Design Parameters for a Rice Husk Throatless Gasifier Reactor

Anil Kr Jain
School of Energy Studies for Agriculture, PAU. Ludhiana, 141 004 (INDIA).
akjain_123@yahoo.com

ABSTRACT

Five open core throatless batch fed rice husk gasifier reactors having internal diameters of 15.2, 20.3, 24.4, 30.3 & 34.3 cm were designed and fabricated. On each reactor 8-10 trial runs were conducted varying the air flow rate or specific gasification rate. Gas quality, gas production rate, gasification efficiency specific gasification rate, and equivalence ratio were determined for every run on each of the five reactors. It was found that for each reactor the gasifier performance was the best at a specific gasification rate of around 200 kg/hr-m^2. Under the best operating conditions, the equivalence ratio was 0.40 and the gasification efficiency was around 65%. These parameters may be used for designing rice husk operated throatless gasifiers in the capacity range of 3 to 30 kW.

Keywords: Throatless gasifier, rice husk, design parameters.

1. INTRODUCTION

Rice is the staple food crop and its annual production in India and the world is about 90 and 400 MT respectively. For every to of paddy processed about 0.25 ton of paddy husk is generated as a by-product in milling operation (Baruah & Jain, 1998). Its heating value is about 15 MJ/kg which supports its application as an energy source. Thus paddy husk is an important agricultural crop residue having potential as renewable energy source. It can be used via combustion route, alternatively be used via gasification where it can be used to run engines and connecting equipment. Use of paddy husk via gasification will provide efficient and environment friendly use of husk as fuel.

Some references on design of large as well as small capacity rice husk gasifiers are documented in the literature (Jain & Bhatnagar, 1990). However, little attention is paid towards the development of systematic reactor scaling factors or design parameters for a small (3 to 30 kW) as well as large capacity rice husk gasifier systems. The performance data for these gasifiers is also not properly reported. Down draft gasifiers with throat (Imbert type) is known to generate best quality producer gas for engines having minimum tar. An extensive literature review conducted by Kaupp and Goss (1984) failed to find any reference on rice husk gasification in a down draft gasifier with throat. Jain & Bhatnagar 1990 and Pathak & Jain, 1985 also reported that rice husk can not be used as a feed stock in Imbert type gas producers due to material flow problems. It is. Therefore, necessary that a suitable gasifier for rice husk gasification is developed which is capable of producing clean gas for running IC engines. The design parameters for such gasifier

---

are properly developed. The gasifier coupled to engine could be used for farm irrigation water lifting and for electricity generation in developing countries.

A small open core throatless rice husk gasifier (15 cm diameter) was designed and developed at University of California Davis, USA (Kaupp, 1984; Cremer et al., 1986 & Tiangoo et al., 1986). The gas was used as fuel in a 3 kW single cylinder spark ignition engine. The gasifier operated trouble free for more than 300 hours. With a view to enhance this technology it was planned to develop the up scaling factors for the gas producer so that higher capacity systems could be designed and developed for other applications.

Reactor diameter is the most critical parameter for a throatless gasifier. Two different approaches are in use for estimation of the reactor diameter. Use of kinetic model is one approach (Jain et al., 1999 & 2002). The other approach is the use of specific gasifiecation rate (SGR). The second approach is investigated in the present study. Five gasifier reactor having internal diameters of 15.2, 20.3, 24.4, 30.3 and 34.3 cm were used. On all the five reactors a series of experiments were conducted keeping air flow rate as a variable parameter. The air flow rate range was selected in such a way so that the variation in SGR was from 100 to 270 kg $h^{-1}m^{-2}$. For each run, gas production rate, gas quality, temperature and pressure at various points in the test set up and gasification rate were monitored. The data was analyzed for the determination of specific gasification rate, specific gas production rate, air fuel ratio, equivalence ratio and cold gas efficiency.

2. GASIFIER SYSTEM

Gasifier system comprised of a gasifier reactor and gas cleaning unit consisting of a water scrubber and a dry filter. A brief description of different units follows:

2.1 Gasifier Reactor

Each reactor was a batch fed down draft throatless gasifier having constant diameter. The internal diameters of the five reactors were 15.2. 20.3, 24.4, 30.3 and 34.3 cm. These were made from 3 mm thick mild steel sheet. Gasifier consists of an inner reactor and a concentric containment tube. Internal diameter of the containment tube for the five reactors were 18.5, 25.3, 29.3, 35.8 and 41.2 cm respectively, where as length of containment tube was 20 cm more than the reactor in each case. The diameter of the containment tube was selected in such a way that the producer gas velocity in the space between the reactor and the containment tube was around 0.6 m/s in each case. The containment tube and the reactor were flanged together at the top. The top end of the reactor remained opened during the operation. The bottom of the containment tube was water sealed.

2.2 Gas Cleaning Unit

The gas cleaning unit consisted of a flooded sieve plate water scrubber and a dry packed bed filter. Cool gas was piped through flexible PVC hose from the water scrubber to the dry filter packed with rice husk residue of the gasifier. After the dry filter, a small portion of the gas was taken through two ice-cooled condensers connected in series for analysis. An orifice meter was connected in the main line to measure the gas flow rate. Gas was flared on a L P gas burner through suction blower. The experimental setup for the gasifier unit is shown in Figure 1.

2.3 Start up of the Gasifier

Small amount of char (rice husk residue from previous run) was placed over the grate followed by fresh rice husk. The purpose of adding char over the grate was to protect the grate from high temperature. The suction blower connected in the down stream section of gasifier (after the dry filter) was turned on and some burning pieces of paper were dropped in the reactor. When the fire spread over rice husk in the reactor, the reactor was considered to be ready for experiment.

3. MATERIAL AND METHODS

Eight runs on 15.2 cm diameter reactor and ten runs each on the remaining four reactors were conducted at different specific gasification rate. In each run gas flow rate, operating period, amount of husk consumed, temperature and pressure at various points and gas composition were monitored. The data was used to compute the air flow rate, gas heating value, specific gasification rate, gasification efficiency, air fuel ratio and equivalence ratio. Methods for various determinations are outlined below.

3.1 Temperature Measurement

The system was fitted with Chromel/Alumel (K type) thermocouple to measure temperature of gas at the gas outlet of gasifier, gas inlet and outlet temperature of water scrubber, dry filter and at orifice meter. The temperature values were recorded continuously on HP data acquisition system.

3.2 Pressure Drop

Pressure taps were provided to measure the pressure drop across the reactor, water scrubber and dry filter. Each pressure tap was connected to the pressure transducer and to HP data acquisition system. Glass U tube manometer and inclined tube manometer were also used to measure pressure drop across the reactor and the orifice meter respectively.

3.3 Gas Analysis

A small portion of the gas was taken out of the main gas line, between the air flow meter (orifice meter) and the dry filter. The producer gas was passed through an assembly of two ice cooled condensers and a suction blower, to remove the tars and condensate. Cool and dry gas was analysed using Beckman online gas analyzers. Cool and dry gas during each run was also filled in air tight glass sampling bottles after every 15 minutes. The gas in the glass bottles was latter used for analysis on Nucon 5700 Gas Chromatograph for carbon monoxide, carbon dioxide, hydrogen, oxygen, nitrogen, methane, acetylene, ethane and ethylene compositions. The analysis was done using thermal conductivity detector and Argon was used as carrier.

3.4 Gas Flow Rate

A calibrated orifice meter was connected in the gas line between the dry filter and suction blower. Pressure drop was measured using an inclined manometer. Standard curve between the pressure drop and flow rate was referred to get gas flow rate.

3.5 Heating Value of Producer Gas

Gas analysis data obtained on gas chromatograph for each run was used to compute the lower heating value of producer gas. Lower heating value of different constituents of producer gas at STP (20 ^oC & ! atm) used in the calculation is: Carbon monoxide – 11.57; Hydrogen – 9.88; Methane – 32.79; Acetyline – 51.32; Ethylene – 54.09 and Ethane – 59.36 MJ m^{-3} (Perry, 1984). The following expression (Jain et al, 2002) was used for calculating the lower heating value of producer gas.

$$CV_G = \sum X_i H_i$$

X_I = volume fraction of producer gas constituent
H_i = lower heating value of the gas constituent

3.6 Weight of Material and Operating Time

After firing, small quantity of rice husk (about one kg) was added to the reactor. When fire reached the top layer of the husk in the reactor, the weighed amount of rice husk for the run was added. The time was taken as the starting time for the run. Towards the end of the run when the fire again reached the top layer of husk, the run was concluded. The difference was recorded as net operating time.

3.7 Equivalence Ratio

Equivalence ratio is defined as the ratio of actual air used in a run to stoichiometric air requirement for the run. Knowing the elemental composition of rice husk, the stoichiometric air requirement was estimated as 3.3468 m^3 $kg^{-1}$of dry rice husk (Jain, 1996).

ER = (Amount of air used in a run)/(Amount of stoichiometric air in the run)

38 Specific Gasification Rate

Specific gasification rate (SGR) was calculated using the weight of dry rice husk gasified for a run, net operating period and the cross sectional area of the reactor using the following relation.

$$SGR = \left[\frac{Weight\ of\ dry\ husk\ used\ (kgh^{-1})}{Cros\sec tional\ area\ of\ the\ reactor\ (m^2)} \right]$$

3.9 Specific Gas Production Rate

Specific gas production rate is the rate of producer gas generation at STP per unit cross-sectional area of the gasifier.

$$SGPR = \left[\frac{Rate\ of\ gas\ production\ (m^3 / h)}{Cros\sec tional\ area\ of\ the\ gasifier} \right]$$

3.11 Gasification Efficiency

Gasification efficiency is the percentage energy of rice husk converted in to cold producer gas (free from tar). The following expression was used to compute the gasification efficiency.

$$\eta = \left[\frac{Amount\ of\ gas\ produced\ x\ LCV\ of\ gas}{Quantity\ of\ Husk\ used\ x\ LCV\ of\ husk} \right] x\ 100$$

4. RESULTS AND DISCUSSION

Gas flow rate, air fuel ratio, equivalence ratio, specific gasification rate, specific gas production rate, lower heating value of producer gas and gasification efficiency for each run on 15.2 cm, 20.3 cm, 24.4 cm, 30.3 cm and 34.3 cm diameter reactors are given in tables 1, 2, 3, 4, and 5 respectively. Lower heating value of husk was 14.35 MJ kg^{-1} (Jain et al., 1997).

4.1 Performance of the Reactors

With the increasing gas flow rate in a single reactor; air fuel ratio, equivalence ratio and specific gasification rate increased linearly in all the five reactors. Gasification efficiency increased with increasing specific gasification rate and started decreasing after passing through a maxima for each reactor. The variation of specific gasification rate vs gasification efficiency for each run on all the five reactors is depicted in Figure 2. The trend lines for the data depicted in the figure indicates very clearly that for all the five reactors, the maximum gasification efficiency falls in a narrow range of specific gasification rate i.e. between 185 to 215 kg h^{-1}m^{-2}. Therefore, an average value of optimum specific gasification rate as 200 kg hr^{-1}m^{-2} may be considered as a design parameter for throatless rice husk gasifier.

Specific gas production rate (SGPR) increased linearly with increasing SGR. Like SGR, the optimum value of SGPR that corresponds to maximum gasification efficiency, falls in a narrow range from 410 to 429 m^{3}h^{-1}m^2. An average value of SGPR as 420 m^3 hr^{-1}m^{-2} may be used for design of throatless rice husk gasifiers.

The data in Tables 1-5 indicate that, the maximum gasification efficiency corresponds to equivalence ratio of 0.40, 0.39, 0.40, 0.41 and 0.41 respectively for the five reactors. An average equivalence ratio of 0.40 may be selected for making material and energy balance calculations over the gasifier engine systems and their design work.

The gas temperature leaving the reactor was found to vary from 200 to 350 °C. In smaller diameter reactors the hot gas temperature was generally low. In a gasifier reactor the producer gas temperature depends upon gas flow rate. Higher gas flow rate accounted for higher producer gas temperature. Since the formation of carbon monoxide, hydrogen and methane is a function of reactor temperature, the lower temperature in the smaller diameter reactors resulted lower carbon monoxide and hydrogen, and therefore, lowers heating value of producer gas. That explains the lower gasification efficiency in smaller diameter reactors.

The temperature of the producer gas entering the water scrubber varied from 80 °C to over 150 °C. Generally higher producer gas temperature accounted for higher gas temperature at gas inlet to scrubber. During each trial run as the fire zone moved up, the heat transferred from hot producer gas to fuel bed in the containment tube reduced and caused higher gas inlet temperature to water scrubbers. The temperature of the gas leaving the water scrubber was fairly constant at 40 to 50 °C.

The optimum value of gasification efficiency is about 60% as given in the tables. In the system gas sample was continuously taken for analysis before the gas measurement. The sampling gas was estimated in a separate measurement to be about 10% of the total gas production. If this is taken into account, the maximum gasification efficiency comes to around 65% for rice husk gasification in open core down draft throatless gasifier.

4.2 Energy Output

The energy output for a gasifier is the chemical energy in producer gas when we want to use the producer gas for engine applications. It is determined as product of gas flow rate and gas LCV. For each reactor the energy output for the run when the gasification efficiency is maximum is shown in Table 6.for 15.2 cm diameter reactor the energy output is 29.5 MJ/h which corresponds to the energy requirement of a 3 kW diesel engine, operating in dual fuel mode. For 34.4 cm diameter reactor the energy output is 158.9 MJ/h which corresponds to the energy requirement of a 15 kW diesel engine, operating in dual fuel mode.

4.3 Design Parameter for Large Capacity Gasifiers

A rice husk gasifier system manufactured by a commercial gasifier manufacturer .i.e. M/s Associated Engineering Works, Andhra Pradesh, INDIA was investigated by the Author. The gasifier system is an open core throatless type gasifier reactor having a capacity to gasify 100 kg/h rice husk. The gasifier about 4 m high has a cross-sectional area of 1x 0.5 m^2. Based on the size of the gasifier and the husk gasification capacity, the specific gasification rate comes out to be 200 kg m^{-2}-h^{-1} which matches to the optimum value of SGR determined in the present study. The gasifier system is installed in the Laboratory of the School of Energy Studies. The performance evaluation studies on the system are yet to be carried. This clearly indicate that the SGR approach for designing the rice husk gasifier in the capacity range under study is valid even for large capacity systems up to 100 kg-h^{-1} capacity. However more systematic study on this aspect should be carried.

For determining the reactor diameter for a downdraft stratified gasifier , Reed et al, 1987 has indicated an optimum value of specific heat rate as 11.6 GJ m^{-2}-h^{-1} for 8 to 75 cm diameter reactors. It is further reported by in the same reference that the maximum specific heat rate can climb to 23.3 GJ m^{-2}-h^{-1} with gasifier having mechanical ash removal unit. However it is reported that these figures are derived from experiment with the particular gasifier type and mode of operation. These are not based on a scientific and systematic study. Using the data in the present study, the corresponding specific heat rate comes out to be 2.7 GJ m^{-2}-h^{-1}. Thus the value reported by Reed et al, 1987 do not match with the findings of the present study.

5. CONCLUSIONS

5.1 Optimum value of specific gasification rate for gasification of rice husk in throatless open core gasifier reactor is 200 kg $h^{-1}m^{-2}$.

5.2 Optimum value of equivalence ratio is 0.40 .

5.3 The lower heating value of producer gas under the optimum operating conditions is about 4.5 MJ Nm^{-3}.

5.4 The cold gas efficiency for throatless rice husk gasifier is around 65%.

6. REFERENCES

Baruah, D.C. & Jain, A.K., 1998, Distribution of agricultural residues in India. Jr. of Agril. Engineering, 35 (1):7-12, July-Sept, 1998

Creamer, K.S., Jenkins, B.M. and Goss, J.R. 1986, Small scale rice hull gas producer-gasoline engine performance. Paper No.86-3071-ASAE Summer meeting, June 29-July 2, San Luis Obispo, CA.

Jain, A.K. and Joss, J.R,, 2000, Determination of reactor scaling factors for throatlessrice husk gasifier. Biomass & Bioenergy, vol 18, 249-256

Jain, A.K., and Bhatnagar, A.P. 1990, Gasifier research at punjab agricultural university. International Symposium on Application and Management of Energy in Agriculture-the Role of Biomass Fuels. IIT, New Delhi, India, 1-22.

Jain, A.K., Sharma, S.K. and Singh, D. 1997, Availability and characteristics of paddy husk as a renewable energy source. Journal of Agricultural Engineering 34 (1): 10-14.

Jain, A.K., Sharma, S.K. and Singh, D. 1999, Reaction kinetics of paddy husk decomposition. Jr. of Solar Energy, Engineering, ASME, vol 121, 25-32, February, 1999.

Jain, A.K., Sharma, S.K. and Singh, D. 2002, Development of a kinetic model for designing throatless gasifier. Indian Chemical Engr, Section A, vol 44, No. 4, October-December, pp 232-240.

Jain, A.K., Sharma, S.K. and Singh, D. 2002, Energetics of rice husk gasification in a throatless gasifier. Indian Chemical Engr, Section A, vol 44, No. 4, October-December, pp 232-240.

Kaupp, A. & Goss J.R., 1984, Small scale gasifier engine systems. Friedr. Vieweg & Sohn Verlagsgesellschaft mbH, Braunschweig.

Kaupp, A. 1984, Gasification of Rice Hulls. Friedr. Vieweg & Sohn Verlagsgesellschaft mbH, Braunschweig.

Pathak B.S. and Jain, A.K., 1985, Gasification of rice husk in an updraft reactor. Energy Management, NPC, Vol 3, 38-45.

Perry, R.H. 1984, Chemical engineers' handbook. sixth edition, McGraw Hill Publication, USA.

Reed, T.B., Levie, B and Graboski, M.S. Fundamentals, development and scaleup of air-oxygen stratified down draft gasifier, Golden, Colorado, USA, SERI/PR-234-2571, US category, 245, 1987.

Tiangoo, V.M., Jenkins, B.M. and Chancellor, W.J. 1986, Design and development of a continuous small scale rice hull gas producer. Paper No. 86-3070, ASAE Summer meeting, June 29 - July 2, at San Luis Obispo, USA.

Table 1 Performance characteristics of 15.2 cm diameter gas producer.

Run No.	Gas flow rate (m^3 hr^{-1})	ER (φ)	SGR (kg $h^{-1}m^{-2}$)	SGPR (m^3 $h^{-1}m^{-2}$)	L.H.V. of P.G. (MJ m^{-3})	η (%)
1	3.32	0.31	117.90	182.89	4.02	43.46
2	4.53	0.33	147.80	249.54	4.07	47.89
3	5.87	0.35	175.80	323.36	4.18	53.58
4	6.72	0.38	184.00	370.18	4.07	57.06
5	7.55	0.40	195.00	415.91	3.91	58.11
6	9.68	0.44	233.00	533.24	3.59	57.25
7	11.55	0.50	251.00	636.25	3.08	54.41
8	13.00	0.53	264.10	716.13	2.68	50.64

Table 2 Performance characteristics of 20.3 cm diameter gas producer.

Run No.	Gas flow rate (m^3 hr^{-1})	ER (φ)	SGR (kg $h^{-1}m^{-2}$)	SGPR ($m^3 h^{-1}m^{-2}$)	L.H.V. of P.G. (MJ m^{-3})	η (%)
1	5.66	0.27	128.8	174.8	4.21	39.82
2	7.20	0.30	142.3	222.4	4.15	45.19
3	8.63	0.34	153.5	266.5	4.07	49.25
4	10.27	0.36	169.7	317.2	4.10	53.41
5	11.60	0.38	181.2	358.3	4.05	55.80
6	12.10	0.38	185.0	373.7	4.05	57.01
7	13.28	0.39	195.5	410.1	4.02	58.78
8	13.80	0.39	198.5	426.2	3.85	57.62
9	15.50	0.41	229.5	478.7	3.65	53.07
10	17.40	0.44	247.5	537.4	3.38	51.14

Table 3 Performance characteristics of 24.4 cm diameter gas producer.

Run No.	Gas flow rate (m^3 hr^{-1})	ER (φ)	SGR (kg $h^{-1}m^{-2}$)	SGPR ($m^3 h^{-1}m^{-2}$)	L.H.V. of P.G. (MJ m^{-3})	η (%)
1	6.62	0.27	105.3	141.5	4.22	39.52
2	7.62	0.29	110.1	162.9	4.15	42.79
3	9.20	0.31	126.0	196.7	4.20	45.68
4	12.36	0.34	151.0	264.2	4.15	50.60
5	14.35	0.37	159.3	306.8	4.05	54.35
6	16.34	0.39	170.8	349.3	4.05	57.72
7	19.26	0.40	189.9	411.7	4.00	60.44
8	20.90	0.43	200.0	446.8	3.85	59.94
9	23.87	0.44	230.8	510.3	3.49	53.77
10	25.23	0.43	246.7	539.4	3.20	48.75

Table 4 Performance characteristics of 30.3 cm diameter gas producer

Run No.	Gas flow rate (m^3 hr^{-1})	ER (φ)	SGR (kg $h^{-1}m^{-2}$)	SGPR ($m^3 h^{-1}m^{-2}$)	L.H.V. of P.G. (MJ m^{-3})	η (%)
1	13.85	0.33	111.96	189.52	4.25	50.1
2	15.90	0.34	124.68	217.48	4.28	52.0
3	18.25	0.36	136.01	249.68	4.27	54.6
4	20.31	0.37	144.66	275.35	4.34	57.6
5	22.37	0.38	155.53	306.08	4.35	59.7
6	25.07	0.39	168.38	342.90	4.35	61.7
7	28.66	0.39	188.99	392.04	4.40	63.6
8	31.49	0.41	204.31	430.79	4.20	61.7
9	34.68	0.43	215.14	474.37	3.80	58.4
10	36.55	0.44	224.5	499.95	3.50	54.3

Table 5 Performance characteristics of 34.3 cm diameter gas producer

Run No.	Gas flow rate (m^3 hr^{-1})	ER (φ)	SGR (kg $h^{-1}m^{-2}$)	SGPR ($m^3 h^{-1}m^{-2}$)	L.H.V. of P.G. (MJ m^{-3})	η (%)
1	13.50	0.28	105.0	146.0	4.28	41.48
2	16.25	0.30	116.2	175.8	4.25	44.81
3	18.74	0.31	128.8	202.7	4.30	47.17
4	22.35	0.33	141.9	241.8	4.21	49.99
5	26.00	0.35	152.0	281.3	4.11	53.00
6	29.20	0.37	160.0	315.9	4.00	55.03
7	35.00	0.39	180.0	378.6	4.02	58.93
8	39.70	0.41	193.7	429.5	3.98	61.49
9	41.75	0.42	210.0	451.7	3.86	57.85
10	43.00	0.41	235.0	465.2	3.55	48.97

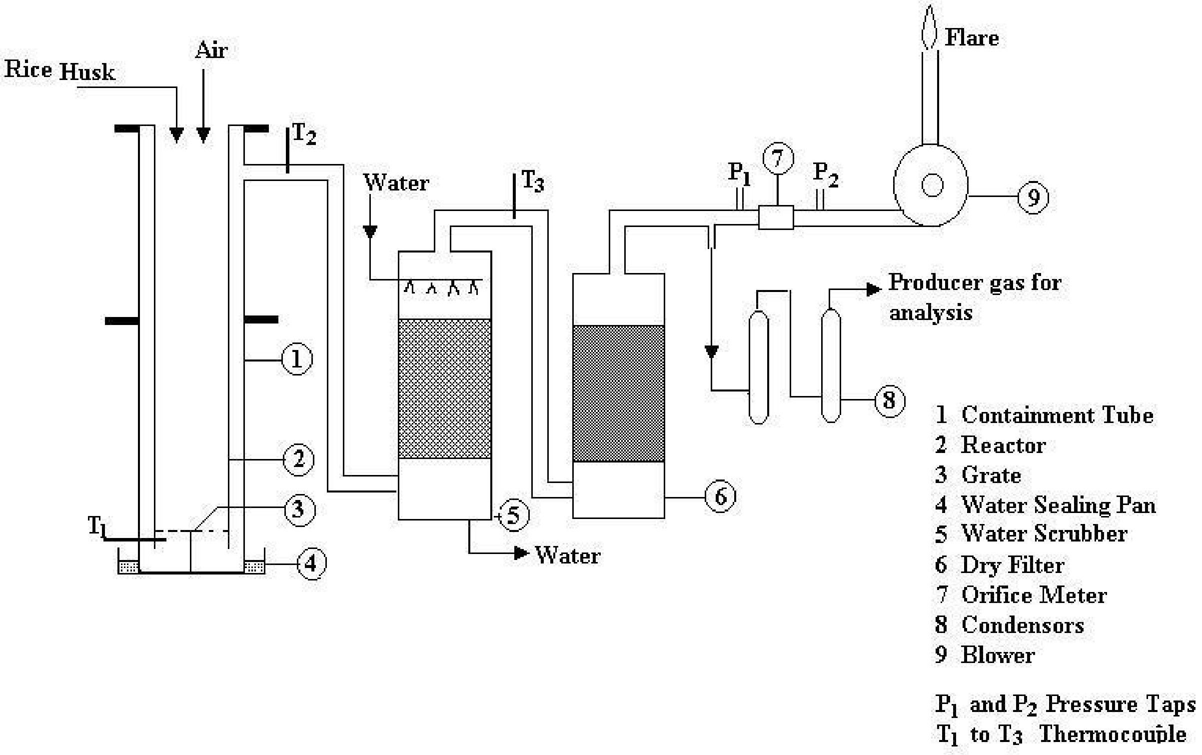
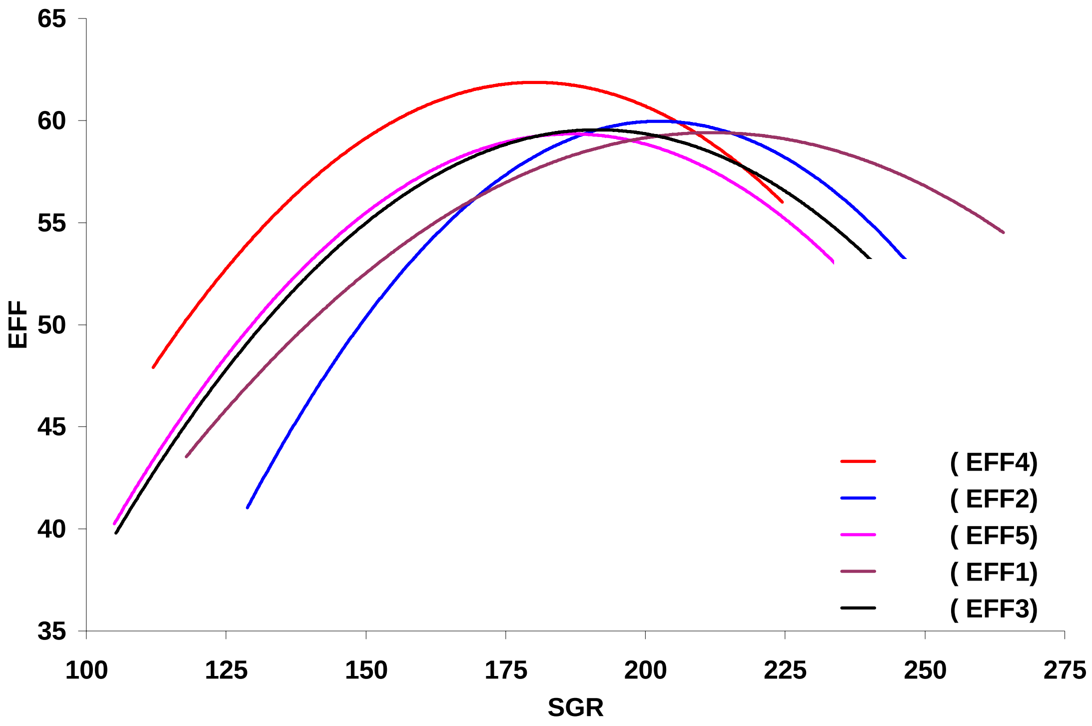


Figure 1 Experimental setup of the gasifier unit



Specific gasification rate (kg $h^{-1}m^{-2}$)

Figure 2 Gasification efficiency Vs SGR for the five reactors