International Journal of Science and Research (IJSR)
ISSN (Online): 2319-7064
Index Copernicus Value (2013): 6.14 | Impact Factor (2013): 4.438

Production of Biomass by Gasification Using Coconut Shell

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Abstract: ***Now a days there is increase in demand of alternate fuels as the availability of preponderant fuels like petroleum, crude oil, etc. are declining day by day. To meet out the energy demand alternate process of producing fuel is carried out. One among those is the production of Biomass. There are many methods in producing the biomass but gasification is the best. This paper deals with the production of biomass by gasification using coconut shell, significance & chemistry of gasification and design of downdraught gasifier.***

Keywords: Biomass, gasification, gasifiers, coconut shell.

1. Introduction

The petroleum resources are deteriorating day by day and it will vanish in few decades. So, the worlds new concept towards energy is to explore alternative resources of energy. They are going for non conventional energy resources. Biomass energy is the best option and is cheaper due to the following reasons.

- It is estimated that there are more than 250 million tones of biomass is available.
- Using biomass the recycling of water energy which is let out as a waste. Hence, it benefits so many ways, like energy conservation and utilizing waste product.
- Disposal of waste is tremendous problem in growing country. Using biomass plants the problem is reduced to most extent.
- It has high flexibility of using various materials.
  "Saving waste energy is equal to producing energy".

2. Definitions

2.1. Gasification

The word gasification implies converting a solid or a liquid into a gaseous fuel without leaving any solid carbonaceous residue.

2.2 Gasifier

It is an equipment that can gasify a variety of biomass such as wood, agriculture wastes like stalks, roots of various crops, maize cobs, etc. It is essentially a chemical reactor where various complex physical and chemical process takes place. Biomass gets dried, heated, pyrolyzed, partially oxidized and reduced as it follows through it. The gas produced in the gasifier is a clean burning fuel having heating value of about 950-1200 kcal/m^3. Hydrogen (18-20%) and Carbon monoxide (18-24%) are the main constituents of the gas.

2.3 Biomass

Biomass is defined as a living matter or its residues like wood, grass, crop residues, etc. and the agricultural residues like groundnut shells, corn hobs, etc. are being burnt directly with low efficiency of combustion. If they are burnt with controlled quantity of air (A/F = 1.6 to 1.9, equivalence ratio $\phi = 0.25$ to 0.35) a gas having CO and H_2 and a small proportion of CH_4 and CO_2 can be obtained which can be used in an internal combustion engine.

3. Significance of Gasification

The significance of gasification are as follows:

- Gasification offers high flexibility in terms of various biomass materials as the feedstock.
- Gasification outputs are suitable as a fuel to all types of internal combustion engines with capacity in the range of 18% to 36%.
- Gasification has thermo-chemical conversion efficiencies in the range of 72% to 90% which is highest among various alternative.
- The gasification equipment has high turn down ratios comparable to biogas and higher than stream turbine systems.
- The area requirement for gasification equipment is lowest per unit output of energy in the form of heat and electricity.
- Gasification output capacity, especially in the high output ranges, is controlled only by availability of adequate feed materials rather than other technical consideration.

4. Gasification Theory

The essence of gasification is the conversion of the solid fuel to gaseous fuel by thermo chemical reactions of a fuel. Gasification involves partial combustion and reduction operations biomass with air/oxidant under sub-stoichiometric conditions, while combustion is the chemical combination of biomass with air or oxidizer resulting in release of energy in the form of heat. The block diagram as shown in figure 1 indicates different stages during gasification process. The gas composition with equivalence ratio is show in figure 2.

Figure 1: Block diagram of different stages during gasification process

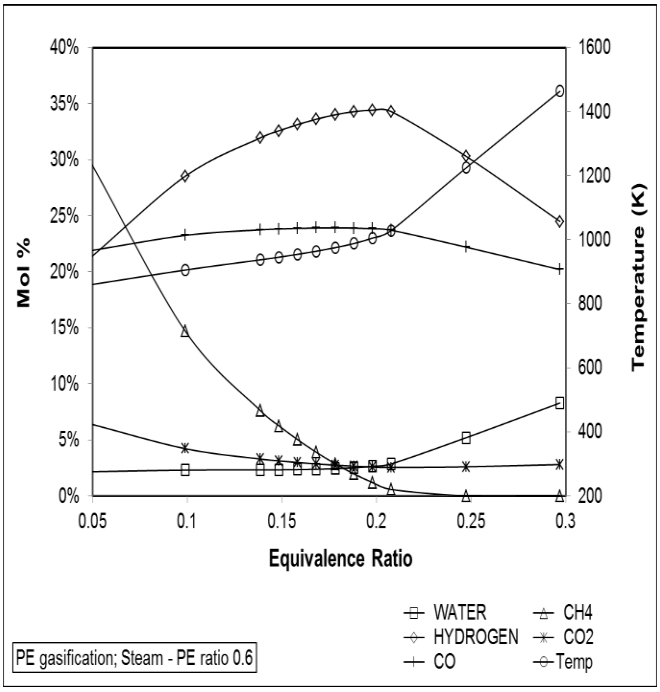

Figure 2: Gas composition with equivalence ratio

Based on the sequencing of the above process, there are three types of gasifiers.

4.1 Up Draught Gasifiers

In this gasifiers the air enters below the combustion zone and the producer gas leaves near the top of the gasifier. This type of gasifier is easy to build and operate. The gas produced practically has no ash but contains tar and water vapor because of passing of gas through the un burnt fuel. Hence they are suitable for tar free fuels like charcoal, especially in engines.

4.2 Down Draught Gasifiers

Here the air enters at the combustion zone and the gas produced leaves near the bottom of the gasifier. The volatiles and the tars produced from the descending fixed bed have to pass through the reaction zone where mostly they are racked and gasified. The throat ensures that the gaseous products pass through the hottest zone. These gasifiers are suitable for fuels like wood and agriculture wastes.

4.3 Cross Draught Gasifiers

In this type of gasifiers the gas produced passes upwards in the annular space around the gasifier is filled with charcoal. The charcoal acts as an insulator and a dust filter. They are usually suitable for power generation up to 50kW.

5. Chemistry of Gasification Process

The producer gas is formed by the partial combustion of solid biomass in a vertical flow packed bed reactor. In conventional producer gas theory, the reactions take place in three zones of a deep fuel bed, namely oxidation, reduction and distillation zones. In the oxidation zone the oxygen in the air stream blast reacts with the carbon in the fuel to reduce carbon to hydrogen and carbon monoxide, the CO_2 coming from the oxidation zone is also reduced to CO in the reduction zone, the final gas consumption relies on the water gas shift reaction

$$CO + H_2O = CO_2 + H_2$$

which approaches chemical equilibrium corresponding to the prevailing exit gas temperature. In the distillation zone the raw fuel is preheated and carbonized giving of condensable and non condensable gases.

This process is called "gasification" as it transfers the majority of the chemically bound of the solid fuel into the gas phase.

As already stated, pyrolysis converts organic wastes to char, tar oils and gas. Here gases produced are CO, CO_2 and H_2. The organic which are used in operation are called pyrolysis plants and vessel in which this takes place is called pyrolyzer.

There are four separate zones viz. Drying zone, Pyrolysis zone, Oxidation zone and Reduction zone. In the downdraught gasifier as shown in figure 3, the fuel is introduced at the top, the air is normally introduced at some intermediate level and the gas is taken out at the bottom.

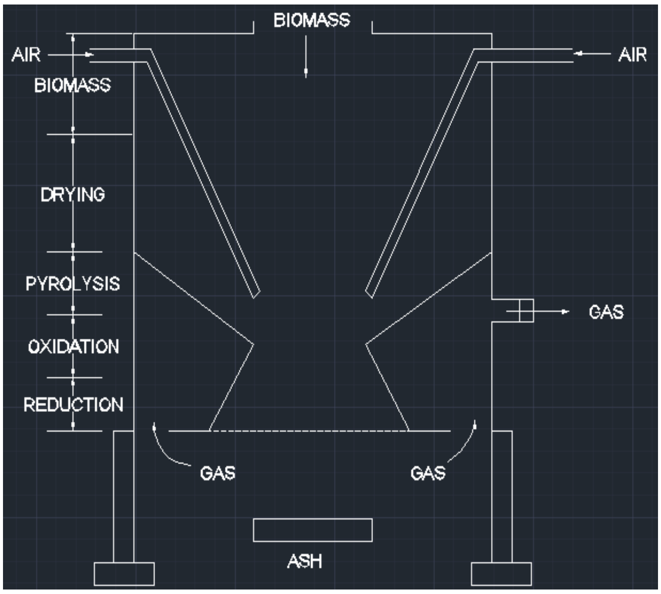

Figure 3: Schematic diagram of a gasifier

The processes in the four zones are explained below and the design basis will be discussed in the following section.

5.1. Bunker Section (Drying Zone)

Solid fuel is introduced into the gasifier at the top. It is not necessary to use complex fuel feeding equipment because a small amount of air leakage can be tolerated at this spot. As a result of heat transfer from the lower parts of the gasifier, drying of the wood or biomass fuel occurs in the bunker section.

The water vapor will flow downwards and add to the water vapor formed in the oxidation zone. Part of it may reduced to hydrogen and the rest will end up as moisture in the gas.

5.2. Pyrolysis Zone

At the temperature above 250°C the biomass fuel starts pyrolysing. The details of these pyrolysis reactions are not known well, but one can surmise that large molecules break down into medium sized molecules and carbon during the heating of the feedback. The pysolysis products flow downwards into the hotter zones of the gasifier. Some will be burnt in the oxidation zone and the rest will break down into even smaller molecules of H_2, CO, ethane, ethylene, etc. if they remain in the hot zone for long time.

If the residence time in the hot zone is too short or the temperature too low, then the medium sized molecules can escape and will condense tar and oil in the low temperature 1200-1500°C.

5.3. Oxidation Zone

The burning zone is formed at the level where air is introduced. Reactions with oxygen are high exothermic and result in a sharp rise of the temperature up to 1200-1500°C.

As mentioned above, an important function of the oxidation zone, apart from heat generation, is to convert and oxidize virtually all condensable products from the pyrolysis zone. In order to avoid cold spots in the oxidation zone, air inlet velocities and the reactor geometry must be well chosen.

Generally two methods are employed to obtain an even temperature distribution.

- Reducing the cross sectional area at certain height of the reactor
- Spreading the air inlet nozzles over the circumference of the reduced cross sectional area or alternatively using a central air inlet with a suitable spraying device.

5.4. Reduction Zone

The reaction products of the oxidation zone move downward into the reduction zone. In this zone the sensible heat of the gases and the charcoal are converted into chemical energy of the producer gas.

The end product of the chemical reactions that take place in the reduction zone is a combustible gas which can be used as fuel gas in burners and after dust removal and cooling is suitable for internal combustion engines. The ashes which result from gasification of the biomass should occasionally be removed from the gasifier. This market is possible to stir the charcoal bed in the reduction zone and thus helps to prevent blockages which can lead to obstruction of the gas flow.

6. Thermo Chemical Reactions

The conversion process revolves around the combustion reaction equation(1) which supplies heat to the neighboring zones in the reactor. Carbon constitutes the major proportion of the feed and the main reactions are:

$$C + O_2 + 3.79N_2 = 3.79N_2 + CO_2 \qquad (1)$$

Exothermic reactions (heat evolved) 3950 MJ/Kg atom of carbon. The carbon dioxide formed is reduced in the presence of flowing carbon, over 90% of CO_2 is reduced to CO at temperature above 900°C

$$C + CO_2 + 3.79N_2 = 3.79N_2 + 2CO \qquad (2)$$

Endothermic reaction (heat absorbed) 172 MJ/Kg atom of carbon.

$$2C + O_2 + 3.79N_2 = 3.79N_2 + 2CO \qquad (3)$$

Exothermic reaction 223.3 MJ/Kg atom of carbon.

The composition of producer gas formed under 100% conversion conditions assuming a carbon feed based on the above equations would be 34.5% CO and 65.5% N_2 by volume. The calorific value of the gas thus formed is 4359 KJ/m^3 at STP. Based on the above, the potential heat available is 2 Kg atoms of carbon is 790.8 MJ and of this 223.3 MJ are evolved as sensible heat (equation 2). Consequently 567.5 MJ are available in the producer gas as potential heat in 5.79 Kg moles of producer gas. The potential cold gas efficiency is therefore approximately 72%.

The hot gas reserves the heat evolved in equation(3) and therefore in practice the hot gas efficiency is much higher. The process is particularly efficient therefore when the gas is to be used as a heat source.

$$\text{Hot gas efficiency} = \frac{\text{Potential heat in gas} + \text{Sensible heat in gas}}{\text{Total heat available in the solid fuel}}$$

$$\text{Cold gas efficiency} = \frac{\text{Potential heat in gas}}{\text{Total heat available in the solid fuel}}$$

The injection of water into the reactor by introduction in the feed or by direct injection of stream into the reaction zone or increasing the humidity of the combustion air can improve the calorific value of the resultant gases formed by shifting the gasification in favor of equation(1).

An important function of the combustion zone is to raise the reduction zone temperature to promote the carbon/steam, gasification reaction which as higher activation energy. This reaction requires temperature of 90°C and above.

$$C + H_2O = CO + H_2 \qquad (4)$$

Endothermic reaction 130 MJ/Kg atom of carbon. This practice is termed "wet-gasification" and has the added advantage of dropping the temperature in the immediate vicinity of the hearth and reducing the formation of clinker.

This equation(4) is very important in producer gas generation as it can enrich the gas manufactured with hydrogen, thus enhancing its calorific value. The other reaction with carbon/steam occurs at lower temperature and predominated between 500-600°C.

$C + 2H_2O = CO_2 + 2H_2$ (5)
Endothermic reaction 88 MJ/Kg atoms of carbon.

A further steam reaction which occurs in the gas producer with an excess of steam is the water gas shift reaction. This should be avoided in the producer gas generation as it reduces the cold gas efficiency, though, on the other hand, it reduces the CO which is highly toxic in the fuel gas distribution for public use.

$C + 2H_2O = CO_2 + 2H_2$ (6)
Exothermic reaction 42 MJ/Kg mole of CO.

Factors affecting gasification are air velocity, zone thickness, particle size and chemical composition of the feed. In the process design the after-treatment of the gas is also very important that the CO leaving the reduction zone should be cooled rapidly to below 600°C as it breakdown, to soot predominated at high temperatures. This cooling down of the hot gases reduces the deposit of soot and is called "Freezing the equilibria".

$C + 2H_2 = CH_4$ (7)
Endothermic reaction 75 MJ/Kg mole of carbon.

$CO + H_2O = CO_2 + H_2$ (8)
Endothermic reaction 42 MJ/Kg mole of CO.

7. Design Details

Fuel : Coconut Shell
Power rating: 5 kW

7.1. Properties of coconut shell

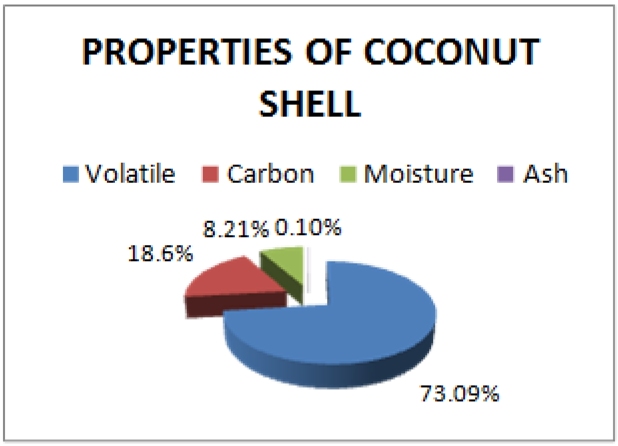

Figure 4: Properties of coconut shell

7.2 Element analysis by weight

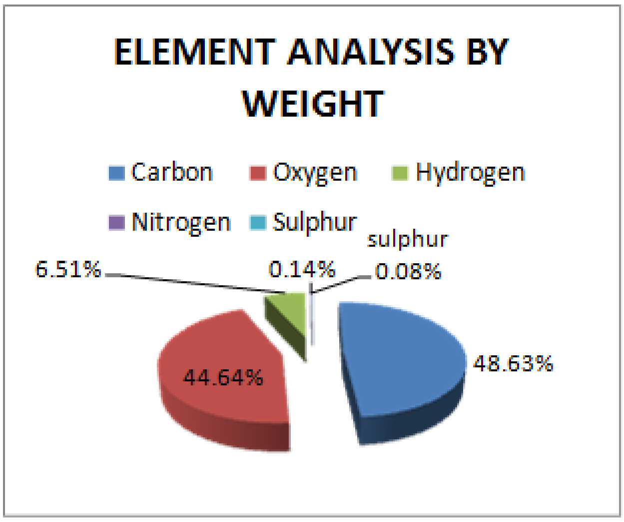

Figure 5: Element analysis by weight

7.3. Air consumption

$$= \frac{100}{23}\left[2.67 \times C + 8\left(H - \frac{O}{8}\right)\right]$$
$$= \frac{100}{23}\left[2.67 \times 0.4863 + 8\left(0.0651 - \frac{0.4464}{8}\right)\right]$$
$$= \frac{100}{23}\left[1.2984 + 0.0744\right]$$

= 5.65 Kg of air / Kg of fuel.

7.4. Gasification air requirement

By taking 30% of total air requirement for incomplete combustion and gasification.

$$= \frac{30}{100} \times 5.65$$

= 1.695 Kg of air / Kg of shell.

7.5. Sizing of hearth

Specific gasification rate = 900 Kg/m^2hr .

Gas generated per Kg of Coconut Shell
= 0.9 + 1.695
= 2.595 Kg of gas / Kg of shell.

For 5 Kg of Coconut Shell
= Total gas generated / Hr
= 5 Kg × 2.595
= 12.975 Kg of gas.

7.6. Area of hearth grate

= Total gas rate / SGR
= 12.975 / 900
= 0.0145 m^2.

7.7. Diameter of hearth

Area = $\frac{\pi}{4} d^2$
0.0145 = $\frac{\pi}{4} d^2$
d = 13.5 cm .

7.8. Size of inlet nozzle

Considering the air velocity as 6 m/s

Air requirement for one hour
= 1.695 × 5 Kg of shell
= 8.295 Kg of air.

Area of inlet nozzle $= \frac{\text{Total air}}{\text{Velocity of air}}$

$\frac{\pi}{4} d_1^2 = \frac{8.295}{6 \times 3600}$

$d_1 = 0.022$ m (or) 22 mm.

7.9. Design of hopper

Time between 2 feed = 5 Hr
Density of coconut shell = 300 Kg/m^3
Length / Height of hopper = l_h
Diameter of hopper = d_h

Considering Slenderness ratio

$d_h / l_h = \frac{100}{23} d_h$

Storage volume $= \frac{\pi}{4} d_h^2 \times l_h$

$\frac{5}{300} = \frac{\pi}{4} \times (1/4)^2 \times l_h$

$l_h = 0.697$ m (or) 69.7 cm.

Height of Hopper = 69.7 cm.
Diameter of Hopper = 69.7 / 4 = 17.43 cm.
Distance between Inlet nozzle and Grate = 10 cm.

7.10. Overall dimensions of gasifier

Table 1: Overall dimensions of gasifier

Hearth Diameter	13.5 cm + Insulation
Inlet Air Nozzle Diameter	2.2 cm + Insulation
Diameter of Hopper	18 cm + Insulation
Height of Hopper	70 cm

Figure 6 shows the designed downdraught gasifier for coconut shell.

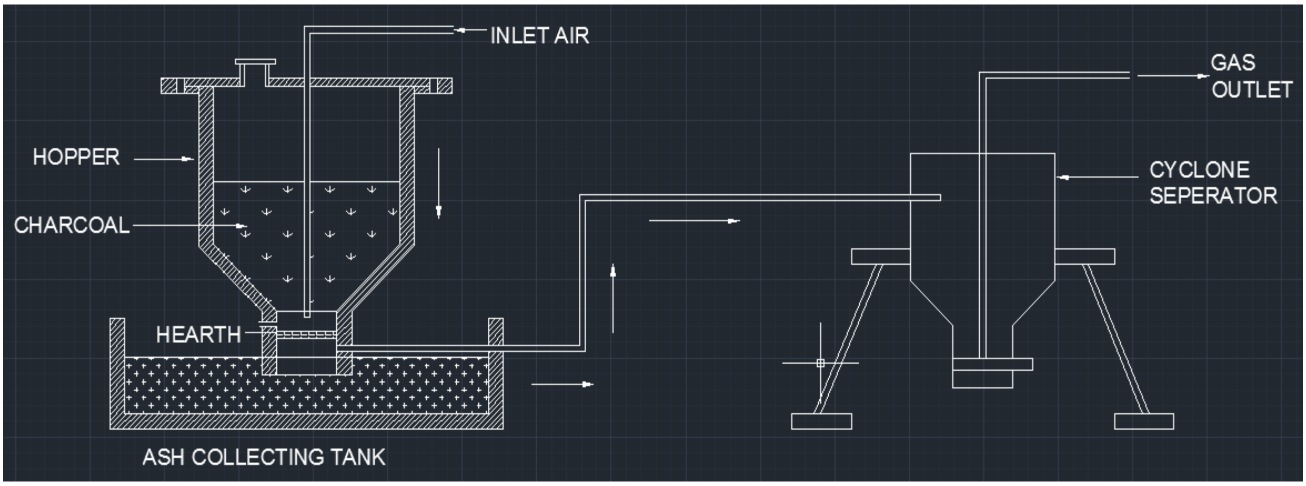

Figure 6: Downdraught gasifier for coconut shell.

8. Applications

8.1 Small Size Gasifier (upto 10 kW)

Normally this type of gasifiers shall find applications in rural areas, especially for providing shaft line power to agriculture pumps, processing, machinery and agriculture-processing machineries like Thrashers, straw choppers,etc.

8.2 Medium Size Gasifier (10kW - 50kW)

This type of gasifiers can easily meet the shaft line power requirements of various rural industries like saw mills, carpentry workshops, mechanical fabrication shops as well as small rice mills. They can also used as a source of electrical energy in milk chilling centers, primary health coverage centers and for rural electrification.

8.3 Large Size Gasifier (50kW and above)

This type of gasifiers can be used in urban industries, besides being a source of decentralized electrification. They can meet the shaft power requirements directly or indirectly of various industries like dairy, oil mill, mineral processing, brick manufacturing, ceramics, pottery industries, etc. These gasifiers can also be used in mining operations, forest based wood processing units, well drilling, etc.

9. Conclusion

The biomass gas is useful in many ways.

- Using for domestic application.
- Used as fuel for running IC engines.
- Research and Development work is going on for developing Wankel engine with biomass fuel.

Many industries are now exploring with greater enthusiasm in adopting gasifier for generating thermal energy for industrial use as an alternative.

10. Acronyms

Table 2: Acronyms.

A/F	Air Fuel ratio
C	Carbon
CO	Carbon monoxide
CO_2	Carbon dioxide
H_2	Hydrogen
HC	Hydrocarbon
H_2O	Water
N_2	Nitrogen
MT	Million Tones

11. Nomenclature

Table 3: Nomenclature.

cm	Centimeter
°C	Degree Celsius
g/hr	Grams / hour
Hr	Hours
Kg	Kilogram
Kg/m^3	Kilogram per cubic meter
Kg/hr	Kilogram per hour
Kg/min	Kilogram per minute
kJ/Kg	Kilo joule per Kilogram
J	Joule
kJ	Kilo joule
MJ	Mega joule
kW	Kilowatt
m	Meter
m^2	Square meter
m/s	Meter per second

Reference

[1] "Nonconventional energy sources" by G.D. Rai
[2] "Renewable energies for rural area" by Astra

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