM 3 | RHM 4 | RHM 5 |
|---|---|---|---|---|---|
| GAS FLOW RATE (Ncu.m/h) | 15 | 20 | 25 | 30 | 35 |
| AIR FLOW RATE (Ncu.m/h) | 13.33 | 17.09 | 19.63 | 24.54 | 30.92 |
| EQUIVALENCE RATIO (ER) | 1.2 | 1.3 | 1.5 | 1.45 | 1.4 |
| AIR TEMPERATURE ( C) | 30 | 28 | 30 | 29 | 30 |
| RELATIVE HUMIDITY ( % ) | 65 | 63 | 94 | 72 | 80 |
| FUEL MOISTURE (% by wt.) | 5.01 | 5.22 | 5.2 | 5.21 | 5.12 |
| FUEL BULK DENSITY (g/cu.cm) | 0.27 | 0.26 | 0.22 | 0.25 | 0.29 |
| GAS COMPOSITION ( % vol.) | | | | | |
| CO | 2.5 | 6.72 | 9.4 | 6.51 | 3.47 |
| $H_2$ | 4.28 | 8.1 | 9.78 | 8.42 | 5.53 |
| $CO_2$ | 8.69 | 10.2 | 10.11 | 10.45 | 9.3 |
| $CH_4$ | 0.78 | 1.25 | 1.77 | 1.22 | 1.4 |
| $N_2$ | 77.12 | 67.5 | 62.44 | 64.69 | 70.78 |
| $O_2$ | 6.63 | 6.23 | 6.5 | 8.08 | 9.55 |
| GAS CALORIFIC CONTENT(kcal/scm) | 280.3 | 568.99 | 750.67 | 569.56 | 406.74 |
| $CO/CO_2$ | 0.29 | 0.66 | 0.93 | 0.62 | 0.37 |
| Tav | 200 | 310 | 400 | 250 | 250 |
| Tgrate | 370 | 400 | 500 | 250 | 260 |

TABLE 4.4 GASIFICATION OF SHREDDED RICE HULL, INFLUENCE OF AIR FLOW RATE

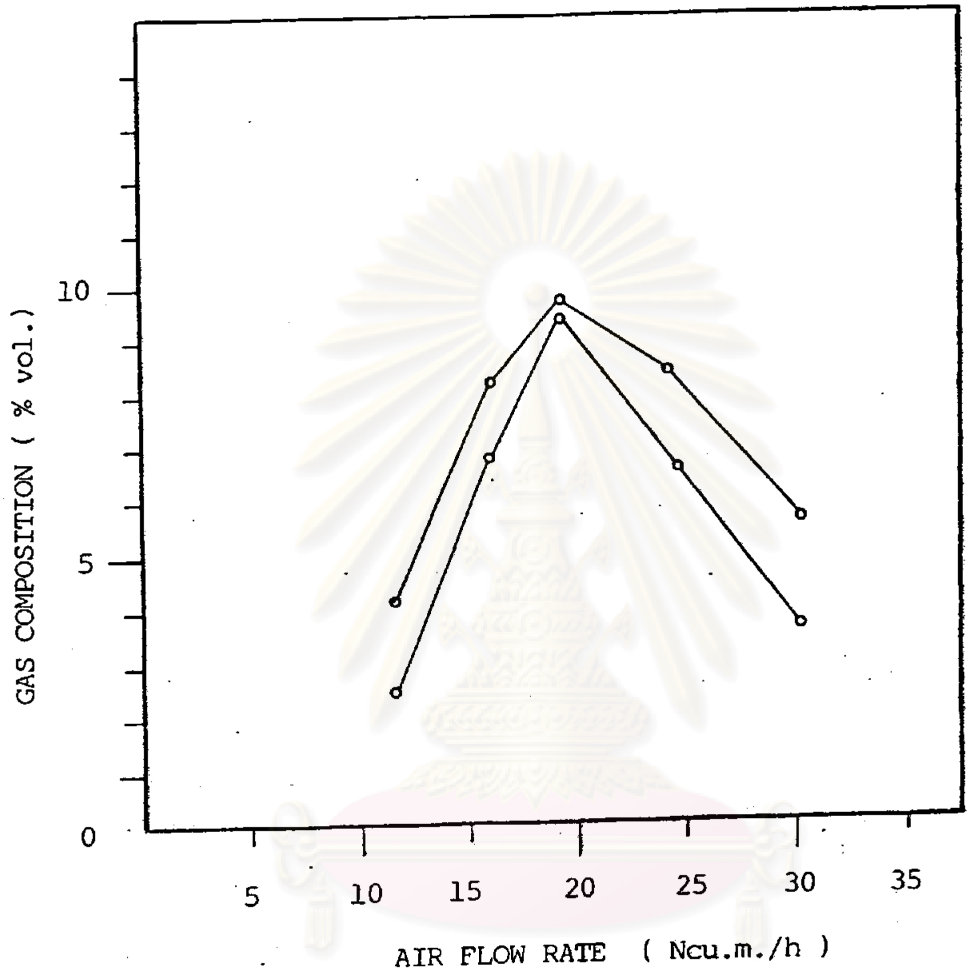


FIGURE 4.3 GAS COMPOSITION vs. AIR FLOW RATE FOR SHREDDED RICE HULL

DATA FROM TABLE 4.4.

pellets of the size of ping pong balls made by adding tapioca starch and semi-carbonized rice hulls into a rolling drum. The result was a round pellet fuel which held together with the added starch but was fragile and would break in pieces when dropped. Breakage was increased upon drying the round pellet fuel in an oven. The round pellets when dropped into the gasifier would break and create fines through which resistance to flow was high. It was not possible to ignite the bottom of the gsifier successfully. After three unsuccessful attempts at igniting the gasifier the tests were stopped for this fuel.

4.2 The gasification of corn cobs

Corn cobs purchased from Saraburi Province were gasified in this study. A hammermill was used to break the cobs into various sizes. Eventually a series of cob sizes were used in the gasifier starting from whole unbroken cobs (15cm long on the average) down to corn cob shredds passing through a 0.5cm * 0.5cm sieve opening.

The corn cob retained for detailed testing in the gasifier were as follows:

- Broken corn cobs retained by a 3 cm * 3 cm sieve opening (size4)
- Broken corn cobs retained by a 1.5 cm *1.5 cm sieve opening (size 3)
- Broken corn cobs retained by a 1,0 cm * 1,0 cm sieve opining (size 2)
- Broken corn cobs retained by a 0.5 cm * 0.5 cm sieve opening (size 1)

Where for example size 3 broken cobs are retained by a 1.5 cm * 1.5 cm sieve but not including broken cobs retained by the next largest sieve.

The proximate analysis of a sample of corn cobs used in this study is presented in table 4.1 . The water content of the corn cobs as received were of the order of 20-30 percent. However as with rice hulls , the corn cobs to be used in the gasifier were oven dried to 6 percent and stored in sealed plastic bags. The water content of the corn cobs used in the experiment was of the order of 6 percent and the influence of water content was not studied

4.2.1 <u>Data with whole corn cobs</u>

In the initial testing of corn cobs entire unbroken corn cobs of 15 cm size on the average were tested in our system. The ignition of unbroken corn cobs presented no difficulties in our system, and actually all corn cobs whether broken or unbroken allowed easier ignition inside the column than any other fuel tested in this study. Four of five trial runs were made with unbroken corn cobs. The major problem that was found was the fact that gasification was not smooth and the inability to ignite the producer gas in the burner. This was due to cavity formation caused by collapse of fuel as it was being consumed, and failure of the fuel on top of the gasifier to fall down and fill the cavities. Even by poking into the open core to force the corn cobs down was met with resistance.

Thus the inability to sustain a steady gas was flow the reason the detailed analysis of experimental runs with unbroken corn cobs was not undertaken.

4.2.2 <u>Data with corn cob shredds</u>

During the hammermilling of corn cobs and after sieving, a percentage of 20 percent of the material passes through a 0.5 cm by 0.5 cm sieve as shredded corn cobs. Two or three trial runs were made using this shredded materials with the following observations. The corn cob shreds at the bottom of the gasifier could be ignited easily but when the batch of shredds was filled in the combustion surface it did not creep up into the raw fuel bed. The air flow resistance was not high as corn cob shreds seems to have more void fractions than sawdust. However the fire was not self sustaining and would die out in the first few minutes. The water content of the fuel used in these initial tests were maintained at about 6 percent by pre-drying.

Thus as the combustion zone could not be maintained in the gasifier no detailed analysis of experimental runs could be made and recorded with shredded corn cobs.

### 4.2.3 Data with corn cobs of four sizes

Detailed experimental data records were performed and retained for four broken corn cob sizes as follows.

- size 4: broken corn cobs retained by a 3.0 cm *3.0 cm sieve opening
- size 3: broken corn cobs retained by a 1.5 cm *1.5 cm sieve opening
- size 2: broken corn cobs retained by a 1.0 cm *1.0 cm sieve opening
- size 1: broken corn cobs retained by a 0.5 cm *0.5 cm sieve opening

The ignition of broken corn cobs did not reduce the air flow rate substantially, certainly not above 10 percent of the flow rate with the gas producer empty. The case of ignition of all corn cobs was of the same order as rice hulls and woodshavings, but ignition was slightly more difficult than shredded water hyacinth stems and sieved bagasse, and less difficult than sawdust and powdered rice hulls. The operation of the gasifier with corn cobs also sufferred from problems of cavitation such as for the case of rice hulls; but poking with corn cob is much more difficult as strongly poking is needed for the cobs to fall.

15 experiments were conducted with the above 4 fuels as follows

run 1 size 1 at 20 Nm3/hr
run 2 size1 at 25 Nm3/hr
run 3 size 1 at 30 Nm3/hr
run 4 size 1 at 35 Nm3/hr
run 5 size 2 at 20 Nm3/hr
run 6 size 2 at 25 Nm3/hr
run 7 size 2 at 30 Nm3/hr
run 8 size 2 at 35 Nm3/hr
run 9 size 3 at 20 Nm3/hr
run 10 size 3 at 25 Nm3/hr
run 11 size 3 at 30 Nm3/hr
run 12 size 3 at 35 Nm3/hr
run 13 size 4 at 25 Nm3/hr
run 14 size 4 at 30 Nm3/hr
run 15 size 4 at 35 Nm3/hr

The detailed data is presented in table 4.5 and table 4.6.

## 4.3 The gasification of sawdust and wood shavings

Sawdust from a sawmill and wood shaving from a furniture manufacturer were tested on the equipment. Prior to fuel testing both raw materials were oven dried down to about 6 percent. The results of the tests are as follows.

### 4.3.1 Data with sawdust

Sawdust used in this study had a bulk density in the neighborhood of .963 g/cu.cm . The proximate analysis of the sawdust was found to be very similar to wood shaving and will be mentionned later.

In this study it was found that the gas producer operating with sawdust would not ignite. The start-up operation as described in a previous section was repeated several times without success. It was found that when the small amount of sawdust needed to start ignition was thrown into the gas producer the flow rate of air decreased by as much as 30 to 40 percent, whereas it would normaly decrease by 5 to 10 percent with other fuels. It was also found that

| RUN NUMBER | CN 1 | CN 2 | CN 3 | CN 4 |
|---|---|---|---|---|
| GAS FLOW RATE (Ncu.m/h) | 20 | 25 | 30 | 35 |
| AIR FLOW RATE (Ncu.m/h) | 17.87 | 21.7 | 21.56 | 26.45 |
| EQUIVALENCE RATIO (ER) | 1.2 | 1.68 | 1.05 | 1.03 |
| AIR TEMPERATURE ( C) | 28 | 30 | 30 | 29.5 |
| RELATIVE HUMIDITY ( % ) | 72.5 | 73 | 61.5 | 61 |
| FUEL MOISTURE (% by wt.) | 6.2 | 5.9 | 6.5 | 5.95 |
| FUEL BULK DENSITY (g/cu.cm) | 0.215 | 0.124 | 0.19 | 0.176 |
| GAS COMPOSITION ( % vol.) | | | | |
| CO | 3.75 | 4.93 | 12.41 | 12.37 |
| H2 | 5.21 | 5.22 | 12.64 | 10.48 |
| CO2 | 8.21 | 8.2 | 8.17 | 8.7 |
| CH4 | 3.2 | 3.6 | 2.47 | 2.67 |
| N2 | 70.58 | 70.56 | 56.8 | 59.71 |
| O2 | 9.05 | 7.49 | 7.51 | 6.24 |
| GAS CALORIFIC CONTENT(kcal/scm, | 576.795 | 650.816 | 995.446 | 947.40 |
| CO/CO2 | 0.45676 | 0.6012195 | 1.5189718 | 1.4218391 |
| Tav | 400 | 370 | 350 | 520 |
| Tgrate | 500 | 520 | 350 | 600 |

TABLE 4.5 GASIFICATION OF CORN COBS INFLUENCE OF AIR FLOW RATE ( SIZE 3)

the sawdust would ignite with difficulty and the flames would die out after a while, probably when the diesel oil impregnated on the sawdust had all burned. On all occasions the operation with sawdust was found to be dangerous as we had to repeatedly throw in a torched piece of cloth until some combustion of the sawdust had taken place and it seemed that some combustible gas was igniting in the gas producer. It was believed that this sporadic gas phase combustion was caused by diesel oil vapor emanating from the solid fuel.

After several unsuccessful ignition trials the tests using sawdust were discontinued

4.3.2 Data with woodshavings

The proximate analysis of wood shavings is presented in table 4.1. The wood shavings tested in the gas producer were oven dried to about 6 percent prior to testing. The bulk density of the woodshavings was of the order of .573 g/cu.cm . Operation with wood shavings did not present an ignition problem, the air velocity drop when a small amount of wood shavings was thrown into the gasifier was small. Ignition was relatively easy and of the same order as corn cobs and rice hulls. The drop in air flow rate upon introduction of a small amount of woodshavings was of the order of 10 percent and an additional 7 to 8 percent when the gas producer was all filled up. However the power of the blower could be controlled according to the pressure drop encountered. On the question of cavity formation during operation, it was found that wood shavings flow downward in a smooth manner with actually no need to poke periodically, although on most runs poking was done.

Data on 5 runs with wood shaving are reported in the annex .

The runs are listed as follows.

run 1 wood shavings at air flow rate 11.41 Ncu.m./hr

run 2 wood shavings at air flow rate 17.38 Ncu.m./hr

run 3 wood shavings at air flow rate 21.44 Ncu.m./hr

run 4 wood shavings at air flow rate 24.88 Ncu.m./hr

run 5 wood shavings at air flow rate 31.51 Ncu.m./hr

And the results are presented in table 4.7 and figure 4.8 .

### 4.4 The gasification of bagasse

Bagasse obtained from a sugar mill in Radburi Province was tested on the equipment. As the bagasse as received had a moisture content of 30 to 40 percent the bagasse was oven dried to about 6 percent prior to all runs. The first set of runs involved bagasse as received. The second set of runs involved bagasse with the fines removed. The results of the tests are as follows.

#### 4.4.1 Data with bagasse as received from the sugar mill

The bagasse as received had a bulk density slightly over 0.1 g/cu.cm. The bagasse as received contained a substantial amount of fines (about 20 percent).

Three runs using bagasse as received were made. During ignition it was found that the initial batch of bagasse thrown in the gas producer decreased the flow rate of gas by as much as 15 percent. This was probably caused by the amount of fines present in the fuel. As the fuel was being thrown in, an excessive amount of bagasse dust was generated. The actual ignition of the bagasse was spontaneous but the fire zone would not expand radially. Then after two or three minutes of combustion the fire would extinguish itself even when

| RUN NUMBER | WS 1 | WS 2 | WS 3 | WS 4 | WS 5 |
|---|---|---|---|---|---|
| GAS FLOW RATE (Ncu.m/h) | 15 | 20 | 25 | 30 | 35 |
| AIR FLOW RATE (Ncu.m/h) | 11.41 | 17.38 | 21.44 | 24.88 | 31.51 |
| EQUIVALENCE RATIO (ER) | 0.96 | 0.91 | 1.86 | 1.86 | 1.52 |
| AIR TEMPERATURE ( C) | 30 | 29 | 30 | 30 | 31 |
| RELATIVE HUMIDITY ( % ) | 71 | 67 | 65 | 72 | 69 |
| FUEL MOISTURE (% by wt.) | 6.2 | 5.8 | 6.5 | 6.32 | 5.54 |
| FUEL BULK DENSITY (g/cu.cm.) | 0.1 | 0.11 | 0.12 | 0.1 | 0.11 |
| GAS COMPOSITION ( % vol.) | | | | | |
| CO | 9.46 | 15.54 | 7.08 | 6.12 | 6.32 |
| $H_2$ | 5.15 | 5.18 | 5.28 | 4.45 | 5.07 |
| $CO_2$ | 10.2 | 10.6 | 10.6 | 12.24 | 9.48 |
| $CH_4$ | 3.15 | 7.73 | 2.1 | 2.43 | 0.67 |
| $N_2$ | 63.08 | 52.85 | 67.82 | 65.9 | 71.14 |
| $O_2$ | 8.96 | 8.1 | 7.12 | 8.86 | 7.32 |
| GAS CALORIFIC CONTENT | 742.65 | 1363.19 | 574.78 | 551.88 | 409.28 |
| $CO/CO_2$ | 0.93 | 1.47 | 0.67 | 0.5 | 0.67 |
| Tav | 300 | 250 | 310 | 400 | 350 |
| Tgrate | 375 | 275 | 520 | 510 | 410 |

TABLE 4.6 GASIFICATION OF WOOD SHAVINGS. INFLUENCE OF AIR FLOW RATE.

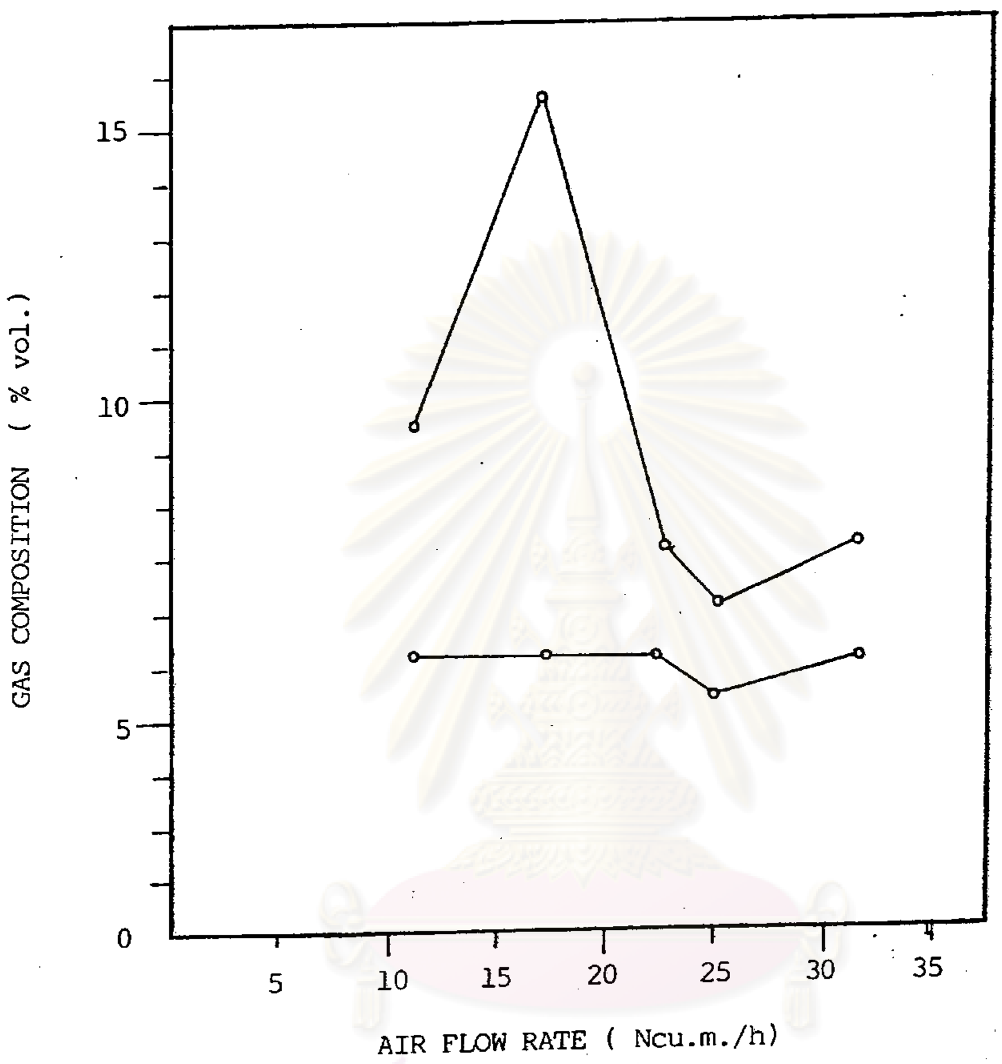


FIGURE 4.4 GAS COMPOSITION vs. AIR FLOW RATE FOR WOOD SHAVINGS

DATA FROM TABLE 4.6

additional bagasse was added. Thus ignition of bagasse as received was not self-sustaining and the tests on this material were discontinued.

Upon removal of the batch after each test it was found that below the combustion zone the bagasse combustion was also not self-sustaining under the experimental conditions ( about 25 Ncu.m./h ). Furthermore it was found that upon removal of the grate the mostly uncarbonized fuel had to be poked out from the bottom unlike all the other biomass fuels.

Thus no data of bagasse as received (unprocessed) was recorded in this study.

4.4.2 Data with bagasse fibers

The bagasse as received from the sugar mill containing about 20 percent of fines was sieved (using a 0.5 cm by 0.5 cm wire mesh sieve) very briefly to removed all fines. The bagasse fibers now had a bulk density of .95 g/cu.cm. The proximate analysis of the materail is presented in table 4.1.

The ignition procedure with bagasse fibers indicated that the air velocity drop was only about 5 percent upon addition of the initial amount of material for ignition purposes. The ignition of the material was instantaneous and the expansion of the fire zone quickly covered the entire cross section of the bed. Upon addition of the entire batch of bagasse fibers the air velocity drop was of the order of 2 to 3 percent only.

During a typical run it was necessary to poke down into the gas producer to force the biomass to fall down and prevent cavitation which would cause decrease of gas flow and gas quality.

Three runs were conducted with bagasse fibers as follows

run 1 at 15 Ncu.m./hr

run 2 at 20 Ncu.m./hr

run 3 at 25 Ncu.m./hr

The results are presented in table 4.8 and the detailed data is presented in the annex .

4.5. The gasification of water hyacinths stems

Water hyacinth was tested as gasifier fuel in our apparatus. Fresh water hyacinths was collected from a pond in Chulalongkorn University, dried in open air for two days, the roots and leaves were then cut out, and the stems cut into 1 inch pieces, then oven dried down to 6 percent. The proximate analysis of water hyacinth stems is presented in Table 4.1. The bulk density of the material is about 0.0975 g/cu.cm.

The ignition procedure with water hycinth stems upon addition of a small amount of ignition material resulted in a decrease in flow rate of air of 5 percent, and upon addition of the entire batch a decrease in flow rate of an additional 7-8 percent was obtained. It is to be noted that the decrease in flow rate of air occurs at one flow rate during ignition and at another flow rate during operation and thus both data cannot be compared. They are mentionned only to serve as comparison between various fuels. In any case the centrifugal suction fan is equipped with a variable speed system and any

| RUN NUMBER | B1 | B2 | B3 |
|---|---|---|---|
| GAS FLOW RATE (Ncu.m/h) | 15 | 20 | 25 |
| AIR FLOW RATE (Ncu.m/h) | 11.90 | 14.67 | 19.73 |
| EQUIVALENCE RATIO (ER) | | | |
| AIR TEMPERATURE (C) | 28 | 30 | 30 |
| RELATIVE HUMIDITY (%) | 70 | 72.5 | 5.02 |
| FUEL MAISTURE (%by wt.) | 5.17 | 6.01 | 5.02 |
| FUEL BULK DENSITY (g/cu.cm) | 29.84 | 27.52 | 29.01 |
| GAS COMPOSITION (%vol) | | | |
| CO | 8.21 | 12.45 | 10.10 |
| $H_2$ | 9.43 | 9.32 | 9.35 |
| $CO_2$ | 12.31 | 17.23 | 12.41 |
| $CH_4$ | 4.21 | 3.46 | 1.08 |
| $N_2$ | 62.69 | 52.23 | 62.35 |
| $O_2$ | 3.15 | 5.31 | 4.71 |
| GAS CALORIFIC CONTENT (kcal/Ncu.m) | 936.25 | 989.64 | 693.01 |
| $CO/CO_2$ | 0.67 | 0.72 | 0.81 |

TABLE 4.7 GASIFICATION OF BAGASSE INFLUENCE OF AIR FLOW RATE

flow rate needed is adjusted manually to compensate for pressure drop. For the ignition of water hyacinth stems the ignition itself is relative fast, but to a slightly lesser extent than bagasse fiber. The fire zone will then expand radialy to cover the entire cross section of the gas producer,but at a slower rate than bagasse fibers. After the entire cross section is red hot the entire batch of water hyacinth stem is thrown into the gasifier.

During gasification it was found that poking into the gas producer was unnecessary although we did poke occasionaly. Thus with this chopped water hyacinth stem fuel is was found that cavitation was not a problem. After each run and after removal of the grate the carbonized fuel would fall down without difficulty into the water seal. The water hyacinth stem pieces retain their shapes with some reduction in size (about 20 percent), however upon the slightest pressure the pieces would disintegrate into ash.

Two detailed runs were made as follows

run 1 gas flow rate: 20 Ncu.m./hr

run 2 gas flow rate: 25 Ncu.m./hr

and are presented in details in the annex with the main results presented in table 4.8.

4.6 <u>The ultimate analysis of wood, corn cobs, and rice hulls</u>

In order to study equilibrium reaction compositions during gasification, samples of wood shavings, corn cobs, and rice hulls were send to the Equipment Center of Chulalongkorn University for testing. The data obtained on two samples of each material is presented in table 4.9 .

| RUN NUMBER | WH 1 | WH 2 |
|---|---|---|
| GAS FLOW RATE | 20 | 25 |
| AIR FLOW RATE | | |
| AIR TEMPERATURE ( C) | 30 | 27 |
| RELATIVE HUMIDITY (%) | 74.1 | 72.5 |
| FUEL MOISTURE (% wt.) | 5.25 | 5.14 |
| FUEL BULK DENSITY (g/cu.cm.) | 51.9 | 50.1 |
| GAS COMPOSITION (% vol.) | | |
| CO | 9.03 | 11.25 |
| $H_2$ | 10.00 | 12.01 |
| $CO_2$ | 10.95 | 14.81 |
| $CH_4$ | 2.68 | 2.16 |
| $N_2$ | 58.95 | 56.05 |
| $O_2$ | 8.39 | 3.72 |
| GAS CALORIFIC CONTENT | 832.84 | 911.96 |
| $CO/CO_2$ | 0.82 | 0.76 |

TABLE 4.8 GASIFICATION OF WATER HYACINTH, INFLUENCE OF AIR FLOW RATE

| BIOMASS TYPES | % CARBON | % HYDROGEN | % OXYGEN | % ASH |
|---|---|---|---|---|
| RICE HULLS | 42.12 | 5.31 | 31.72 | 20.85 |
| CORN COBS | 45.33 | 4.97 | 47.25 | 2.45 |
| WOOD SHAVING | 52.5 | 12.75 | 31.52 | 3.23 |

NOTE : THESE DATA MADE BY SCIENCETIFIC INSTRUMENTS CENTER CHULALONGKORN UNIVERSITY. (NITROGEN FREE BASIS)

TABLE 4.9 ULTIMATE ANALYSIS OF RICE HULLS, CORN COBS AND WOOD SHAVINGS.