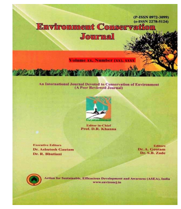
Environment Conservation Journal 24 (1): 204-208, 2023

Journal homepage:https://www.environcj.in/

Environment Conservation Journal

ISSN 0972-3099 (Print) 2278-5124 (Online)



Development of laboratory model of fluidized bed gasifier for low density leafy biomass

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ARTICLE INFO

Received : 16 March 2022
Revised : 27 June 2022
Accepted : 28 August 2022

Available online: 15 January 2023

Key Words:
Fluidized Bed Gasifier
Leafy Biomass
Low Density
Performance

ABSTRACT

Crops can also be grown for energy could be produced in large quantities, and likely to become the most popular in the future. One of the most widely used renewable energy source for heating is biomass in the form of fuel wood, charcoal, agriculture residues etc. A lab model of Fluidized Bed Gasifier (FBG) for handling low density and leafy biomass materials like rice husk, saw dust, bagasse, tree leaves etc. was developed. The performance study of the gasifier was determined by different parameters such as air factor, gas yield, calorific value and hot gas efficiency. The average gas yield of 2.5 m^3/kg and a maximum possible feed rate 10 kg/h with the existing feeding system the capacity of the unit was worked out as 20kW.

Introduction

Crops can also be grown for energy could be produced in large quantities, and likely to become the most popular in the future. One of the most widely used renewable energy source for heating is biomass in the form of fuel wood, charcoal, agriculture residues etc.Agricultural residues are available in almost every country around the world while municipal waste is available in every city. India produces about 320 million tones of agricultural residues comprising of mainly rice husks, paddy straw, sugarcane leaves and wheat residues (Jorapur and Rajvanshi, 1997;). It is guesstimated that about one third of this or 100 million tons of residues are not being utilized and are disposed of by burning them in the open fields (NPCMR, 2014). Unsustainable management practices of biomass waste would create high adverse environmental impacts (Ross, 2018; ruhela *et al.,* 2020; Bhardwaj *et al.,* 2019).

Energy can be harvested from a biomass, a significant renewable energy source forever. Biomass energy can be produced from plants and agricultural wastes, crops, trees, and crop residues to manure. Gasification is a promising route to harness the source of biomass energy. In India, gasifiers being used for thermal applications (Mukunda *et al.* (1994)). Jorapur and Rajvanshi (1997) developed a commercial-scale (1080 MJ h^{-1}) model of a gasifier, which can handle low density and leafy biomass materials like sugarcane leaves and bagasse and also analyzed the techno-economic feasibility. Fluidized bed gasification is one of the major processes to reach a high gas product yield from a large panel of carbonaceous resources (biomass, wastes). Some advantages of implementing fluidized bed for gasification have been reported in several studies (Basu, (2006) and Bain (2004). Alauddin *et al.* (2010) presented the merits of gasification of lignocellulosic biomass in fluidized beds for renewable energy development. Ramjani *et al.* (2020) showed the characterization of Coir pith for fluidized bed gasification. This

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Doi:https://doi.org/10.36953/ECJ.11442298

paper reports the development of a lab model Fluidized Bed Gasifier (FBG), which can handle low density and leafy biomass materials like rice husk, saw dust, bagasse, tree leaves etc. The performance study of the gasifier was determined by different parameters such as air factor, gas yield, calorific value and hot gas efficiency.

Material and Methods

The study was conducted at Agricultural Engineering College and Research Institute, Kumulur, Tamil Nadu, India which has Leafy biomass potential around 30 tonnes per annum. The major leafy biomass of Teak leaves, mango leaves, and rice husk are taken for the development of FBG and for gasification studies.

Development of a fluidized bed gasifier

Development of Fluidized Bed Gasifier includes reactor dimension, estimation of bed dimensions, distributor plate, fuel feeding and air supply system, and producer gas burner. The reactor was made of M.S. Pipe of 12" diameter and 10' length. The reactor was covered at the top and bottom with an air tight detachable lid. The reactor consists of provision for fuel inlet, producer gas outlet, air supply, temperature measurement and heat source inlet. The feed point was kept at height of 30" from the bottom of the reactor. The distributor plate was fixed at a level of 17" from the bottom the reactor. Cr/Al thermocouples were inserted to measure the bed temperature and gas temperature.A simple perforated air distributor is used for the uniform supply of air. Orifices that are too small are liable to become clogged and that are too large may cause uneven distribution of fluidizing air. According to Howard (1987), the orifice diameter has to be in the range of 2 to 3 mm. Hence orifice of 2.5 mm diameter and 300 numbers were adopted, giving fractional open area of 2.0%. The feeding system consists of a screw auger with hopper run by a one horse power single phase AC motor. The length, diameter and pitch of the screw are 45.0cm, 7.5cm and 5.0 cm respectively. The feeding rate was adjusted by adjusting the speed of the motor through a variable frequency drive. The air required for fluidization and gasification was supplied by a one horse power blower. An orifice meter with water manometer was fixed in the air supply line to measure the volume of air supplied. The air flow rate was controlled by a gate valve in the air supply line. The experimental set up is shown in Figure 1.

Figure 1: Fluidized bed gasifier for leafy biomass

Estimation of bed dimensions

Sand (Silica sand) was used as a bed material in fluidized bed gasifier. Sand is an inert material and has high heat retention capacity makes it suitable for use as bed material in a fluidized bed Gasification system. The physical properties of bed materials are furnished in Table 1. As leafy biomass can cause intensive elutriations, hence a low static bed height of 5 cm was maintained. The fluidization parameters of the sand bed are given in Table 2.

Table. 1 Physical properties of sand

S. No.	Properties	Value
1	Bulk density, kg/m^3	1355.0
2	Porosity, %	38.2
3	Particle density, kg/m^3	2193.0
4	Mean Particle size, mm	0.672

Table.2 Fluidization parameters of the sand bed

S. No.	Parameters	Value
1.	Bed height at minimum fluidizing velocity , L_{mfs} (Kunii and Levenspiel, 1969)	8.1 cm
2.	Minimum Fluidization velocity (Kunii and Levenspiel, 1969)	0.1 m/s
3.	Quality of fluidization (Product of four dimensional groups - {Fr, Re, $(\rho_{ps} - \rho_f)/ \rho_f$, L_{mfs} / d}(Howard, 1987)	> 100, Smooth or Particulate fluidization

Biomass feeding system

The biomass feeding system consists of a screw feeder with a hopper. A variable frequency drive is connected to the 1 horse power three phase motor that controls the biomass feed rate. The feed was calibrated with various frequency of the drive motor. The feeding point is fixed at the height of 0.125 m above the distributor plate, to avoid pyrolysis of biomass inside the screw feeder. The screw feeder pushes the biomass materials instantaneously into the bottom dense region of the fluidized bed. The mass flow rate of biomass fuels was maintained at the desired operating conditions.

Air and gas flow measurement system

An orifice plate was positioned on the duct between blower delivery end and the air supply point in the plenum chamber to measure the air flow rate into the fluidized bed gasifier. Another orifice plat was fixed between producer gas outlet and burner to measure the product gas flow rate. The pressure drop across this plate was measured using a differential pressure manometer (water column) and this pressure drop was then used to estimate the flow rate of the gases through the orifice. Air required for complete combustion of a biomass is calculated based on the composition of leafy biomass and by using the given empirical formula:

Air requirement for complete combustion = 100/23 $[8/3\ C + 8H_2 + S) - O_2]$

Where, C, H_2, and S mass of carbon, Hydrogen and Sulphur in 1 kg of fuel.

Performance study of the gasifier

The performance study of the gasifier was determined by different parameters such as air factor, gas yield, calorific value and hot gas efficiency. The proximate analysis of selected leafy biomass are determined by using ASTM standards E 871, E 1755 and E872; for moisture, ash and volatile matter, respectively and fixed carbon content was calculated by difference. Thermogravimetric analysis of selected leafy biomass was carried out in a TGA Q50 V20.13 Build 39 model instrument.

Results and Discussion

Characterization of selected biomass

For gasification process teak leaves, rice husk and mango leaves were selected. The raw materials are collected in the college campus premises are sundried for a week. The Proximate and ultimate analysis, Thermo gravimetric analysis and Higher Heating Value of biomass samples were analyzed and presented. The proximate and ultimate analysis are given in the Table 3 and 4 respectively.

Table 3: Proximate composition of selected leafy biomass.

Biomass	Moisture content, %	Volatiles, %	Ash %	Fixed Carbon ,%
Teak leaves	7.2	65.8	10.9	16.1
Mango leaves	7.5	47.0	10.5	35.0
Rice husk	8.1	53.2	24.1	14.0

Table 4: Ultimate analysis of Leafy biomass.

Elements	Teak leaves	Mango leaves	Rice husk
Carbon , %	56.97	44.12	50.45
Hydrogen, %	6.79	6.1	06.57
Oxygen, %	35.01	47	41.26
Nitrogen, %	1.22	2.66	01.49
Sulfur, %	-	0.12	0.23
Heating value (MJ/ kg)	22.73	15.24	19.10

Thermogravimetric analysis of selected leafy biomass.

The most common technique used to investigate the thermal behaviour and kinetics of fuels is TGA. TGA was conducted in the temperature range of 50 °C to 1000 °C with the heating rate 40 °C/min with suitable cooling attachment with thermocouple sensor Pt-Pt/Rh. The thermograms of selected leafy biomass materials are divided into four distinct stages (A to E). The percentage and rate of mass loss are shown in Table 5. The thermograms are divided into four distinct stages as shown in Fig. 2. The rate of mass loss in the first stage varies from 5.00 to 11.17 % which occurs upto the temperature range of 100 to 150°C. The mass loss indicates the removal moisture from the biomass. The mass loss in the second stage is slow and varies from 3.29 to 8.00 % which may be due to the volatilization of

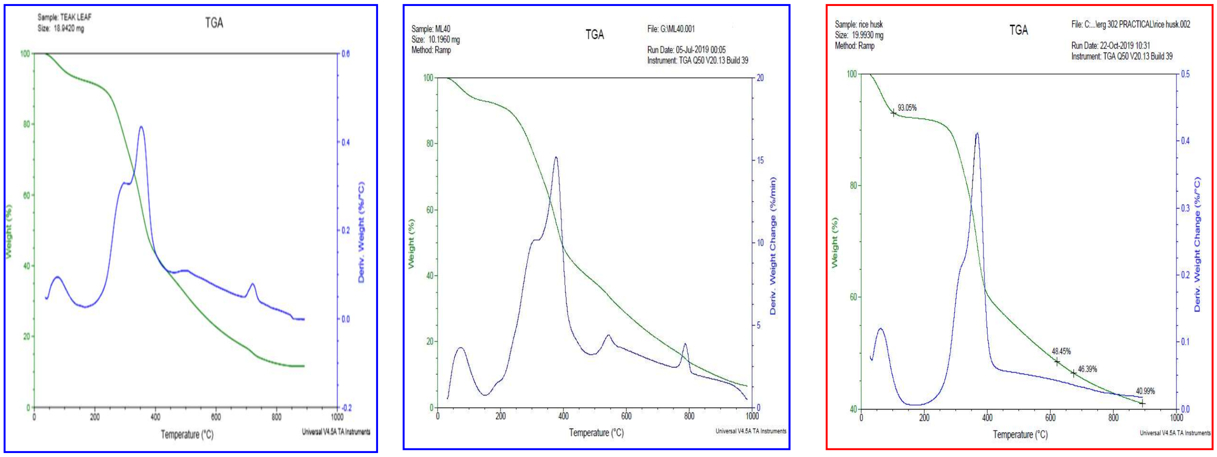

Figure 2: Thermogram of Teak leaves, Mango leaves and Rice husk

Table.5. Percent and rate of mass loss (mg/min) in different stages

Biomass	Stage A – B		Stage B – C		Stage C – D		Stage D – E	
	%	Rate (mg/min)	%	Rate (mg/min)	%	Rate (mg/min)	%	Rate (mg/min)
Teak leaf	5.22	0.45	7.83	0.53	45.24	1.85	23.49	0.53
Mango leaf	6.58	0.21	3.29	0.14	44.08	0.97	38.16	0.31
Rice husk	11.17	0.83	5.26	0.15	50.00	0.95	22.32	0.85

simple volatile matters. The steep fall in the third stage contributes maximum mass loss (44 to 50%) for each biomass and it is due to the removal of remaining volatile matters. The fourth stage which starts at the temperature range of 450 to 700°C may considered as the start of ignition of fixed carbon in the biomass. After reaching the temperature level of 800 °C, the mass loss is constant which indicates the ash content of the biomass.

Air required for gasification leafy biomass

For gasification 25 to 40% of stoichiometric has to be supplied (Reed, 1984). Air required for complete combustion of the biomass is given in Table 6.

Table 6. Air requirement for complete combustion

Biomass	Air requirement, m^3/ kg of fuel
Teak leaves	9.08
Mango leaves	6.34
Rice husk	7.75

Hot run of the gasifier

To start up the system known quantity of red hot charcoal was fed into the charcoal chamber. From the Table 7, it is observed that the fluidizing bed temperature ranges from 400 to 750°C for all the leafy biomass taken for the study. When the temperature of the bed exceeds 600°C, feeding of raw biomass was started. The results of gasification of leafy biomass are presented in the Table.8. The product gas flow rate for the leafy biomass varies from 2.8 to 3.1 m^3 per kilo gram of biomass feed. The calorific value of producer gas from the gasification varies from 3.0 to 3.6 MJ/m^3.

Table 7: Temperature Profile in the fluidized bed gasifier for leafy biomass

Time, min	Bed Temperature °C		
	Teak leaves	Mango leaves	Rice husk
10	443	496	532
20	490	507	537
30	535	505	563
40	550	534	595
50	576	554	605
60	614	600	640
70	635	625	655
80	621	554	528
90	590	560	522
100	551	510	510
110	523	485	515

Table 8: Performance of Fluidized bed gasifer for selected leafy biomass

Parameters	Biomass		
	Teak leaves	Mango leaves	Rice husk
Feed rate, kg/h	2.0	2.0	3.0
Air factor	0.3	0.3	0.3
Bed temperature, °C	700	680	700
Gas yield, m^3/kg	2.9	2.8	3.1
Average Gas Composition of Producer gas, %			
CO	13.5	13.7	14.2
H_2	12.3	11.4	15.4
CO_2	18.4	16.5	13.1
Calorific value of Producer gas, MJ/ m^3	3.1	3.02	3.56
Hot gas efficiency, %	40.0	55.0	54.0

Fluidized bed gasifier capacity

Average capacity of the gasifier is arrived based on the assumption that the average gas calorific value of producer gas obtained from leafy biomass is 3.0 MJ/m^3, average gas yield of 2.5m^3 /kg and a maximum possible feed rate 10 kg/h with the existing feeding system the capacity of the unit was worked out as 20kW.

Conclusion

Fluidized bed is one of the major platforms of biomass gasification. A fluidized bed biomass gasifier of 20kW capacity was developed for leafy biomass gasifier with all sub systems. The gasifier runs smoothly with the selected leafy biomass and in few runs the fluidizing air escapes through biomass feed port when the airflow rate is more than 0.4. The thermograms showed that after reaching the temperature level of 800 °C, the mass loss is constant which indicates the ash content of the biomass. Average capacity of the gasifier is arrived based on the assumption that the average gas calorific value of producer gas obtained from leafy biomass is 3.0MJ/m^3 and average gas yield is 2.5m^3/kg.

Conflict of interest

The authors declare that they have no conflict of interest.

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