International Journal of Thermal Technologies, Vol.2, No.1 (March 2012) ISSN 2277 - 4114

Review Article

Parametric Study of Fixed Bed Biomass Gasifier: A review

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Accepted 22 March 2012, Available online 28 March 2012

Abstract

In this paper, various parametric aspects of biomass gasification have been discussed. The most widely used configurations of biomass gasifiers and the effect of various operating parameters on the quality of producer gas and performance of gasifier are considered. The performance of the biomass gasifier system is evaluated in terms of zone temperature, calorific value, equivalence ratio, producer gas composition, gas production rate, and cold gas efficiency.

Keywords: *Fixed bed gasifier, Types, Thermo-Chemical process, Parameters, Equivalence ratio, Cold gas efficiency.*

1. Introduction

Biomass has been one of the main energy sources for the mankind ever since the dawn of civilization, although its importance dwindled after the expansion in use of oil and coal in the late 19th century. There has been a resurgence of interest in the recent years in biomass energy in many countries considering the benefits it offers. It is renewable, widely available, and carbon-neutral and has the potential to provide significant productive employment in the rural areas. Biomass is also capable of providing firm energy.
Estimates have indicated that 15%–50% of the world's primary energy use could come from biomass by the year 2050. Currently, about 11% of the world's primary energy is estimated to be met with biomass. For India, biomass has always been an important energy source. Although the energy scenario in India today indicates a growing dependence on the conventional forms of energy, about 32% of the total primary energy use in the country is still derived from biomass and more than 70% of the country's population depends upon it for its energy needs.

2. Fixed Bed Gasifiers

In the fixed bed gasifier, the fuel is fed to the top of the gasifier. Meanwhile, at the bottom, oxygen and steam are instituted and the slag is withdrawn. The fuel is gasified in a bed layer. The fuel goes through four different zones; drying, pyrolysis, oxidation and reduction. Drying occurs when the hot producer gas contacts the feed at the top of the gasifier. Next the fuel devolatilizes, forming tars and oils. These compounds exit with the raw producer gas, and are captured in downstream cleanup processes and recycled to the gasifier. The devolatilized fuel then enters the higher temperature gasification zone where it reacts with steam and carbon dioxide. Near the bottom of the gasifier the resulting char and ash react with oxygen creating temperatures high enough to melt the ash and form slag.

2.1 Types of fixed bed gasifier

The choice of one type of gasifier over other is dictated by fuel, its final available form, size, moisture content and ash content. Table 1 lists the operations advantages and disadvantages for fixed bed gasifiers**.**

2.2 Different gasifying agents used in fixed bed

Different gasifying agents used in fixed bed are shown in Table 2

2.3 The process of gasification

Gasification is the conversion process of biomass to producer by heating in an oxidant or gasifying agents such as oxygen, air or steam. Because, the oxidant or gasifying agents and reaction conditions are always different, so the process of biomass gasification is very complex. On the whole, this process includes four stages: drying, pyrolysis, oxidation, reduction.

A. Drying

In this stage, the moisture content of biomass is typically reduced to be 5-35%. Drying occurs at about 100-200°C with reduction in moisture content of biomass to <5%.

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B. Pyrolysis

Pyrolysis is breakdown material by heat. It is the first step in the combustion or gasification of biomass. When biomass heated in the absence of air to about 350^{0}C, It foam charcoal, gases and tar vapors. The tar vapors are gases at the temperature of pyrolysis but condense to foam a smoke composed of fine tar droplets as they cool.

Table 1 Comparison of Fixed Bed Gasification Technologies

	Downdraft	**Updraft**	**Cross-flow**
Operations	Biomass is introduced from the top and moves downward. Oxidizer (air) is introduced at the top and flows downward. Producer gas is extracted at the bottom at grate level.	Biomass is introduced from the top and moves downward. Oxidizer is introduced at the bottom and flows upward. Some drying occurs. Producer gas is extracted at the top.	Biomass is introduced from the top and moves downward. Oxidizer is introduced at the bottom and flows across the bed. Producer gas is extracted opposite the air nozzle at the grate.
Advantages	▪ Tars and particulate in the producer gas are lower	▪ Can handle higher-moisture biomass. ▪ Higher temperatures can destroy some toxins and slag minerals and metal. ▪ Higher tar content adds to heating value.	▪ Simplest of designs. ▪ Stronger circulation in the hot zone. ▪ Lower temperatures allow the use of less expensive construction materials.
Disadvantages	▪ Feed size limits ▪ Scale limitations ▪ Low heating value gas ▪ Moisture-sensitive	▪ Feed size limits ▪ High tar yields ▪ Scale limitations ▪ Low heating value gas	▪ More complicated to operate. ▪ Reported issues with slagging. ▪ High levels of carbon (33%) in the ash.

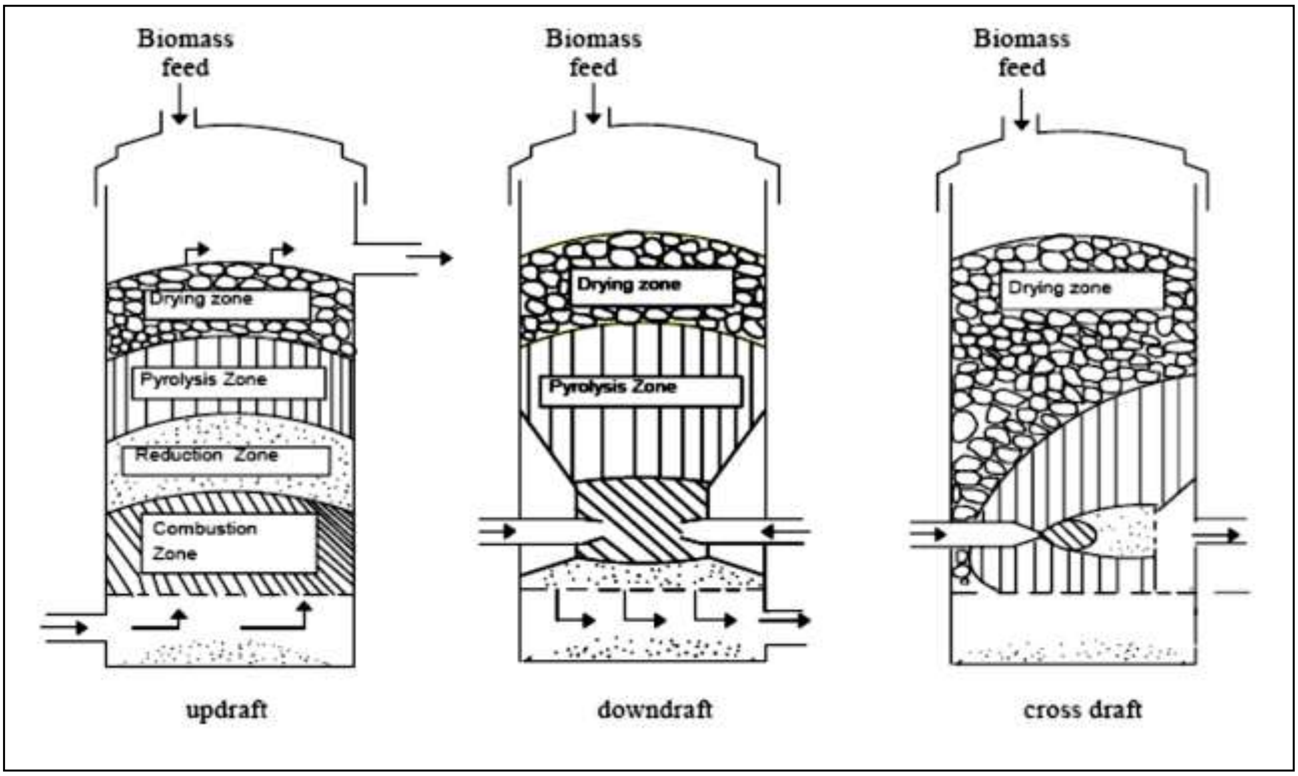

Fig.1 types of fixed bed gasifiers

Biomass + heat → solid, liquid, gases products (H_2 , H_2O, CO , CO_2)

Table 2 Advantages of different gasifying agents

Gasifying Agents	Advantages
Air	1. Partial combustion for heat supply of gasification 2. Moderate char and tar content
Steam	1. High heating value producer gas (10–15 MJ N/m3) 2. H_2-rich producer gas (e.g., 450% by volume)
Carbon dioxide	1. High heating value producer gas 2. High H_2 and CO and low CO_2 in producer gas

C. Oxidation

This is reaction between solid carbonized biomass and oxygen in the air, resulting in formation of CO_2. Hydrogen present in the biomass is also oxidized to generate water. Large amount of heat is released with the oxidation of carbon and hydrogen.

$C + O_2 \rightarrow CO_2$

D. Reduction

In absence of oxygen, several reduction reactions occur in the temperature range of 800-1000ºC. These reactions are mostly endothermic. The major in this category are as follows:

$C + H_2O \rightarrow CO + H_2$
$C + CO_2 \leftrightarrow 2CO$
$CO_2 + H_2 \leftrightarrow CO + H_2O$
$C + 2H_2 \leftrightarrow CH_4$

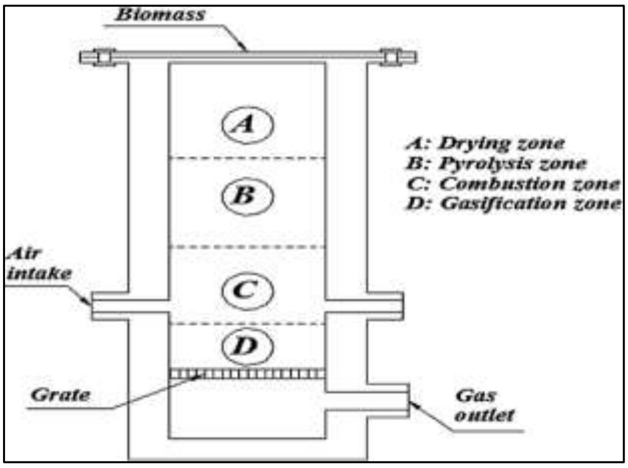

Fig 2 Schematic view of different process zone in fixed bed biomass gasifier

2.4 Types of fuel used in gasifier

Wood: Wood fuel has several environmental advantages over fossil fuel. The main advantage is that wood is a renewable resource, offering a sustainable, dependable supply. Other advantages include the fact that the amount of carbon dioxide (CO_2) emitted during the burning process is typically 90% less than when burning fossil fuel.
Sawdust: sawdust leads to the problems of excessive tar production, inadmissible pressure drop and lack of bunker flow. Small sawdust particles can be used in fluidized gas procures to produce gas. If this gas is used to be in internal combustion engines, fairly good clean-up system is essential.
Peat: Peat is the first stage of coal formation. Freshly mined peat contains 90 % moisture and 10 % of solid. It cannot be utilized unless air dried to reduce moisture content to 30 % or less. As peat contains very high level of moisture and ash, it creates problems in the gasification process.
Agricultural residues: Agricultural residues are basically biomass materials that are by product of agriculture. It includes cotton stalks, wheat and rice straw, coconut shells, maize and rice husks etc. Coconut shells and maize cobs have been successfully tested for fixed bed gasifiers. Most cereal straws contain ash content above 10% and present slagging problem in downdraft gasifier. Rice husk with ash contents above 20% is difficult to gasify.

3. Process Parameters

The performance of gasifier is directly affected the following parameters-

Zone Temperatures

Temperature is considered as the main parameter for estimating on biomass gasifier performance. Increase in temperature reduces the tar content as well as decreases char inside the gasifier. Gas yield increases due to higher tar cracking.

Calorific value (CV)

The calorific value (CV) of a material is an expression of the energy content, or heat value, released when burnt in air. The CV is usually measured in terms of the energy content per unit mass or volume (MJ/m^3).

Equivalence ratio

Equivalence ratio (ER) is the most influential parameter in any gasification process and often has significant impact on producer gas composition. Equivalence ratio was calculated from the amount of oxygen fed into the gasifier divided by the amount of oxygen required for complete fuel combustion. For the effective gasification, ER should be range 0.2-0.4.

Table 3 Composition of Producer Gas from various fuels

Fuel	Gasification method	Volume Percentage					Calorific value (MJ/m^3)
		CO	H_2	CH_4	CO_2	N_2	
Charcoal	Downdraft	28-31	5-10	1-2	1-2	55-60	4.60-5.65
Wood	Downdraft	17-22	16-20	2-3	10-15	55-50	5.00-5.86
Wheat straw pellets	Downdraft	14-17	17-19	-	11-14	-	4.50
Coconut husks	Downdraft	16-20	17-19.5	-	10-15	-	5.80
Coconut shells	Downdraft	19-24	10-15	-	11-15	-	7.20
Corn cobs	Downdraft	18.6	16.5	6.4	-	-	6.29
Rice hulls pelleted	Downdraft	16.1	9.6	0.95	-	-	3.25
Cotton stalks cubed	Downdraft	15.7	11.7	3.4	-	-	4.32

$$\text{Equivalence ratio} = \frac{\text{air volume consumption by gasification}}{\text{air volume needed for compelete combution}}$$

Producer gas composition

Producer gas composition means quantities volume of different gases in producer gas. Typical composition of producer gas is as follows.

Table 4 Typical composition of producer gas composition

Gas	Composition
Carbon monoxide	18%–20%
Hydrogen	15%–20%
Methane	1%–5%
Carbon dioxide	9%–12%
Nitrogen	45%–55%

Gas production rate

Gas production rate means the producer gas production rate per unit weight of biomass (Nm^3/kg). When increase in the equivalence ratio, producer gas production rate continuously increases. Higher equivalence ratio signifies higher air flow rate for a specific biomass consumption rate.

Cold gas efficiency

Cold gas efficiency is defined as the ratio of energy of the producer gas per kg of biomass to the higher heating value (HHV) of the biomass material .cold gas efficiency depends upon the calorific value and the amount of producer gas released at constant HHV of biomass.

Cold gas efficiency =

$$\frac{(\text{Calorific value})(\text{Gas Production per weight of biomass})}{\text{Higher Heating Value of the biomass}}$$

4. Worldwide Installations of fixed bed gasifiers

Fixed bed updraft gasifier has been installed at a CHP power plant in Kokemaki. Biomass residues and energy crops are used as fuels. The feedstock is dried to about 20% moisture by using low 15 temperature waste heat from the plant and fed at the top of the gasifier. The produced gas is cleaned by a tar reformer, cooled and scrubbed in a wet scrubber, boost and injected in the three turbocharged 0.6 MWe gas engines to produce 1.8 MWe power and 4.3 MWth for district heating (Nilsson, 2008).

The gasifier was developed and constructed by the Energy Department of Finish Ministry of Trade and Industry in co-operation with VTT. Eight BIONEER gasifiers were commercialized in 1985-1986, five in Finland and three in Sweden. Four plants are operated with wood or wood and peat mixture, while the rest are operated with peat only. BIONEER gasifier is an updraft fixed bed gasifier with the outputs of the range of 4-5 MWth.

A 500 kW (5 x 100 kW) biomass gasifier has been installed and commissioned in Gosaba Island, West Bengal, India in July 1997 for electrification of five villages comprising more than 10, 000 people.

The biomass CHP facility in Skive, Denmark is an air-blown bubbling fluidized bed gasifier developed by Carbona Company and in operation since late 2005. The gasifier converts 110 tons/day (20 MW) wood fuel into 6 MW electricity and 12 MW district heat. The overall efficiency is 87% and electrical efficiency of 28%.

A biomass gasifier for bark, wood chips, sawdust, etc. has been installed at the 137 MWe pulverized coal fired power station of Verbund-Austrian Hydro Power AG in Zeltweg, Austria.

A 1.2-MW gasification plant has established in a rice mill located in Changxing, Zhejiang Province, China. The system has been able to run safely and continuously for 4 years, from October 2004 to June 2008. The gasification system consists of an air-blown fluidized bed gasifier, a combined gas cleaner (including an inertial separator, a cyclone separator, two Venturi tubes and two water scrubbers), and a power generation subsystem (containing four gas engines of 200 kW, and one gas engine rated at 400 kW), in addition to a wastewater treatment system.

Many countries have developed commercial biomass gasification technologies. Some of the commercially available fixed bed gasifiers are listed in Table 5

5. Literature review

D.F. Fletcher et al (2000) provided of a detailed Computational Fluid Dynamics (CFD) model developed to simulate the flow and reaction in an entrained flow biomass gasifier. The model is based on the CFX package and represents a powerful tool which can be used in gasifier design and analysis. The model provides detailed information on the gas composition and Temperature at the outlet and allows different operating scenarios to be examined in an efficient manner. The initial calculations suggest that simulations to examine the effect of gasifier height and the steam flux in the upper inlets can be beneficial in process optimization. The simulation of sawdust gasification in one case gave an exit composition on a dry basis of 10% CO, 12% CO_2, 20% H_2 and 1.2% CH_4, compared with 16% CO, 14% CO_2, 10% H_2, 1% CH_4 measured in the experiments, the hydrogen generation was too high. The model with further validation against detailed experimental data, will aid with the design process of such gasifiers.

M. Miltner et al (2006) presented the joint application of process simulation and computational fluid dynamics (CFD) is a helpful tool for the design and optimization of complex and innovative concepts in chemical engineering practice. The major goals of this paper to comprise the maximization of the thermal efficiency and the reduction of gaseous and particular matter emissions .The modeling approaches are presented that especially focus on the treatment of the heterogeneous combustion and prediction of gaseous emissions such as carbon monoxide and nitrogen oxide. The agreement between measured and calculated temperatures and volume flows is rather good, especially when the uncertainty of flow measurements is taken into account.

The maximum deviation between the measured and calculated values is 0.1% for gas volume flows, 6.4% for the flue gas temperature, and 3.6% for the combustion chamber wall temperatures.

SU Yi et al (2009) Analyses the technical features and innovative structure of the two-stage gasifier and experimentally detected the effect of different parameters on gasification performance. In this work, main parameters, such as ER's effect on gasifier temperature, content of product gas, low heat value, gas yield rate, carbon conversion, gasification efficiency, were investigated. The effect of equivalence ratio (ER) on gasification performance is detected under a certain condition: feeding rate is around 100 kg/h, char bed height is kept about 100 cm high. Results show that: within the experimental condition, when ER is between 0.3 to 0.35, the heat value of product gas can reach as high as 7247.7 kJ/m^3, gas yield rate is 1.84 m^3/kg, carbon Conversion rate is 91.3%, the overall gasification efficiency is 84.6%.

P.N. Sheth, B.V. Babu (2009) Presented a downdraft biomass gasifier is used to carry out the gasification experiments with the waste generated while making furniture in the carpentry section of the institute's workshop. Generally known as sesame wood or rose wood is mainly used in the furniture and wastage of the same is used as a biomass material in the present gasification studies. The effects of air flow rate and moisture content on biomass consumption rate and quality of the producer gas generated are studied by performing experiments. The performance of the biomass gasifier system is evaluated in terms of equivalence ratio, producer gas composition, calorific value of the producer gas, gas production rate and zone temperatures. Based on the results of this study, with an increase in the moisture content, biomass consumption rate decreases and the air flow rate increase the biomass consumption rate also increases. Molar fraction of N_2 and CO_2 decrease with an increase in equivalence ratio (λ) till $\lambda = 0.205$. The fraction of CO and H_2 shows increasing and decreasing trend exactly oppo site to that of N_2 and CO_2. The calorific value, pyrolysis zone temperature and the oxidation zone temperature are maximum at $\lambda = 0.205$.With an increase in λ, the production rate of producer gas continuously increases. The value of cold gas efficiency is 0.25 for $\lambda = 0.17$. It becomes almost double with a small increase of 0.035 in the value of λ.

Y. Ueki et al (2010) focused on woody biomass gasification fundamentals, using a bench-scale packed-bed reactor. In this experiment, pellets of black pine were gasified, using air as the oxidizing agent. Gasification tests were carried out under both updraft and downdraft conditions. Temperature distributions and compositions of producer gas inside the gasifier were continuously monitored during gasification experiments at several ports on the wall of the reactor. The results are summarized as the temperature fluctuations in the reactor under downdraft conditions are larger than those under updraft conditions, causing unstable gas composition at the exit of the gasifier. An updraft setup yields a lower heating value of producer gas greater than a downdraft setup as a time average. Lower heating values of the producer gas under updraft and downdraft conditions were 4.8 and 3.8 MJ/ m^3N, respectively. Tar compounds in producer gas under

Table 5 A Few commercially available fixed bed gasifiers

Country	Type of fixed bed gasifiers	Fuel	Size	Organization / project
USA	Downdraft Downdraft	Hogged wood, stumps Woodchips, corn cobs	1 MW 40 kW	CLEW Stwalley Engg.
Denmark	Updraft Updraft Downdraft	Hazardous, leather waste Straw, woodchips, bark Wood residues	2-15 MW 0.5 MW 1-15 MW	DTI VOLUND R&D Centre Hollesen Engg.
New Zealand	Downdraft	Wood blocks, chips, coppice willow chips	30 kW	Fluidyne
France	Downdraft	Wood, agricultural residues	100-600 kW	Martezo
UK	Downdraft Downdraft	Wood chips, hazel nut shell, MSW Industrial agricultural wastes	30 kW 300 kW	Newcastle University of technology Shawton Engineering
Switzer- land	Stratified Downdraft	Woody and agricultural biomass Wood, wood- waste	50-2500 kW 0.25-4 MW	DASAG HTV Energy
India	Downdraft Downdraft	Wood chips, rice hulls Wood stalks, cobs, shells, rice husk	100 kg/h	Associated Engineering Works Ankur Scientific Energy Technologies
Belgium	Small scale	Wood chips	160 kW	SRC Gazel
South Africa	Downdraft briquettes	Wood blocks, chips,	30-500 kW	SystBM Johansson gas producers
Netherland	Downdraft	Rice- husk	150 kW	KARA Energy Systems
China	Downdraft Downdraft	Sawdust Crop residues	200 kW 300 kW	Huairou wood Equipment Huantai Integrate Gassupply System

down-draft conditions are smaller than those under updraft conditions, because they can be decomposed during passage through the char grains section at high temperature.

S. Murgia et al (2011) presented a comprehensive CFD model of an air-blown coal fired gasifier has been setted up and tested using the CFD code MFiX. The comprehensive 2D CFD model is able to simulate and evaluate the dynamics of the gasification process in an updraft air blown coal gasifiers. it is an important means in understanding the sequence of the different steps, from combustion to devolatilization, needed for the conversion of coal to producer gas and to characterize the temperature, species concentrations, velocities and reaction rates for the gas and solid phases in function of time and space. Gas temperature and gas composition on the gasifier are simulate six different time step. And Result show In first time step gas maintain constant temperature 290˚C then it increase and reached 1300˚C and after reacting zone it decrease gradually. First operating period gas composition is stable .when time increasing the tar and CH_4 increase and CO decrease.

Conclusion

Gasifiers have taken continuously growth with its design, working fuel, performance parameters issues. It is obvious from the above discussion that parametric study of gasification of biomass into gaseous product by different gasification fuel is feasible. The performance of gasifier is evaluated in term of different parameters. These all parameters take significant impact on the performance of gasifier. When Increase in temperature reduces the tar content as well as decreases char inside the gasifier. Gas yield increases due to higher tar cracking. Increase in ER increases the temperature inside the gasifier while ER decrease increases char formation inside the gasifier.

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