BIOMASS GASIFICATION- BASICS AND CONSIDERATIONS.

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ABSTRACT

THE PAPER DEALS WITH THE BASICS OF THE BIOMASS AND ITS APPLICATION FOR GASIFICATION AND USAGE OF PRODUCER GAS GENERATED THERE FROM FOR THERMAL APPLICATION AND POWER GENERATION. THE AUTHOR HAS ALSO BROUGHT OUT THE DIFFERENCE BETWEEN THE BIOMASS AND COALS, A FOSSILIZED SOLID OF BIOMASS ORIGIN. THE KEY PARAMETERS SEPERATING THE TWO HAVE ALSO BEEN HIGHLIGHTED. GASIFICATION OF BIOMASS FOLLOWS THE SAME PRINCIPLE SO FAR THE REACTION CHEMISTRY IS CONCERNED. BUT THE OTHER RELATIVE ASPECTS BEARS SOME SPECIALITY AND CRITICALITY FOR WHICH NUMBER OF BIOMASS TECHNOLOGIES APPEARED IN TEXT BOOKS, BUT ONLY FEW COULD PROVE COMMERCIAL SUCCESS. WHILE COAL GASIFICATION USING AIR AND STEAM HAS BEEN WELL ESTABLISHED, BIOMASS GASIFICATION SOMEWHAT LAGS BEHIND DETAILS OF WHICH HAVE BEEN ELABORATED IN THE PAPER. VARIOUS ISSUES CONCERNING USAGE OF BIOMASS BASED PRODUCER GAS FOR THERMAL APPLICATION AND POWER GENERATION, RISK FACTORS, SAFETY AND OTHER ASPECTS HAVE BEEN DISCUSSED IN THIS PAPER.

INRTODUCTION:

At present coal & petroleum based oils account for nearly 80% of the total energy consumed in India. The balance is derived from natural gas, nuclear power & non conventional forms of energy. The carbonaceous fuels release heat through combustion system & the quantum of heat is dependent on the heating value of the fuel. The atomic fuels release heat through nuclear fission / fusion in term of the Einstein's theory of relativity. A small quantity of matter lost in a radio active material would produce huge quantity of energy. In a nuclear power plant, this heat energy is utilized to generate steam to drive turbine for power generation. However, the misuse of atomic power coupled with some accidents in power plants in Russia (Chernobyl April 26, 1986) & also disaster in Japan (Fukushima March 11, 2011) caused by natural calamities (Tsunami earthquake) had created some fear throughout the world about the safety & environmental aspects of atomic based power plants. Even then adoption of modern technology will set aside the apprehensions about the setting up of atomic power plants to tide over the global energy crises to the extent possible. It is worth mentioning, any energy utilization system whether based on fossil fuel, oil or gas must be associated with adequate safety arrangements, energy saving equipment to attain the best result in a sustained manner.

Energy utilization is the yardstick to assess the development of a nation. A fact it is that, without imparting priority on the use of coal & oil, economic planning even today is unthinkable. This has created enormous pressure on the fossil fuel & perhaps no country can come out of this situation unless there is sudden scintillating discovery of the alternatives. For the last few decades use of biomass in a selective manner is being advocated throughout the world to generate energy as much as possible to give some relief on the burden of the fossil fuels. It is well understood that generation of energy from biomass would be a drop in the ocean compared to the total energy required not only in India but also in many other countries. The Government of India is advocating use of biomass for thermal & power application through a separate Ministry titled Ministry of New & Renewable Energy. Release of energy from biomass may be through the conventional combustion technique or gas making technologies. The process of gas making from biomass is by & large similar to that of gasification of coal using air/ oxygen, but bears a special significance with regard to the design of the gas making equipment & also operational techniques. The subject of biomass as such is quite vast in respect of behavioral aspects of different types of biomass though the chemical parameters could be similar to each other & it is for this reason the processing of biomass calls for careful technological assessment.

BIOMASS & THEIR RELATIVE CHARACTERISTICS:

Biomass is essentially a product of photosynthesis & it is in fact a natural solar cell, storing solar energy. On dry mineral matter free basis all biomass have roughly the same CHON (Carbon, Hydrogen, Oxygen, and Nitrogen) elements & this implies that the heating values of all biomass will be about the same on that basis excepting the effects of moisture content & non combustible mineral matters. The low heating value of the different biomasses (as received or air dried basis) is due to the presence of high oxygen content in it, high moisture content & variation in ash content in different biomasses. It is well understood that all biomasses are wood linked & therefore the analysis results of most of the biomasses on dry mm free basis will be closed to those of wood. Wood is the forefather of solid carbonaceous materials like peat, lignite, bituminous coal, as shown in Table-1 (on dry mm free basis). Bituminous coal is also of different types like non caking coals, high volatile blendable coals termed as semi-coking coals, good coking coals & finally the most matured variety known as anthracite. These terminologies have close linkage with the maturity of coal during the past decades & are related to geological transformation of wood which we today call a biomass. The conception of coal is inseparable from wood whether it is in India or any part of the world.

Table-1
Wood VS Coal (% on dry mm free basis)

Constituents	C	H_2	O_2	C.V. Kcal/Kg
Wood	50	6.5	43.0	4440-4460
Peat	60	6.0	32.0	5550
Lignite	68-72	5.0-5.3	21-23	6400-7500
Non Caking Coals	79-83	5.1-5.5	8-13	7800-8220
Blendable Coals (H.V)	84-86	5.2-5.6	6.0-7.5	8300-8560
Coking Coals	88-91	4.6-5.0	2.5-4.5	8600-8780
Anthracite	92-94	3.5-4.0	1.2-2.5	8600-8660

From the above it will be noted that wood has the lowest carbon, highest O_2 & lowest heating value & its transformation into coal is interesting with the conspicuous changes of the relative constituents particularly in respect of carbon going higher & higher, hydrogen going lower & then again coming up in the high volatile coals & then going down in coking coals & anthracites. Further the heating value increases up to the stage of coking coals & then marginally falls in the case of anthracite.

It has already been stated that biomass is a woody material containing moisture & ash. If a biomass contains 20% moisture & say 2% ash its calorific value can be calculated as follows:
2% ash = 2x1.1= 2.2 (mineral matter)
So inert matter= 20+2.2=22.2
Combustible matter in wood = (100-22.2) =77.8 or 0.778Kg/Kg biomass.
Hence heating value of a biomass having 20% moisture & 2% ash will be
4440 x 0.778= 3454.32Kcal/Kg wood.

In the case of rice husk having moisture content 15% & ash content 20% (mm 22%) the calorific value will be 4440x0.63= 2797 Kcal/Kg & when moisture is 12% the calorific value of rice husk will be 4440x0.66=2930 Kcal/Kg. (rounding to 2900)

It has to be borne in mind that in working the energy balance involving usage of biomass, the heating value has to be taken in the realistic manner rather than going in for some extreme/ unreliable data provided by any user. Since all biomasses are wood linked the results of analysis of most of the biomasses, on dry mm free basis will be close to those of wood as exemplified in two extreme cases in Table-2.

Table-2
Proximate, ultimate analysis & calorific value of wood & rice husk (approx.)

	Wood		Rice Husk	
Basis	Air Dried	Dry mm free	Air Dried	Dry mm free
a) Proximate (% W/W)				
Moisture	10-12	2	10-12	-
Ash	0.6-1.5	-	19-21	-
V.M.	68-70	78-79	58-60	77-79.5
F.C.	18-19	20.5-22.0	14-16	20.5-23
b) Ultimate (% W/W)				
Moisture	10-12	-	10-12	-
Ash	0.6-1.6	-	19-21	-
Carbon	44-45	49-52	36-37	50-52
Hydrogen	5.4-5.5	6.2-6.5	4.4-4.5	6.2-6.4
Oxygen	36-39	41-42	28-29	41-43
Sulphur	0.03-0.04	0.04	0.03-0.04	0.05
Nitrogen	0.35-0.40	0.4	0.4	0.6
Phosphorus	0.03-0.04	0.04	0.06-0.08	0.09
c) C.V.(Kcal/Kg)				
Gross	4000-4100	4400-4600	3350	4680
Net	3700-3800	4100-4200	3100	4400

All woody material having low ash (say 1-3%) & low moisture content (10-12%) will have fixed carbon ranging from 16-19 which functions as one of the parameters to identify a biomass without going into the criteria of the respective constituent like CHON & C.V. on dry mm free basis. Unlike coal ‘Wood’ is the only one material & has no geological maturity parameters as in coal & hence offers easy clue for identification.

CHARACTERISATION OF BIOMASS SPECIES FOR ENERGY GENERATION:

The basic characteristic parameters involved in the selection of biomass for energy generation should take into consideration the following categories:

1) Physical Characteristics: shape, structure, size, bulk density & flow properties. The other aspects are equilibrium moisture content of the biomass, cutting & crushing behavior.
2) Chemical Analysis: This will include proximate analysis, ultimate analysis, determination of heating value, ash fusion point temperature & ash analysis.

Once a material is identified as a biomass it may not be necessary to perform the entire test except the proximate analysis, calorific value, ash fusion point & the size of the biomass & the flow characteristics. Generally all biomass for energy generation should not contain more than 20% moisture content, the ideal one would be 12-15%. Bulk density is another important parameter which will control the fuel depth & also accessibility of air during gasification. Too big particle size will lead to incomplete combustion of the biomass during energy generation. The ideal size of wood for gasification would be 12mm to 40mm. The granular biomass should have particular "Aspect Ratio" i.e. length v/s width for free flowing & also for gasification purpose. This aspect ratio (A.R.) is different for different biomasses. Generally the minimum length of the biomass should be 5-15mm & width or diameter about 2-3mm. There is no precise A.R. value which can be recommended for any biomass because of involvement of many other characteristics in different biomasses. Many biomass residues are cut into smaller sizes to have the desired A.R. value for free flowing & also for gasification. Straw as such does not flow unless it is chopped by chaff- cutter. Powdery biomasses require to be densified by converting them into pallets or briquettes of appropriate size. These are some of the hindrances in processing biomass.

SOURCES OF BIOMASS:

In general the sources of main biomass could be as follows:

1) Woody Biomass or Forestry Waste: wood chips & wood, saw dust etc.
2) Agricultural Residues: coconut shell, rice husk, bagasse, straw, groundnut shells, coffee husk, stalks, bamboo dust & bamboo slice etc.
3) Aquatic Biomass: water hyacinth, aquatic weeds, algae etc.

4) Wastes: municipal solid waste & sewage sludge, animal wastes, industrial wastes etc.

Leaving aside the abnormally high ash content of rice husk it has been seen that the deoiled seeds, paddy straw, tea wastes contain high ash ranging from 10-20% or even higher. Some of the agro residues also contain high ash.

The ash fusion point is a very important parameter in combustion & gasification reactions. Generally the ash from deoiled seeds, groundnut shells, nutshells, corncob, coconut coir, coffee husk & even the coconut shells has low ash fusion point due to the presence of relatively higher alkali oxide i.e. oxides of sodium, potassium & calcium. In the present context for powering biomass we shall consider only item number 1 & 2 as the sources of biomass. Item number 4 i.e. municipal solid wastes, animal wastes, industrial wastes particularly the distillery wastes produced by fermentation of sugar, molasses & starch are subjected to anaerobic digestion for the production of biogas/ methane along with carbon dioxide, hydrogen sulphide etc.

BIOMASS CHARACTERISTICS & CHEMICAL ANALYSIS

Innumerable data have been published in the above regards by the MNRE (Ministry of New & Renewable Energy) & also by the SPRERI (Sardar Patel Renewable Energy Research Institute), Vallabh Vidya Nagar, Gujarat & other organizations. The author will refrain from furnishing details of the biomasses except some key aspects which would be normally useful for consideration in energisation of biomass. Besides the proximate & ultimate analysis, the other parameters which play significant role in gasification processes are the Bulk Density (B.D.) & the ash fusion data. For better understanding the difference between the fossil based fuel & the biomass a composite table is presented below (Vide table-3)

Table-3

Bulk Densities & Ash Fusion point of
Lignite, coal, coke, woodchips, saw dust
Paddy husk etc.

SL. No.	Fuels / Biomass	Bulk Density	Ash Fusion Point
		Kg/ m^3	ID^{o}C
1	Lignite (15% moist, 4% ash)	480-520	1100-1200
2	Coal (20-26% ash)	750-800	1110-1350
3	Hard Coke	520-560	1140-1350
4	Coke from Non caking coals	480-520	1140-1350
5	Wood Chips (15-20% moist)	250-280	Over 1300
6	Saw dust (15-20% moist)	250-270	Over 1300
7	Rice Husk (15% moist)	125-150	Over 1250
8	Straw (15% moist)	80-100	Over 1300
9	Cotton Stalk	250-300	Over 1300
10	Bamboo Dust	250-300	1100-1300
11	Coffee Husk	200-250	930-960
12	Coir Pith	45-50	830-850
13	Nutshell	350-400	950-1000
14	Jute Stick	70-100	Over 1300
15	Corn Cob	300	800-900
16	Groundnut Shell	150-200	1100-1200
17	Bagasse (Air dry & brittle)	70-80	Over 1300
18	Mustard Stalk	170-220	Over 1250
19	Sunflower Stalk	200-250	Over 1300
20	Jetropha Cake	300-350	1050-1100

Coal / coke ash generally contains 55-65% SiO_2 & 20-27% Alumina. Ash from paddy husk contains 89-91% SiO_2. Coal & coke generally contain 0.5%-1% sulphur whereas biomass contains 0.008-0.02% sulphur. Plants growing near sea side have high alkali in ash & hence ash fusion point of those plants tends to be low.

Freshly cut biomass / woody materials have very high moisture content (50-70%). Before using biomass either for combustion or gasification, biomass requires to be air dried to attain equilibrium moisture with the surroundings i.e. the relative humidity & temperature. An oven dried biomass if left exposed to the atmosphere at a particular humidity it will pick up moisture from the atmosphere depending on the water content in the atmosphere. In Table 4 the equilibrium moisture content of different biomass material is given.

Table 4

Equilibrium moisture content of some biomass materials:

Biomass	Equilibrium Moisture Content (%)			
	RH-20%	RH-40%	RH-60%	RH-80%
Bagasse	0.55	4.0	16.50	34.86
Cotton Stalk	-	3.03	12.05	27.05
Dhainch Stalk	0.31	5.25	8.76	31.03
Maize Stalk	0.68	6.01	23.06	38.08
Maize Cob	-	3.25	13.73	27.93
Arhar Stalk	0.45	4.57	14.66	20.05
Rice Husk	0.56	1.73	21.6	29.46
Rice Straw	1.47	6.62	13.05	36.78
Wheat Straw	0.42	10.42	15.07	34.03

Source Biomass Management for Energy Purposes- Issues & Strategies. (SPRERI- Vallabh Vidyanagar Publication, January-2005).

From the above it may be noted that equilibrium moisture for woody biomass at 60% RH is in the region of 15-20%. In the rainy season the moisture content in woody biomass could be more than 25%.

Table 5 provides data on proximate analysis & calorific value of some of the common biomasses which may have practical importance for gasification. (Source- MNES, SPRERI & others). The data given are on dry basis of the biomass material.

Table- 5

Proximate analysis & calorific value (gross) of different biomass materials

(Dry Basis) – approx.

BIOMASS	CV Kcal/Kg	ASH %	V.M. %	F.C. %
Woody	4460	1.30	77.00	20.50
Bagasse	4340	3.50	78.00	18.50
Bamboo dust	4400	6.00	76.50	17.50
Cashew nut Shell	4450	3.00	77.00	20.00
Castor seed shell	3900	8.00	72.00	20.00
Coconut Stem	4380	5.60	75.20	19.20
Coconut Shell	3700	2.00	79.80	18.20
Coffee Husk	4100	5.30	75.90	18.80
Cotton Shell	4300	4.60	72.20	23.20
Ground Nut Shell	4200	4.00	75.00	21.00
Jute Stick	4402	1.20	83.40	15.40
Mango Kernel	4360	6.70	75.90	17.40
Paddy Straw	3500	15.00	73.20	11.80
Ragi Stalk	4060	5.40	77.40	17.20
Rice Husk	3000	22.10	65.20	12.70
Subabul	4340	3.50	78.50	18.00
Walnut	4770	1.00	77.50	21.50
Wheat Stalk	3900	5.70	78.70	15.60
Wheat Straw	4100	8.00	72.00	20.00
Wood Saw dust	4380	2.70	82.30	15.00
Jetropha Cake	4540	6.00	75.00	19.00

Ultimate analyses of the different biomass materials are not given because those can be derived from the concept of dry mm-free data presented in Table- 1 & 2. If the moisture & ash of the biomasses are known, carbon, hydrogen, oxygen, nitrogen etc can be worked out.

POWERING OF BIOMASS:

All solid biomass materials containing CHON can be powered by different techniques of which combustion & gasification are most common. By combustion the entire potential heat in biomass can be released by using air or oxygen, which forms the concept of heating value of the carbonaceous materials. The second technique is the gasification of biomass, which is the process of conversion of the potential heat of the solid biomass material into heat in the gases. *The technology may be regarded as fuel switching to convert solid fuel to gaseous fuels.* Gasification is carried out in a specially designed reactor (called gasifier) using air & steam under specific thermal conditions inside the gasifiers.

The gasification technology is an age old technology may be as old as 200 years. Previously this technology was being adopted using coal & coke throughout the world to generate gas for industrial application mainly for heating purpose. Germany had used this technology during the Second World War (1939-45) using lignite briquette to produce CO & H_2 for F.T. synthesis for the production of synthetic petrol. Thereafter gasification process using coal & coke was also used in different industries to obtain heating gases. The global oil crisis of 1970-1973 coupled with hike in petroleum price gave fresh thrust in promoting the age old gasification process. Added to this, depletion of oil reserve throughout the world had roused great concern in the world. Even availability of solid fuels like coal & coke is in the wane. The environmental issues arising out of smoky fuels had restricted the use of coal & coke in haphazard manner. It is stated that environmental degradation & global warming have been caused by indiscriminate use of carbon unfriendly fuels. Therefore attention was diverted to the use of biomass material to generate energy through gasification process. Government of India is also encouraging adoption of biomass gasification technology for thermal application & power generation as much as feasible.

IDEAL FEEDSTOCK FOR BIOMASS GASIFICATION:

Gasification of biomass does not follow any specific venue so far the materials (biomasses) are concerned. The deciding factors to gasify biomass will depend on the type of biomass, physical & chemical characteristics & the type of the processes adopted. It would appear that since all biomasses have on dry mineral matter free basis by and large the same CHON constituents & also the calorific values, all of them could be gasified without any hindrance. Theoretically, this assumption could be correct but in actual practice things could be different. Many of the biomasses would require special treatment to condition them for feeding the gasification reactors & also generating adequate reaction conditions inside the reactor not only for gasification but also for discharge of the ash from the reactors. All such adoptions should be within the reach of the operator. Often laboratory or pilot plant tests done on particular biomass are shown as a final verdict in respect of gasification potentiality of the masses. But its commercial application could be confronted with several problems which might discard some biomasses for gasification, thereby isolating some selected type biomass which could be regarded as difficult materials in respect of viability of those biomasses in large scale operation unless those materials are shaped & conditioned to fit into the gasification process, the cost factor remaining as a major issue besides other factors. For example straw is a very light material for transportation, handling etc. It can be theoretically gasified in small & tall gasifiers. However in large plants rice straw gasification may be beset with innumerable problems. Attempts have been made to gasify rice straw (cut into small pieces) in admixture with rice husk or saw dust. So is the case with the gasification of dry bagasse which is very light, brittle, & highly combustible. Bagasse as such is utilized in the sugar plants as a fuel in the boiler. Rice straw is also utilized as cattle feed & also roofing the huts in the village. Saw dust apparently looks very good for gasification but in the gasifier due to its relatively high bulk density & also the fineness of the material, difficulty arises within the gasifier due to compaction of the mass for which the gasifying media like air & steam cannot pass through conveniently at the desired air flow rate. This difficulty can be overcome by thinning the bed but the thinness of the bed may not accommodate the different reaction zonal parameters of gasification process for which the process of gasification may become unstable inviting serious problems. It is advisable to gasify coarse saw dust after mixing with a low density biomass of appropriate size like rice husk in the ratio of 30% saw dust & 70% rice husk. All these assumptions require to be established in practical application in a commercial plant. This applies to any biomass which is intended to be used in gasification. Mere analytical results of biomasses should not be considered as the deciding factor in respect of gasification potentiality. Its acceptability in a particular type of gasifier has also to be evaluated. The other factor is the ash fusion point of the biomass which should be more than 1200^{o}C (ID) to avoid slagging of the ash during the gasification process. In the case of biomasses having low ash content (say below 3 percent) the problems may not hinder gasification of the mass, but if the ash content of the biomass is high major difficulties will arise.

Fire wood cut into small sizes (50mm to 25mm) & charcoal are excellent materials for gasification as has already being established. Stalks of various plants also constitute ideal feed stock. The yield of gas from wood at different moisture content as furnished in the MNES document (1997) is furnished in Table-6.

Table-6

Specific gas rate (Nm^3 / Kg wood), thermal efficiency of conversion (%) & moisture content of wood.

Thermal Efficiency % Moisture %	100	90	85	80	75	70	65	60	50	40
0	4.20	3.78	3.57	3.36	3.10	2.94	2.73	2.52	2.10	1.68
5	3.96	3.56	3.37	3.18	2.97	2.77	2.57	2.38	1.98	1.58
10	3.72	3.37	3.19	3.00	2.79	2.60	2.42	2.23	1.86	1.49
15	3.49	3.14	2.97	2.80	2.62	2.44	2.27	2.09	1.74	1.40
20	3.25	2.93	2.77	2.60	2.44	2.28	2.12	1.95	1.62	1.30
25	3.02	2.72	2.57	2.42	2.26	2.11	1.96	1.81	1.51	1.21

The abovementioned gas yield data at different thermal efficiencies & moisture content do not take into consideration blast saturation of air (BST) with steam. Normally, air is passed through the gasifier at 60°C BST. The quantity of steam at that temperature is around 0.45Kg per Kg of biomass out of which 80% will go into reaction. The total heat content available in steam for gas production will be around 224 Kcal. If the calorific value of gas obtained by gasification is 1250 Kcal/Nm^3, an additional quantity of about 0.18 Nm^3 gas will be produced due to BST effect. However, this effect is often not taken into consideration since the function of steam inside the gasifier is to control the temperature rise in the oxidation zone to minimize slagging. Steam also increases the hydrogen content (also CO content) in the gas due to steam carbon reaction inside the gasifier, which is essential for flame stabilization when the gas is burnt.

No doubt wood having specific sizes is an ideal feed stock so far biomass gasification is concerned. Indiscriminate use of wood for gasification purpose will have environmental effect arising out of deforestation. Therefore alternative feed stocks should be searched for gasification purpose which will have woody characteristics. The most accepted material in lieu of wood is rice husk particularly in India. On an average yield of rice husk is 20% of the paddy & considering the total output of paddy in India the availability of rice husk could be abundant. Use of rice husk in gasifier has been well established.

Rice husk is a difficult material both for combustion & gasification compared to other biomasses. It requires longer time to react due to its Silica-Cellulose structure. This special feature coupled with the ideal size & texture had generated somewhat low bulk density characteristics (BD is 125 to 150 Kg/m^3). Rice husk cannot be compacted easily for which in the gasifier the mass (rice husk) provides space/ voidage for the air which is blown through the gasifier to affect combustion/ gasification. However for efficient combustion special attention is required towards intimate contact of husk with air & sufficient reaction time. The chemical properties of rice husk are already given in Table-2. Due to critical nature of rice husk & also higher reaction time for gasification, the efficiency of the gasifier rarely exceeds 65%. The carbon lock in the cinder is as high as 15-20%. Due to higher ash content in the rice husk (ash-19-22%) any negligence in operation may create high temperature in the reaction zone & also fusion of the ash to hinder flow of the material inside. The quality of gas will also become poor. The performance of the gasifier may also be erratic. The reverse effect may also be seen i.e. lowering of temperature in the reaction zones arising out of malfunctioning of the gasifier. All these are indicated by the colour & nature of the ash discharged. The yield of gas using rice husk in the gasifier has been found to be 1.65 to 1.85 Nm^3 /Kg rice husk. A yield of 1.70Nm^3/Kg to 1.75Nm^3/Kg rice husk (at 15% moisture) may be accepted as standard data. The ash of rice husk contains 89-90% silica having ash fusion point above 1300^{o}C. Apparently ash from rice husk seems to be an attractive material for recovering silica out of it. However for this purpose the ash requires to be completely made free from the contamination of un-reacted rice husk. Besides this different opinions exist about the usage of the ash of the rice husk as the source of silica because of the heating effects inside the gasifier during gasification reaction. The silica in ash is mostly in finely divided amorphous condition but effect of high temperature in the oxidation zone of the gasifier tends to make it crystalline & some part of the ash also combines with carbon with the formation of inert black ash. This type of ash has been stated to be even worse than river sand.

REACTION FUNDAMENTALS OF PRODUCER GAS GENERATION:

The energy required for gasification is derieved from within the system in the oxidation zone where air generates the required heat during combustion reaction to initiate all the other reactions in different imaginary zones which could be overlapping with one another. It is quite important to maintain these zones in their appropriate status to obtain a gas of required quantity & quality in a consistent manner. The air which is pushed through the gasifier should match the actual requirement which is in the order of 1.6 to 1.8Kg/Kg of biomass. If the air is in excess of the need, the reaction zones will not only be disturbed but un-reacted air will come out with the gas with all its adverse consequences. The different stages involved in gasification are as follows:

Oxidation:

$C+O_2 = Co_2$ + Heat (+393 MJ/k mol)

Hydrogen available in the fuel reacts with oxygen in the air-

$H_2 +1/2. O_2 = H_2O$ + Heat (+242 MJ/k mol)

Temperature of the bed 1000-1200°C

Reduction:

Temperature condition 550-800°C

Boudouard Reaction:

$CO_2 + C = 2CO$ – Heat (-164.9MJ/k mol)

Water gas reaction:

$C+H_2O = CO+H_2$ – Heat (-122.6MJ/k mol)

The reduction reactions are all endothermic bringing down the temperature in that zone to around 600-700°C.

Water shift reaction:

$CO + H_2O = CO_2 +H_2$ + Heat (+42MJ/k mol)

Methane reaction:

$C+2H_2= CH_4$ + Heat (+75MJ/k mol)

In the case of biomass gasification the methane reaction is very nominal. The appearance of methane in the gas is primarily due to distillation of the biomass by the carrier gas evolved during oxidation & reduction reactions.

Pyrolysis/ Distillation of Biomass:

The gas leaving the oxidation reduction zone at a temperature of about 550-700°C passes through the dry biomass distilling it into three products namely bio-char, tar & watery substance called Pyrolignious liquid & gases containing Carbon dioxide, Carbon monoxide, Hydrogen, methane, little quantity of oxygen, Nitrogen etc. In this zone the temperature is reduced to about 300 to 350°C.

Drying of Biomass:

The mixture of hot gases at 300- 350°C then passes through the biomass as charged from the top. As the gas passes through the wet mass, moisture is driven out along with all other volatile products in the oxidation, reduction & distillation zones. The gas comes out of the generator at about 80-200°C in the case of updraft gasifier & 400-500°C in the case of downdraft gasifier. The temperature of the exit gas also depends on the moisture content of the gas, type of biomass & the design of the gasifires. In the case of wood, temperature of the gas coming out may touch 250°C.

The temperature conditions as given above are rather approximate. The concept of different zones is also imaginary for conceiving the chemistry of gasification reactions. Nobody knows what is actually going inside the gasifier.

TYPES OF GASIFIERS:

Generally, gasifiers are of four types.

i) Updraft- in which the biomass is fed from the top & air at particular BST is pushed from the bottom. The gaseous products are drawn from the top of the gasifier for cooling & cleaning. Air & biomass move in counter current direction as shown in fig-1

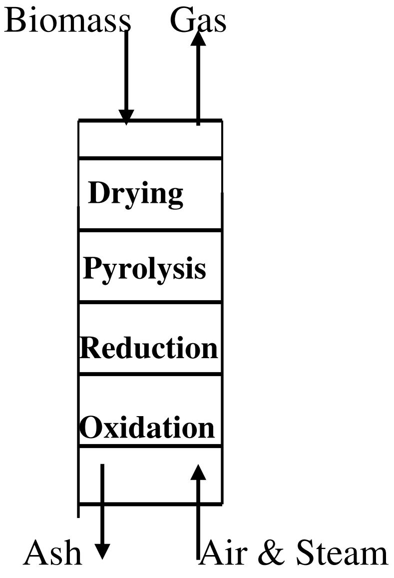


Fig-1
Updraft Gasifier

ii) Down draft- in this gasifier both biomass & air flows co-currently. Ash is withdrawn from the bottom as also gas. Air is sucked from the bottom of the gasifier for necessary reaction- vide fig.2

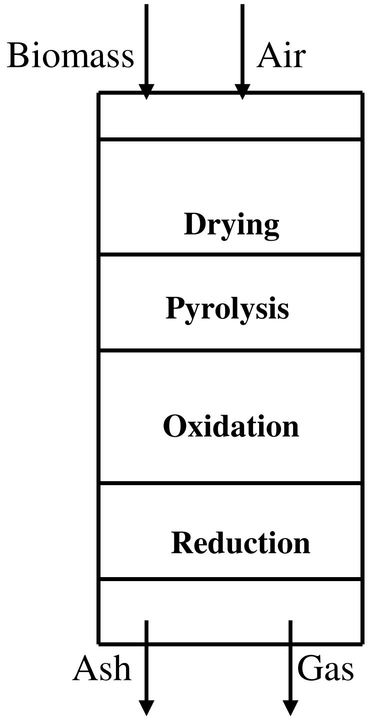


Fig. - 2
Downdraft Gasifier

ii) Cross draft- in this gasifier the biomass is fed from the top, air is pushed to the biomass obliquely from the side of the gasifier which is about 2/3rd downward from the top & gas is taken out from the other side of the gasifier which is almost at the bottom end. The arrangement is shown in fig.3.

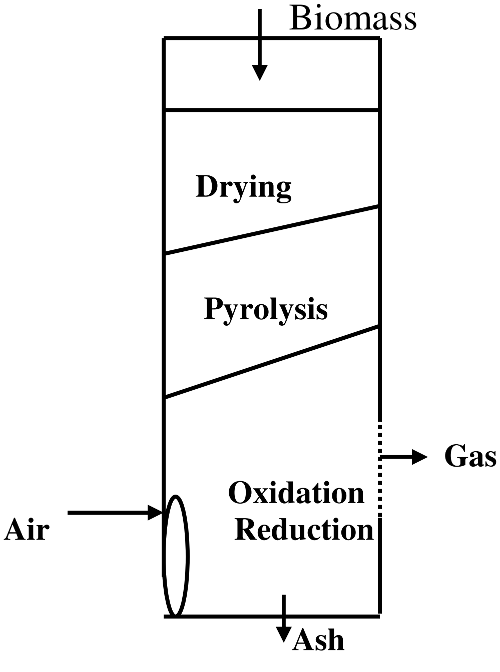
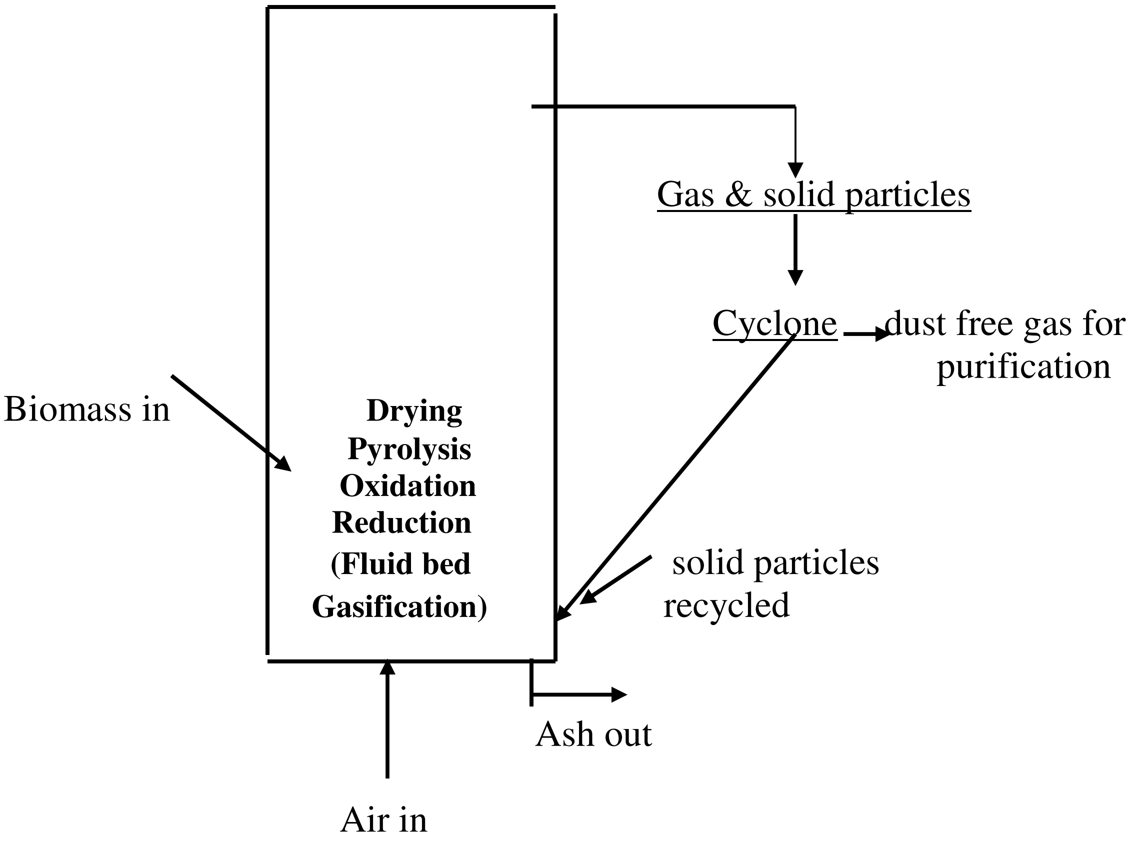


Fig-3
Cross draft Gasifier

iv) Fluid Bed- such gasifiers with circulating system using air as fluidization as well as reaction media with biomass operate as in any fluid bed system. Particles entrained in the gas coming out of the gasifier are entrapped in a cyclone & re-circulated. Reaction takes place at a temperature of 1000-1100ºC. Specific gas production is around 2.4 Nm^3/Kg of dry biomass with cold gas efficiency of about 80%. Tar in gas is low. The arrangement is shown in figure-4.

Systems had also existed to convert biomass/municipal waste into gas in two stages. In the first stage the volatile products containing major quantity of carbon are driven out leaving behind the fixed carbon (overall 18 to 19% carbon) for gasification in fluid bed using steam. Carbon efficiency of such system is obviously very low due to loss of carbon at the initial stage of devolatilasation.

Fig-4
Fluid Bed Gasification



SHORT EVALUATION OF GASIFICATION PROCESSES:

The type of gasifier to be adopted mostly depends on the choice & need of the entrepreneur, availability of the biomass at an acceptable price, cost of the units, flexibility of operation & magnitude of gas generation.

The updraft gasifiers have a primitive history which had followed the pattern of gasification in coal/coke gasifiers & as such their developments using biomass had the advantage to copy the established techniques. Therefore, the updraft gasifiers could be built in large sizes in single unit. In updraft gasifiers biomass with somewhat higher moisture content can be used. Reactions inside the gasifiers are more or less uniformly distributed & the gas produced has low oxygen content (less than 2%). It is true that the tar content in the crude gas is high (4gms to 7gms/Nm^3) as all the tar from the distillation zone come out with the gas. The liquor produced is of pyrolignous type containing aldehydes, ketones, acetic acid etc. This liquor is highly corrosive (Ph 3 to 5) & requires to be neutralized by alkali. The BOD & COD values are also high (16,000 to 20,000). Therefore the excess liquor before discharge requires elaborate treatment. Tar produced is somewhat unrecoverable since it comes out as sludge mixed with solid materials. Entrepreneurs who need more gas (say more than 1000Nm^3/hr) might prefer to have large units which the updraft type can provide. Tar from the gas can also be removed to any desired level using appropriate gas cleaning system. There could be no hindrance in adopting updraft technology from a capacity level of 20KW to 600KW in single units. For larger plants multiple units may be installed. The plant with all its units is sturdy in construction, can run continuously for years together with appropriate operation & maintenance. The gas produced from updraft gasifiers have been successfully used for various thermal applications & also for power generation in dual fuel engines where 65-70% diesel oil could be replaced in several plants for years together. Application of this gas in 100% gas engines is also under trial. Gas produced from updraft gasifiers using rice husk has a characteristic smell which is highly repellant. As such it is advisable not to install such plants in populated areas. The calorific value of the clean gas is 1200-1350 kcal/Nm^3. the yield of gas is 1.65 to 1.85Nm^3/Kg (average 1.75).

The downdraft gasifiers are relatively of smaller sizes & for large quantity of gas more number of units of small sizes are to be installed. Downdraft gasifiers have well been standardized from 100kw to 350kw. Some larger sized units have also been set up but do not seem to be so well established as in the case of updraft types. Downdraft gasifiers use mostly wood. The number of downdraft gasifiers is much more than that of updraft type because of low cost & smaller sizes which are preferred by the small industries. The tar content in crude gas is low (2 to 3gms/Nm^3) compared to that in updraft gasifiers. The liquor produced has also less oxygenated organic compounds because both tar & liquor pass through the oxidation zone while coming out from the bottom. This type of flow of gas through the hot zone destroys the repelling constituents in the gas. Tar also gets somewhat cracked in the hot zone during its passage downwards. This creates problem in the gas off take pipe connecting the wet scrubber as pitchy materials gets deposited in this pipe which has to be cleaned too often. The outlet gas temperature from the gasifier to the wet scrubber is very high (450 to 550^{o}C) which means the cold gas efficiency is low. The calorific value of the gas is 1050 to 1100 kcal/Nm^3 as against 1250 to 1350^{o}C in updraft gasifier. The gas cleaning & purification section consists of a series of gas filtration units (filtration media, rice husk or saw dust) which have to be cleaned/replaced quite frequently. The gas contains as in the case of updraft system 35-38% CO plus H_2 but oxygen content in gas is high. Liquor before discharge requires also to be treated. Even then the popularity of downdraft system has prevailed not only in India but also other parts of the world, perhaps due to patronization from various institutions & also the simplicity of construction & low cost. Purified gas from downdraft system has also been used (besides thermal application) for power generation in dual fuel system.

The cross draft gasifiers are also quite simple in construction. These gasifiers use wood for gasification. In many places the gas is not cleaned & the raw gas is directly used in thermal application. Everyday the gas pipelines are cleaned.

The fluid bed system though not widely used in gasifying biomass in large scale has the inbuilt advantage of having an excellent uniformity in temperature distribution within the mass, efficient contact between solid & gaseous phase & high volumetric capacity of the equipment associated with rigid temperature control in the gasifier. Fuels which have high ash content seem to be more suitable in the fluid bed system. However, these advantages are offset by the complexity of the system & production of more dust & considerable quantity of tar in the gas.

COOLING & CLEANING OF GAS:

The temperature of the gas coming out of the generator is normally 350 to 550^{o}C for downdraft & for fluid bed gasifiers it is much higher (800 to 900^{o}C). In the case of updraft system with appropriate operation it is in the range of 80^{o}C to 150^{o}C when using rice husk. While gasifying wood it may go up to 250^{o}C. In most of the systems the crude gas coming out of the gasifiers are scrubbed with liquor/water to bring down the temperature to about 45-50°C & also remove dust & tar to the maximum possible extent. Thereafter various types of cooling & cleaning appliances are used to reduce the tar content in the gas step by step details of which are beyond the scope of this paper. The cleaning appliances are determined by the extent of reduction of tar & solid particulate matter in the gas as may be required in different usages.

EFFLUENT TREATMENT:

The source of the liquid effluent is the moisture content in the biomass & its distillation products generating additional liquor & also tar. If the moisture content in biomass is 15%, the liquor generated due to hydrogen & oxygen reaction within the biomass is another 6% & the total quantity of liquor produced in the system will be 21%. To this another 2% may be added for undecomposed steam. For all practical purpose the total liquor yield may be taken as 25% or so. The liquor is usually mixed with tar which has low temperature characteristics. This liquor has to be analyzed for its characteristics & accordingly the treatment facilities are to be provided. In a nutshell the facilities may include primary filtration/decantation for separation of tar & other solids, aero-flotation of tar by using air (AFT), chemical dosing, sludge separation, separation of the clean liquor, aeration of the clean liquor for reduction of BOD & COD to the desired level. Before discharging the treated effluent it is customary to dilute it with fresh water. A part of this treated effluent water is re-circulated in the gasification scrubber. An indicative analysis of the liquor could be as follows:

Table-7

Analysis of liquor from biomass gasifier (approx.)

Ph	3-5
Total Suspended solid	400ppm
Total Dissolved solid	3,000-4,000ppm
BOD	12,000-20,000mg/litre
COD	20,000-30,000mg/litre
Total Organic Carbon	5,000-10,000mg/litre
Phenols	80-110mg/litre
Ammonia & Cyanides	Trace

The liquor as obtained is of pyrolignous type containing acetic acid, methyl alcohol, allyl alcohol & ketones. The liquor has a pungent smell & is carsinogenous. The untreated liquor if discharged as such in drains or in the river will kill all flora & funa & also fish. When the liquor is produced in small quantity from small gasifiers treatment of this small quantity liquor may not be necessary. It may be filtered through the ash produced from rice husk.

CHARACTERISTICS OF PRODUCER GAS:

Table 8 gives the characteristics of producer gas obtained from biomass. For the sake of comparison composition of some other industrial gases are also given.

Table-8

Characteristics of producer, coke oven & natural gas.

Gases	Biomass Updraft	Biomass Downdraft	Coal Based producer	Coke oven gas	Natural Gas
Composition (% V/V):					
CO_2	8-10	12-13	5-6	4	2-7
CnHm	0.2 - 0.4	-	0.4	2.5	-
O_2	0.6 - 1.5	Not specified	0.6	0.5	-
CO	23-26	17-20	26	8	-
CH_4	1.5-2.0	1.5-2.0	4.0	26	91-93
H_2	10-12	17-19	12	51.0	-
N_2	52-54	Not Specified	49-50	8	-
C.V.(gross)Kcal/Nm3	1200-1350	1050-1100	1450-1550	4200-4700	8650-8850
Spgr. (Air=1)	0.9	0.91	0.90	0.45	0.6
Viscosity(centipoises)	0.0195-0.0198	0.0195-0.0198	0.0195-0.0198	0.0137	0.0125
Sp.Heat	0.32	0.32	0.32	0.33	0.34
Air reqd. for combustion with no excess air(V/V)	1.0-1.2	0.9-1.0	1.4-1.5	4.5-4.6	9.0
Waste Gas vol. with no excess air(V/V)	1.8	1.8	2.3	5.5	11
CO_2 content in waste gas (%)	19-20	18-19	18-19	9-10	8.5-9.5

NB: i) For combustion of gases about 20-30% excess air is used which increases the waste gas volume & decreases the carbon dioxide content.

ii) BTU/Scuft39.55= Kcal/Nm^3. iii) Viscosity data may vary by 5% to 10%.

The working data available on fluid bed gasifiers are as follows:

a) Specific gas production-2.2 to 2.4 Nm^3/Kg of dry biomass.
b) Gasification temperature-1100-1200°C
c) Gas composition- CO_2 10%, CnHm 1%, O_2 less than 1%, H_2 21%, CO 22%, CH_4 2%, N_2 43%
d) Gross calorific value- Kcal/Nm^3= 1380.

In Table 8 the characteristics of producer gas & other industrial gases like coke oven gas & natural gas have been given. For the sake of comparison the salient technical data on LPG are given below:

LPG is a mixture of 40% propane & 60% butane in admixture with very small quantity of ethane. Though LPG is a gas, it is compressed in cylinders at about 90lb/$inch^2$ by which it is converted into liquid in the cylinder.

a) Its calorific value is 11,840 to 11,900 (gross) & 10,920 (net) in terms of Kcal/Kg. Volumetrically the calorific value (gross) is 28,460 & 26,260 (net) Kcal/Nm^3.
b) Specific gravity in vapor form is 1.80 (air = 1).
c) Bulk density is 2.33Kg/Nm^3.
d) Volume of gas 0.45 to 0.48 Nm^3/Kg LPG.
e) In liquid form if density is 0.55 Kg/litre.
f) Air required for combustion is 29Nm^3/Nm^3 LPG (11- 12Nm^3/Kg).
g) Carbon dioxide content in flue gas (without excess air) 14-15%.
h) Flue gas volume 30-32Nm^3/Nm^3 LPG.
i) Ignition point °C 410-580.
j) Limits of inflammability lower 1.8 upper 9.5 in %.
k) Ethyl Mercaptan is added as an odorant to detect LPG leakage.

GASIFIER FUNCTIONAL GNOSTICS & ARITHMETICS:

Certain fundamental data are necessary to evaluate the performance of gasifiers which are indicated below:

1. Acceptance of the raw materials used in a particular type gasifier, its shape, bulk density, proximate analysis, ash fusion point etc details of which have been dealt in earlier paragraphs (vide Table 2-5 as well).

2. Evaluation of gas output takes into consideration the heat input in the gasifier i.e. calorific value of the biomass plus the heat input by steam, gasification efficiency & the calorific value of the biomass gas as could be expected. Generally while using wood for gasification, the efficiency is taken at 75% & using rice husk it could be 65%. Moisture content in biomass may be taken as 15%.

3. BST & steam quantity in the air blast, variation of steam decomposition at different BST, conversion of carbon dioxide to carbon monoxide after reaction with carbon in the biomass at different temperature & also action of steam on carbon at various temperatures is given in Table-9, 10, 11 & 12.

Table-9

BST & Steam quantity in Air Blast

BST °C	Kg of Steam/Kg dry air	Kg of Steam/Nm^3 dry air
50	0.086	0.111
55	0.115	0.148
60	0.153	0.198
65	0.205	0.265
70	0.271	0.351
75	0.373	0.482
80	0.536	0.692
85	0.812	1.048

N.B. 1Nm^3 Air = 1.291 Kg air (1 Nm^3 = 1000 litre)

Table- 10

Percent Steam decomposition V/S BST

BST °C	Kg Steam/Kg Coal gasified	% Steam decomposition	Kg Steam decomposed
45	0.20	100	0.20
50	0.21	100	0.21
55	0.32	100	0.32
60	0.45	80	0.36
65	0.55	80	0.44
70	0.80	60	0.48
75	1.10	50	0.55
80	1.55	40	0.62

.

From Table10 it can be seen that beyond 55°C the degree of decomposition of steam decreases & at 60 & 65°C it is 80%, the excess steam coming out with the gas without getting into any reaction with carbon. So in energy balance we shall consider 80% conversion of steam into water gas i.e. 0.35 to 0.36 Kg steam to form gas.

Table - 11

CO_2 Conversion to CO at different Temperatures

Temp °C	Gas composition (% v/v) CO_2	CO
600	68.5	31.5
700	36.6	63.4
800	13.7	86.3
900 (deduced)	7.0	93.0
1000	0.6	99.4
1200	0.06	99.94

It may be noted from Table 11 that the major reaction with CO_2 & C takes place between 900 & 1000°C. At a lower temperature CO_2 content increases & adversely affects the quality of producer gas. Therefore the bed temperature in the gasifiers has to be maintained at the appropriate level which is achieved during oxidation reaction taking place below the reduction zone. This also applies in the case of steam carbon reaction taking place most successfully at the temperature level of about 1000°C as may be revealed from table 12.

Table 12

Action of Steam on Carbon at Different Temperatures

Temperature °C	% steam decomposed	Gas composition (% v/v)		
		CO_2	CO	H_2
674	8.8	29.80	4.90	65.20
758	25.3	27.00	7.80	65.20
838	41.0	22.90	15.10	61.90
954	70.2	6.80	39.30	53.50
1010	94.0	1.50	49.70	48.80
1125	99.4	0.60	48.50	50.90

Ref: HMS Publication- The Efficient Use of Fuel

The composition of gasification gas will depend on temperature condition in the gasifier, extent of carbon dioxide & carbon reaction, gas produced by steam carbon reaction & finally the composition of the distillation gas evolved from the top of the reduction zone. All the gaseous constituents evolved along with tar & water vapor arising out of different pyrolysis reactions within the biomass come out of the reactor as producer gas. The tar, condensed water vapor (called liquor) & other impurities are removed from the gas to tune the gas at the desired purity. Normally for thermal application tar content in gas may be kept at 50mg/Nm^3 & for power generation in dual fuel engine & 100% gas engine below 10mg/Nm^3 details of which will further be discussed in the utilization chapter. Characteristics of biomass based producer gas are given in Table 8 in the preceding chapter.

4. **MASS & ENERGY BALANCE**

Table 13

Basis of Calculation

Particulars	Wood	Rice Husk
Biomass	1Kg at 2% ash & 15% moisture	1Kg at 20% ash & 15% moisture
Calorific Value	3700 Kcal/Kg	2900 Kcal/Kg
Gas Output	2.3 Nm^3/Kg at 1250Kcal/Nm^3	1.75 Nm^{3}Kg at 1250Kcal/Nm^3
Tar	0.03Kg/Kg	0.015Kg/Kg
Liquor	0.22Kg/Kg	0.21Kg/Kg

In addition to the above there are some other inputs like steam & air. The quantity of steam at 60°C BST will be 0.45Kg/Kg biomass which will go as input to the producer plant. The entire quantity will not go into reaction & only 80% of it i.e. 0.36Kg/Kg of biomass will react with carbon in the biomass. The quantity of air required for gasification will be 1.78Kg/Kg of wood & 1.61Kg/Kg of rice husk. All such figures have been taken from working data which also vary. This happened because of the complexity of the reactions taking place within the gasifier using different types of biomass. Minor variations will not affect the ultimate results of calculations.

A. MASS BALANCE

		WOOD		RICE HUSK
i) Inputs	Wood	1.00Kg	Rice Husk	1.00Kg
	Steam	0.45Kg	Steam	0.45Kg
	Air	1.78Kg	Air	1.61Kg
Total Inputs		3.23Kg		3.06Kg
ii) Outputs	Gas	2.50Kg (2.3Nm^3)	Gas	1.902Kg (1.75Nm^3)
	Ash	0.025Kg (dry)	Ash	0.250Kg (dry)
	Tar	0.030Kg	Tar	0.0150Kg
	Liquor	0.220Kg	Liquor	0.21Kg
Total Outputs		2.775Kg		2.377Kg
Product Efficiency % (Input/Output)		85.90		77.70
Efficiency of Gas Production %		77.40		62.20

The material balance does not have much significance. The significant item is the efficiency of gas production.

B. ENERGY EFFICIENCY (in totality)

SL. NO	Particulars	Wood (1Kg)	Rice Husk (1Kg)
1.	Heat Input (Kcal/Kg)	3700	2900
	Heat in Steam (Kcal) at 60^{o}C for 0.45Kg steam	279	279
	Total Heat Input	3979	3179
2.	Heat from Product (Kcal/Kg)		
	Gas	2875	2188
	Tar	276	138
	Total Heat Output	3151	2326
3.	Energy Efficiency % Heat output!heat input	79.20	73.20

C. COLD GAS EFFICIENCY

	WOOD	RICE HUSK
η_c %	2.331250 ――――3100＝72.30% 3979	1.7531250 □□□□□□□□3100＝68.80% 3179

D. HOT GAS EFFICIENCY

	WOOD	RICE HUSK
η_h %	**(2.331250)+2.330.323(150-35)** ―――――――――― 3979 ＝74.4%	(1.7531250) + 1.7530.32(150-35) ―――――――――― 3179 ＝70.80%

In the above calculations specific heat of gas has been taken at 0.32, base gas temperature at 35ºC, gas temperature outlet gasifier at 150ºC & calorific value of gas at 1250 (gross) Kcal/Nm^3.

The above calculations are only indicative & not absolute.

APPLICATION OF PRODUCER GAS FROM BIOMASS

1. Thermal

Application of producer gas for thermal use is vast. Producer gas obtained by gasifying coal has higher calorific value (1450-1550Kcal/Nm^3) & higher flame temperature (1800ºC) compared to those of gas obtained by gasifying biomass. The flame temperature of biomass gas is between 1550 & 1600ºC & the average calorific value of gas is 1200Kcal/Nm^3. Using producer gas from biomass, temperature in a well designed furnace can be attained up to 900ºC without preheating of air/ gas. If a furnace is operated continuously one can expect furnace temperature up to 1000ºC or near about. However, if the furnace temperature drops due to introduction of a material inside or due to any other reason, time required to attain the desired temperature(i.e. pick up time) will be quite long compared to that of fuel oil or any other fuel having higher calorific value than biomass based producer gas. The general usage pattern of biomass based producer gas are-

a) Heating furnaces to replace fuel oil.
b) Replacement of fuel oil in boilers of smaller capacities.
c) Melting furnaces like aluminum melting (m.p. 660°C), zinc (m.p. 419°C), lead (m.p. 327°C) etc. Though the temperature of the metal might be low, the furnace temperature has to have in the region of 800 to 850°C for quick temperature pick up and safe ignition of gas.
d) For hot air generation in various industries.
e) Bakery, biscuit & other food product units. Producer gas used should be cleaned & thoroughly purified for this purpose.
f) The possibility of use of biomass based producer gas to dry of tea leaves has been under consideration for sometimes. For this purpose the temperature of the waste gas after burning producer gas has to be maintained at about 120°C & the gas must be completely free from tar & other impurities to ensure that the flavor of the tea does not get disturbed.

Some key fundamentals for replacement of fuel oil by biomass based producer gas are produced below:

One liter F.O. of specific gravity 1.0 (approx) will have heat value 10170Kcal/Kg. heating value of producer gas 1250Kcal/Nm^3.

Equivalent gas = 10170/1250 = 8.14Nm^3/Kg fuel oil.
In replacing fuel oil by producer gas, due to higher stack loss arising out of higher quantity of waste gas volume, about 25% excess gas will have to be used in the furnace.
Amount of gas to be used = 8.1431.25 = 10.20Nm^3 gas to replace 1Kg fuel oil. Air required for the same will be 12Nm^3 with 20% excess air. So total waste gas generated by burning producer gas will be 22Nm^3.

Air requirement (theoretical) to burn 1Kg fuel oil = 10Nm^3.
Excess air used for combustion will be 20%. So total air requirement for burning fuel oil will be 12Nm^3 (1031.2). Waste gas volume will be only 12Nm^3. This means an increase in about 10Nm^3 waste gas (22-12Nm^3) i.e. 83.30% in an effort to replace fuel oil by producer gas having low calorific

value. This excess volume of waste gas has to be evacuated from the furnace without any design modification of the system meant to be operated using oil. The result will culminate in generation of higher stack temperature compared to that while using oil. If the system is meant to replace fuel oil in a boiler, one cannot expect the same output of steam from the boiler by using producer gas. There will be 25-30% derating of the boiler output. One might try to compensate this by using a dual fuel burner through which along with gas some oil could be fired. This effort unfortunately may be unacceptable by the system & temperature of the flue gas will start rising instead of improving the boiler output. This type of irregularity could perhaps be resolved by changing the furnace combustion volume & also the design of the boiler. Otherwise one has to be satisfied with a derated system. Mere pushing more gas in an existing system cannot solve the problem as the furnace will not accept those manipulations. It might so happen that the excess gas could be seen burning at the top of the chimney. Therefore before replacing oil or LPG or any fuel having substantially higher calorific value compared to that of producer gas, the furnace design & other aspects will have to be thoroughly checked. Any arrangement involving handling of gas should take care of the safety aspects both for the man & machinery. If the furnace is red hot the chances of explosion is less but there could be serious back pressure to cause heavy damage. In case the furnace is not red hot & the flame gets extinguished, before relighting the gas the furnace should be purged with air & then relighted. It is advisable to maintain a pilot flame in front of the firing zone to minimize sudden explosion.

The other aspect is the length of the flame of the gas. In case the furnace is very lengthy there could be problems in the attainment of the required temperature throughout the entire length & breadth of the furnace unless provisions are made to install gas burners at the dead zones.

Last but not the least the chance of a gas flame from a burner traveling backwards has to be carefully guarded by installing flame arresters in the gas pipeline leading to the burner. Alternately the gas may be passed through a water seal followed by an anti pulsation tank. The backward travel of the flame is a disturbing feature which has created lots of problems in plants causing explosion & back fire.

Use of producer gas in the tea industry for drying tea leaves may be ventured. In such case the gas obtained from the gasifier has to be thoroughly cleaned from tar & other impurities and then burned & mixed with sufficient excess air in order to achieve the desired waste gas temperature of about 120ºC. The mixture of waste gas at that temperature can be directly passed through the tea dryer (as is normally practiced) while using natural gas or oil. The following calculations will give an idea of specific fuel consumption values (ref: Palit D, Research Associate, The Energy & Research Institute, TERI dated 8th May, 2006).

Dryer capacity 300 Kg made tea/hour.
Hot air flow 11,400 Kg/hour.
It is required to calculate the quantity of wood for gasification purpose.

Calculations:

Total heat in hot air = 1140030.243(120-20) = 273600Kcal where 0.24 is the specific heat of air on mass basis. If the calorific value of the gas obtained by gasification of wood is 1250Kcal/Nm^3 total requirement of producer gas would be = 273600/1250 = 220Nm^3/hr. But we have to use about 25% more gas to compensate the high stack loss. Therefore requirement of gas will be in the order of 275Nm^3/hr. If the yield of gas from the gasification unit is 2.3Nm^3/Kg wood, requirement of wood would be 275/2.3 =120Kg wood/hr which means requirement of wood for gasification purpose would be (1204300) Kg = 0.40Kg. *In other words 0.40Kg wood would be required for 1Kg made tea.* One must be very careful to ensure that neither the quality of tea nor its flavor is degraded.

2. Electrical.

Power generation may be through dual fuel engine or 100% gas engine. For this purpose the gas has to be very clean, the particulate matter & tar content should be less than 5ppm (though some say below 10ppm.) The quality & quantity of gas for the purpose should have consistency. The pressure supplied to the engine should be at a specific level without variation. In the case of gas engine these stipulations are very rigid for smooth running of the engine. In the dual fuel engine the variations are taken care of through supply of diesel inside the engine. Success of producer gas based gas engines meets diversified opinions regarding their long term use. However dual fuel engines have crossed most of the hurdles in this respect & 60-70% diesel replacement is quite common. It is true that the life span of the engines get reduced by 30-35%. Attempt to increase diesel replacement by producer gas more than 65% should be restricted since in an effort to save oil the engine may get damaged. Moreover use of high gas rate makes the engine very hot. Some basic calculations in respect of application of producer gas in engine are furnished below:

We know 860Kcal = 1Kw.

C.V. of diesel oil = 11,700Kcal/Kg or 9832Kcal/liter (sp.gr of diesel 0.84)

Therefore theoretical power generation = 11700/860 = 13.6Kw.

Efficiency of power generation = 25%.

Therefore 1Kg of diesel (1.19 liter) will generate 13.630.25 = 3.4Kw or 1 liter of diesel will generate (3.4 41.19) = 2.90Kw power. In other words for 1Kw power diesel consumption will be (142.9) = 0.345liters rounded to 0.35liter equivalent to 0.3539832Kcal = 3441Kcal.

Producer gas consumption = 3441/1250 = 2.75Nm^3 (C.V. of producer gas being 1250Kcal/Nm^3). If the producer gas yield per Kg of husk is 1.75Nm^3, then requirement of husk will be (2.7541.75) = 1.571Kg/Kw of power in 100% gas engine, where to produce 1Kw power about 0.35 liter diesel was required. Since use of producer gas to replace oil enhances the stack loss in terms of total heat one has to use (as mentioned before) about 25% more gas i.e. 25% more husk which is gasified. Taking this aspect into consideration, requirement of rice husk will be-

1.57131.25 = 1.96Kg. This consideration is very important in evaluating the gasifier capacity as well as the economics of such proposal.

In the case of wood the gas production is 2.3Nm^3/Kg wood. The calorific value of the producer gas will remain the same as in the case of rice husk. However the requirement of wood will be reduced as shown below:

Producer gas consumption = 3441/1250Nm^3 = 2.75Nm^3/Kw.

Wood requirement (2.7542.3) = 1.2Kg/Kw in place of 1.57 while using husk.

Adding 25% extra wood requirement would be = 1.2Kg31.25 = 1.5Kg/Kw power.

MNES now (MNER) in their publication

BIOMASS THERMO-CHEMICAL CHARACRETISATION (2nd Edition) has published interesting data in respect of diesel oil consumption vis a vis producer gas requirement as replacement fuel against diesel oil. The author has deduced the diesel oil replacement value at different levels of replacement using producer gas generated from rice husk as well as wood. For the purpose the author has taken little higher value of diesel oil (0.37 liter) to produce 1Kw power.

Table 14

Diesel oil replacement in engines by Producer gas (basis 1Kw)

Diesel displacement %	Diesel displaced liter	Kcal	Equivalent producer gas Nm^3	Rice Husk Kg/Kw	Rice Husk (25% extra) Kg/Kw	Diesel used liter/hr	Kcal used
100	0.37	3638	2.91	1.66 (1.26)	2.10 (1.58)	Nil	Nil
90	0.33	3245	2.60	1.50 (1.14)	1.87 (1.43)	0.04	393
85	0.31	3048	2.44	1.40 (1.07)	1.76 (1.34)	0.06	590
80	0.30	2950	2.36	1.35 (1.03)	1.66 (1.26)	0.07	688
75	0.28	2753	2.20	1.26 (0.96)	1.56 (1.18)	0.09	885
70	0.26	2556	2.04	1.16 (0.89)	1.45 (1.08)	0.11	1082
65	0.24	2360	1.89	1.08 (0.82)	1.35 (1.02)	0.13	1278
60	0.22	2163	1.73	1.00 (0.76)	1.25 (0.95)	0.15	1474

NB: The figures in the bracket stand for usage of wood.

The above table (Table No. 14) is self explanatory by itself. It is obvious that for generation of 1Kw power in gas engine, about 1.70 to 2.00Kg of rice husk will be required. If wood is used the requirement of wood would range from 1.30 to 1.60Kg/Kw power. Use of 100% producer gas in gas engine is yet debatable for sustainable operation.. It is stated that a gas engine which is being operated by natural gas will be derated by 30-35% when natural gas is substituted by low energy density producer gas.

Compression ignition or diesel engine cannot be operated on 100% gas without injection of some amount of diesel. This is because the producer gas cannot ignite by itself under the operation pressure. Therefore the compression ignition engines have to be operated on dual fuel mode. It is difficult to convert such engines into spark ignition engines. In this case as well, derating will be there. As thumb rule the dual fuel engine producing 1Kw power will require 1 to 1.1Kg of wood consuming 0.07 to 0.08 liters of diesel. For all practical purpose diesel displacement by producer gas should not be forced beyond 70%. It has also to be mentioned that for such operation not all type of diesel engines are suitable. Producer gas application both in gas engine & dual fuel engine involves many complicated calculations which are beyond the scope of this paper. More over diversified opinions are not uncommon.

SELECTION OF BIOMASS BASED PRODUCER PLANT:

Selection of a biomass based producer gas will depend on the following:

a) Provenness of the technologies in commercial operation. Mere success in the pilot scale cannot be relied upon.
b) Sturdy construction of the plant & good engineering practice.
c) Well established gas cleaning & gas purification system to produce the desired purity in gas.
d) Proper selection of engine after thorough check of its performance using producer gas.
e) Guaranteed after sales service by the plant supplier.
f) A good plant will need good money, an aspect which is often ignored by the purchaser for short term benefit.
g) Availability of biomass in quality & quantity in appropriate physical texture.
h) Lastly the price of the biomass & the economic aspect.

RISK FACTORS IN BIOMASS GASIFICATION:

i) Any biomass intended to be used in a gasification plant to produce gas should be carefully tested in respect of its constituents, ash characteristics like ash fusion & other physical properties to ascertain its acceptance in the gasification process. Rice husk, saw dust & wood of particular shapes have been well established for gasification. Any new biomass should not be used in 100% since behavior of such materials for the purpose may be unknown. Such new materials should be tried in admixture with a well established biomass in different proportion till sustained operation for at least 72 hours is attained. Such procedure will show to what extent the new material may be used. At each stage, the operational behaviors should be carefully examined & the gas quality ascertained. It is very dangerous to play with gas & gasification aspects in view of the likely hazards of explosion & other abnormalities.

ii) Gas explosion hazards in the plant caused by back fires & other ignition factors associated with the concentration of high oxygen content in gas as denoted by the lower explosives & higher explosive characteristics of gas.

iii) Tar & waste water management. Tar & pyrolignous liquor are carcinogenic.

iv) Solid disposal.

v) Emission behavior.

vi) Population factors adjacent to the plant & noise pollution.

vii) Effluent disposal.

viii) Non adherence to the prescribed safety norms in relation to plant & equipment & all electricals in a gas plant.

ix) No single person should be posted in a gassy area either for operation or maintenance.

x) No smoking, no alcoholism & no naked flame in the plant area.

xi) CO poising for which the toxic effects of CO are given below.

Toxic effects of CO (approx)

SL. NO	%CO	PPM	EFFECT
1	0.003	30	No significant effect
2	0.02	200	Headache in 2 to 3hours.
3	0.04	400	Headache, nausia within one hour.
4	0.08	800	Headache, Nausia within one hour & after that within 45mins unconscious & collapse.
5.	0.16	1600	Headache, nausia within 20min & then death. within 2 hours.
6.	0.32	3200	Nausia dizziness within 5-10mins & death in 30minuts.
7.	0.64	6400	Immediate unconscious & death in 10 minutes.

8	1.28	12800	Immediate death.

xii) Neat & cleanliness of the plant.

PLANT ECONOMICS:

Plant economics will depend on size of the plant, cost of inputs like biomass, oil, labor etc & maximum utilization factors. It has been observed that about 80% of the production cost depends on the biomass. Details are beyond the scope of this technological paper.

CONCLUSION:

i) Since biomass has the same constituent (CHON) as in the case of coal & is the forefather of coal, a fossilized solid fuel of vegetative origin, its behavior towards gas generation follows the principle of coal pyrolysis. On dry mineral matter free basis carbon in biomass is about 50% in contrast to coal which has carbon content from 75 to 90%. Similarly, the calorific value of biomass is 4450 to 4460 Kcal/Kg & that of coal 7800 to 8780Kcal/Kg (all on dry mineral matter free basis) depending on the rank of coal. The fixed carbon content in biomass on dry mineral matter free basis is 19 to 21%. Therefore, these simple indications in the analytical results would be helpful to identify a particular material as biomass or the other way.

ii) The term biomass also refers to renewable organic matter produced by plants through photosynthesis with the help of solar energy combining carbon dioxide & moisture to form the carbohydrates. Biomass also refers to wood & woody products, agricultural residue, dung, weeds etc.

iii) Biomass gasification is a technology regarded as fuel switching to convert the solid fuel to a gaseous fuel for different uses. Gasification adds value to low or negative value solid feed stocks by converting them to marketable products. Though gasification of coal is well known & well established, gasification of biomass faces some problems which are specific to the characteristics of the biomass. Many designs of gasifiers have been developed with lucrative claims & many have perished. Frankly speaking multiple gasifiers are rarely found successful because of the very nature of the biomass & also the criticality of process parameters which often lead to problems.

iv) The major problem is biomass gasification relates to the cleaning of the gas to make the same free from tar & other impurities including particulate matter. The efficiency of gas cleaning is one of the fundamentals to the success of a plant as a whole. Nature & treatment of the liquid effluent also pose some difficulty so far cost is concerned though the plant size might be small.

v) There are no definite values standardized for impurities in gas. The application of gas in different usages has generated some values which are as follows:

a) For thermal application tar & particulate matter less than 50mg/Nm^3. For specific thermal uses like biscuit manufacture, drying of tree leaves, drying of Titanium dioxide, drying of Alufluoride etc, tar & particulate matter should be less than 25mg/Nm^3 & in certain other cases particularly in the food industries the impurities should be less than 10mg/Nm^3.
b) For dual fuel engines & 100% gas engines the tar & particulate matters should be still lower (less than 5mg/Nm^3). Some engine manufacturers prescribe 100% pure gas. The fact is that nobody is sure about the gas standard & everybody wants to follow the safest route.
c) CO & Oxygen content in the exhaust in an engine application (ref: CO & PAH emission from engines operating on producer gas, Jesper Arendfeldt, Technical University of Denmark).

Biomass based:

CO- mg/Nm^3	300-500
O_2 %	about 5 (11% exception)

Natural gas/Bio gas:

CO- mg/Nm^3	600-1000
O_2 %	5.00

vi) All biomass cannot be gasified in line with the normal procedure applicable for coal though the reaction chemistry in both the cases is the same. To gasify a biomass it should have certain specialized characteristics which will be acceptable in the gasification system.

vii) A diesel engine cannot run completely on producer gas. A dual fuel system using producer gas & diesel oil has to be adopted. Normally 60-70% diesel replacement by producer gas is advisable though higher displacement up to 75% is achievable at the expense of the life of the engine.

viii) To produce 1Kw power in gas engine about 1.70 to 2.00Kg husk will be required. If wood is used about 1.30 to 1.50Kg will be required.

ix) To produce 1Kw power diesel oil requirement will be 0.37 to 0.375liter.

x) Calorific value of biomass based producer gas is 1150 to 1300Kcal/Nm^3 as against 1450 to 1550Kcal/Nm^3 using coal.

xi) Production of gas from 1Kg rice husk (15% moisture) is 1.65 to1.80Nm^3, from 1Kg wood (15% moisture) it is 2.30Nm^3 for coal 2.50 to 2.70Nm^3 based on ash & moisture of coal. Yield of gas from high ash coal (above 35%) will be less than 2.20Nm^3/Kg. All these are dependent on the heating values of coal or biomass.

xii) Biomass based gasification system does not offer wide applicability due to technological limitations coupled with insufficient availability of the biomass. For large scale thermal application like production of steam & power one would like to burn biomass directly & adopt the turbine route.

xiii) The environmental benefits as claimed are too optimistic to be compared with the wide CO_2 emission in the various industries since burning producer gas also gives rise to enough CO_2 production.

xiv) One advantage worth consideration for adoption of biomass system could relate to combined benefits of renewability & decentralized application in relatively smaller scale.

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xii) Chakrabarti H.C.- Air Blown Producer Gas from Coal: The New Generation Energy Substitute, Minetech Vol. 32 April2June 2011.

xiii) Authors innumerable collections from different sources & his long practical experience in the biomass arena including assessment & usage.

xiv) Authors expertise in coal quality assessment, coal technology, coal usage, coke making, coal gasification & gas purification including analytical aspects.

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