Design & Development of 5 KW Downdraft Biomass Gasifier

Ashok M. Thummar[1] Dr. Veera P. Darji[2]
[1,2]Department of Mechanical Engineering
[1,2]C.U. Shah University, Wadhwan City, India, India

Abstract— A laboratory scale downdraft biomass gasifier was designed to deliver a mechanical power of 5 kW and thermal power of about 18 kW. The biomass chosen as sized wood and briquette of saw dust. The various properties of biomass such as biomass size, densities, proximate and ultimate analysis, calorific value etc. have been measured. The design of the biomass downdraft gasifier is basically empirical, that is implied from different mathematical relations and charts based on past experiences.

Key words: Biomass, Gasifier, Design, Downdraft, Power

I. Introduction

The energy demand in industries and households is rapidly increasing. The majority of energy uses are fossil fuels such as coal, petroleum and natural gas. The consumption of fossil fuels causes serious environmental problems. Therefore renewable energy is an alternative energy source that can be substituted for fossil fuels. Biomass is the most common type of renewable energy and its energy utilization is environmental friendly. Because the contents of sulfur and nitrogen in the biomass waste are lower than those in fossil fuels, and furthermore the carbon dioxide emitted to the atmosphere is taken up by plants for their growth.

Biomass utilization as a solid fuel can be used to generated electricity, heat, liquid fuels, or production of modern energy. However, there are many drawbacks from its undesirable properties. In term of physical properties, due to its low bulk density leading to huge storage space requirements, difficulty in handling and high transportation costs. The porous structure is easy to absorb moisture and has high moisture content. This property decreases its heating value and needs pretreatments before utilization. In term of chemical properties, biomass has carbon content lower than fossil fuels such as coal. Some biomass types has a high ash content that may cause problems in combustion devices due to ash fusion inside at higher temperatures [1].

Biomass can be converted to energy via thermo chemical and biochemical routes [2]. Gasification is one of the thermo chemical processes in the presence of controlled air. It is the conversion process of solid, carbonaceous fuel into combustible gas mixture which contains varying amounts of carbon monoxide, and hydrogen, normally known as synthesis gas. This gas can be burned directly in a furnace or internal combustion engine or gas turbine for heat or electricity generation [3].

The gasification reactions are mainly endothermic and thus, heat has to be supplied to the reactor. In directly heated gasifiers, the heat necessary for the endothermic reactions is provided by combustion or partial combustion of the biomass within the gasifier (auto thermal gasification). In indirectly heated gasifiers, the heat is generated outside the gasifier and then exchanged with the gasifier by means of a heat exchanger or a heat carrier. Auto thermal gasification reactors mostly use air as gasification medium because pure oxygen is economic feasible only in large-scale installations [4].

II. Biomass Gasification

Gasification is the conversion of biomass, or any solid fuel, into an energetic syngas through partial oxidation at elevated temperatures. Gasification process is conducted by heat generated from carbon oxidant to conserve the reaction of gasification.

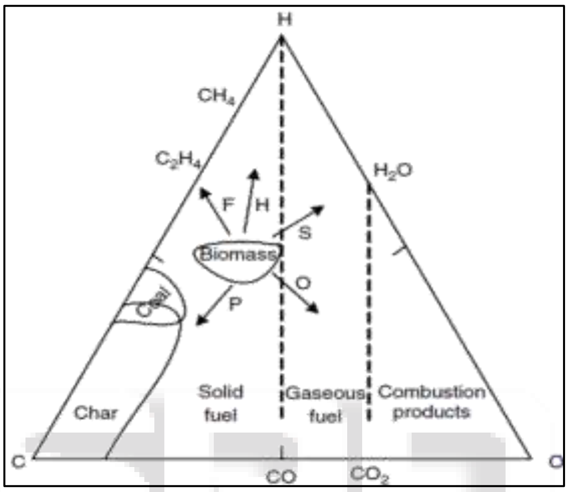

Fig. 1: C-H-O Ternary Gasification Process

Gasification agent or oxidant (air or oxygen) will be added to solid fuel and produce gasify fuel. Some of the gasification reactions involve the participation of water or steam. In addition, water or steam will be used to control reaction temperature. Studies on the development of gasification have long been carried out by many researchers to improve the efficiency, operability and the yield of the system. In general, the product yields and the composition of gases are dependent on several parameters including temperature, gasifying agent, biomass species, particle size, heating rate, operating pressure, equivalence ratio, catalyst addition and reactor configuration increase syngas yield and reduce formation of tar [5].

The combustible gas comprises mainly of carbon monoxide (18-22%); hydrogen (15-20%); methane (1-5%); carbon dioxide (8-12%) and nitrogen (45-55%). The calorific value of producer gas is 1000-1200 kcal/Nm3.Whereas the conversion efficiency is 80 per cent. Reliable gasification systems related to the quality of the gas in terms of energy and the tar content and particulates in the gas. Though the poor energy conversion of solid fuel to the gas was acceptable, the higher particulate and tar content caused difficulties in using the gas for engine [6]. The conventional gasification technologies include fixed bed (updraft and downdraft), fluidized bed, and entrained flow reactors. A wider variety of new gasification technologies have been further developed, including plasma gasification and gasification in supercritical water of wet biomass, to convert different feedstocks to gas. Besides, process integrations and combinations aim to achieve higher process efficiencies, better gas quality and purity, with lower investment costs. Therefore, the so called "emerging technologies" have received increasing attention recently, such as integration of gasification and gas cleaning technologies, or pyrolysis combined with gasification and combustion [7].

A. Process Zones

Four distinct processes take place in a gasifier as the fuel makes its way to gasification. They are drying of fuel, Pyrolysis, Combustion and Reduction. Though there is a considerable overlap of the processes, each can be assumed to occupy a separate zone where fundamentally different chemical and thermal reactions take place.

B. Drying of Fuel

Wood entering the gasifier has moisture content of 10-30%. Various experiments on different gasifier in different conditions have shown that on an average the condensate formed is 6-10% of the weight of gasified wood. Some organic acids also come out during the drying process. These acids give rise to corrosion of gasifier. In order to prevent these adverse effects, moisture content must be removed from the biomass prior to gasification process. In this drying zone the main process is of drying of wood.

C. Pyrolysis Zone

Wood pyrolysis is an intricate process that is still not completely understood. The products depend upon temperature, pressure, residence time and heat losses. However following general remarks can be made about them. Upto the temperature of 200^0C only water is driven off. Between 200 to 280^0C carbon dioxide, acetic acid and water are given off. The real pyrolysis, which takes place between 280 to 500^0C, produces large quantities of tar and gases containing carbon dioxide. Besides light tars, some methyl alcohol is also formed. Between 500 to 700^0C the gas production is small and contains hydrogen. Thus it is easy to see that updraft gasifier will produce much more tar than downdraft one. In downdraft gasifier the tars have to go through combustion and reduction zone and are partially broken down.

D. Combustion Zone

The combustible substance of a solid fuel is usually composed of elements carbon, hydrogen and oxygen. In complete combustion carbon dioxide is obtained from carbon in fuel and water is obtained from the hydrogen, usually as steam. The combustion reaction is exothermic and yields a theoretical oxidation temperature of 1450^0C. The combustion products from complete combustion of biomass generally contain nitrogen, water vapor, carbon dioxide and surplus of oxygen. However in gasification where there is a surplus of solid fuel (incomplete combustion) the products of combustion are combustible gases like Carbon monoxide (CO), Hydrogen (H_2) and traces of Methane and no useful products like tar and dust. The main reactions, therefore, are:

$$C + O_2 = CO_2\ (+393\ MJ\ /\ kg\ mole) \quad (1)$$

$$2H_2 + O_2 = 2H_2O\ (-242\ MJ\ /\ kg\ mole) \quad (2)$$

E. Reaction Zone

The products of partial combustion (water, carbon dioxide and uncombusted partially cracked pyrolysis products) now pass through a red-hot charcoal bed where the following reduction reactions take place:

$$C + CO_2 = 2CO\ (-164.9\ MJ\ /\ kg\ mole) \quad (3)$$

$$C + H_2O = CO + H_2\ (-122.6\ MJ\ /\ kg\ mole) \quad (4)$$

$$CO + H_2O = CO + H_2\ (+42\ MJ\ /\ kg\ mole) \quad (5)$$

$$C + 2H_2 = CH_4\ (+75\ MJ\ /\ kg\ mole) \quad (6)$$

$$CO_2 + H_2 = CO + H_2O\ (-42.3\ MJ\ /\ kg\ mole) \quad (7)$$

Reactions (3) and (4) are main reduction reactions and being endothermic have the capability of reducing gas temperature. Consequently the temperatures in the reduction zone are normally 800-10000C. Lower the reduction zone temperature (700-800^0C), lower is the calorific value of gas [7].

III. TYPES OF GASIFIER

Since there is an interaction of air or oxygen and biomass in the gasifier, they are classified according to the way air or oxygen is introduced in it. There are three types of gasifier Downdraft, Updraft and Cross draft. Gasifier equipments are generally classified as upward draft, downward draft and cross draft gasifiers, based on the direction of air/oxygen flow in the equipment. The choice of the gasifier largely depends upon the fuel, its final available form, moisture and ash content, volatile matter, calorific value etc.

A. Updraft Gasifier

Updraft gasifier has air passing through the biomass from bottom and the combustible gases come out from the top of the gasifier.

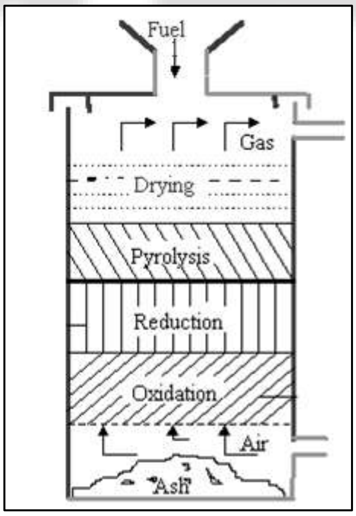

Fig. 2: Updraft Gasifier

In the updraft gasifier as shown in the Fig. 2, the feed (biomass) is introduced from the top and moves downwards while gasifying agents (air, steam, etc.) are introduced at the bottom of the grate so the product gas moves upwards. In this case, the combustion takes place at the bottom of the bed which is the hottest part of the gasifier and product gas exits from the top at lower temperature (around 500 °C). The producer gas has no ash but contains tar and water vapor because of passing of gas through unburnt biomass but, usually 5% to 20% of tars and oils are produced at temperature too low for significant cracking and are carried out in the gas stream and the remaining heat dries the wet biomass so that none of the energy is lost as sensible heat in the gas and the advantage of updraft gasifier over other gasifier is its high conversion efficiency up to 80% but it produces tar with producer gas which is the major feedback of updraft gasifier and its tar content producer gas cannot be used in engine application, it may corrode the engine parts like valve, piston and fuel line [8].

B. Downdraft Gasifier

In downdraft gasifier shown in Fig. 3, gas is drawn from the bottom of the reactor while the hottest reaction zone is in the middle. The volatile matter in the fuel gets cracked within the reactor and therefore the output gas is almost tar-free. However, the gas, as it comes out of the reactor, contains small amounts of ash and soot. After the air contacts the pyrolyzing biomass before it contacts with char and support a flame and the limited air supply in the gasifier is rapidly consumed, therefore that the flame gets richer as pyrolysis proceeds. Next to the end of pyrolysis zone, the gases consist mostly of CO_2, H_2O, CO and H_2 and the throat ensures that the gaseous products pass through the hottest zone someplace most of the tar cracked into gaseous hydrocarbon. So produces relatively clean gas.

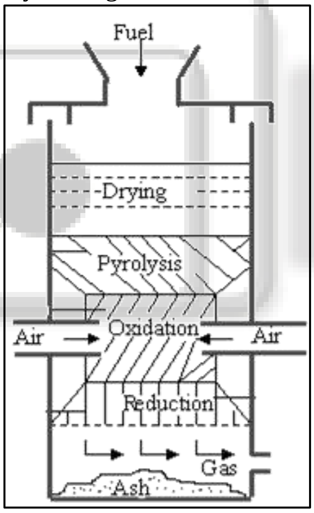

Fig. 3 Downdraft Gasifier

Designed for the application of producer gas in CI engine, downdraft gasifier is more suitable as it produces very less tar. Its advantages include Flexible adaptation of gas production to load and low sensitivity to charcoal dust and tar content of fuel. Its limitations include design tends to be tall and not feasible for very small particle size of fuel. Downdraught gasifiers also suffer from the problems associated with high ash content fuels (Slagging) to a larger extent than up draught gasifier [9].

C. Crossdraft Gasifier

The Crossdraft gasifier as shown in Fig. 4, air enters at high velocity through a water cooled nozzle mounted on one side of the induces substantial circulation, firebox, and flows across the bed of char and fuel.

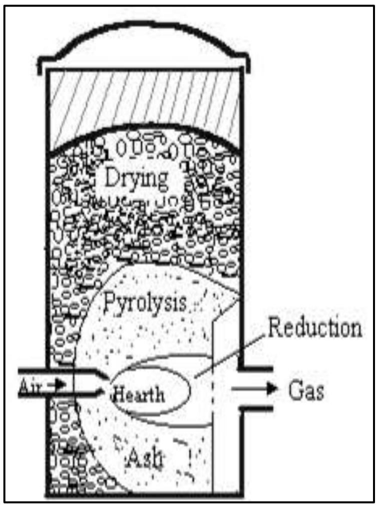

Fig. 4 Crossdraft Gasifier

The gas is produced in the horizontal direction in front of the nozzle and passes through a vertical grate into the hot gas port on the opposite side and this produces very high temperature in a very small volume and results the production of very low tar gas. However, the cross draft gasifier is not commonly used.

The major advantages of cross draft gasifier are short design height, very fast response time to load and flexible gas production. Advantages of the system lie in the very small scale at which it can be operated. Installations below 10 kW (shaft power) can under certain conditions be economically feasible. It also has some limitations as Very high sensitivity to slag formation, high pressure drop etc [9].

IV. DESIGN OF DOWNDRAFT BIOMASS GASIFIER

Design of gasifier essentially means obtaining the various geometric dimensions of the different parts of the gasifier. Design of gasifier is largely empirical. Design of gasifier is carried out partly using empirical relations and using some experimental data. The entire design of gasifier is based upon pure empirical, parametrical and numerical relations who are based upon the past experience and research outcome.

A. Power Consumption of the Gasifier

For an engine with a compression ratio of 9.5:1, the efficiency has been estimated to be 28 per cent [10]. Therefore, the thermal power in the gas can be estimated as,

$$P_g = \frac{P_m}{\mu} \tag{8}$$

Where,

P_m = 5 KW

μ = 0.28 which yields,

P_g = 17.85 KW

If the thermal efficiency of the gasifier is taken at 70 per cent, the thermal power consumption at full load can be estimated as,

$$P_t = \frac{P_g}{0.7} \tag{9}$$

$$= 25.5 \text{ KW}$$

B. Biomass Consumption of the Gasifier

A heating value of biomass with 8% moisture content is taken to be 3800 kcal/kg. So, it will become,

$$= \frac{Thermal\ Power\ Consumption}{Heating\ Value\ of\ Biomass} \quad (10)$$

= 24 kg/hr

C. Reactor Diameter

The reactor diameter is the function of the amount of the fuel consumed per unit time (FCR) to the specific gasification rate (SGR) of the biomass, which is in the range of 40 to 210 kg/m^2-h as revealed by the results of several test on different types of biomass [11].

$$D = \sqrt{\left(\frac{1.27 \times FCR}{SGR}\right)} \quad (11)$$

By assuming SGR as 80 kg/m^{2}h, the reactor diameter will be, 617 mm.

D. Height of Reactor

It refers to the total distance from the top and the bottom end of the reactor.

$$Volume = \left(\frac{mass}{density}\right) \quad (12)$$

= 0.3 m^3

$$Height\ of\ the\ cylinder\ reactor = \frac{Volume}{Cross\ sectional\ area} \quad (13)$$

= 1.0 m

E. Amount of Air needed for Gasification

This refers to the rate of flow of air needed to gasify the biomass under study. It is very important in determining the size of the natural draft of primary air supply for starting of the gasification process needed for the reactor in gasifying the fuel [11]. This can be simply determined using the rate of consumption of fuel (FCR), the Stoichiometric air of biomass briquette (4.5 kg of air) and the recommended equivalence ratio (e) for gasifying the fuel (0.3 to 0.4) and air density is taken as 1.25 kg/m^3. AFR can be computed by using the formula,

$$AFR = \frac{e \times FCR \times SA}{R_a} \quad (14)$$

= 26 m^3/hr

F. Superficial Air Velocity

This refers to the speed of the air flow in the fuel bed. The velocity of air in the bed of maize cob and biomass pellets will cause channel formation, which may greatly affect gasification.

$$V_s = \frac{4 \times AFR}{3.14 \times D^2} \quad (15)$$

= 89 m/s

G. Size of the Throat

The gasifier is designed based on the following engine specifications,

Sr. No.	Parameters	Specifications
1	Engine	CP186FA
2	Engine type	4 stroke, single cylinder, air cooled, direct Injection, diesel engine
3	Output	5.83kW
4	Bore x stroke	86x72
5	Displacement:	418cc
5	Rated RPM	1500
7	Cooling system:	forced air cooled
8	Starting system:	electric start

Table 1: Engine Specifications

For an engine, the max air/gas intake,

$$= \frac{\frac{1}{2} \times RPM \times D}{60 \times 1000} \quad (16)$$

$$= 5.2 \times 10^{-3}\ m^3/sec$$

By taking into account of air/gas ratio (Stoichiometric) as 1.1:1.0, the Maximum gas intake will be,

$$= \frac{1.0}{2.1} \times \frac{air}{gas} \text{int}ake \quad (17)$$

$$= 2.47 \times 10^{-3}\ m^3/sec$$

Assuming that the volumetric efficiency of the engine to be 0.8, which is depend upon the engine rpm, air inlet manifold design and fouling of the air inlet manifold. Hence, the real gas intake becomes,

= Maximum gas intake × volumetric efficiency (18)

$$= 1.98 \times 10^{-3}\ m^3/sec$$

The recommended value for Bg falls in the range of 0.30 to 1.0. By assuming the value of Bg as 0.3 for single throat downdraft gasifier holds [12],

$$B_g = 0.3 = \frac{Gas\ \text{int}ake\ to\ engine}{Surface\ area\ throat} \quad (19)$$

$$0.3 = \frac{Gas\ \text{int}ake\ to\ engine \times 10^{-3} \times 3600}{S}$$

$$S = 23.76\ cm^2 = \frac{\pi}{4} \times d^2$$

d_t = 5.5 cm = 55 mm, The throat diameter

Sivakumar et al. [12] discovered from their model that for throat angles of about 45°, the cumulative conversion efficiency is increased while larger angles of about 90° decrease the cumulative conversion efficiency because of a decreased temperature for larger throat angles due to the divergent effect and the reaction rate. Venselaar [13] also recommended, after comparison of the design characteristics of a number of gasifier, that the throat inclination should be around 45° to 60°. A throat angle of 60° is used.

H. Size of the Throat

Diameter of the fire box or hearth, d_h is a function of throat diameter and can be estimated from the proportional dimensions from the chart as,

$$\frac{d_h}{d_t} = 3.5 \quad (20)$$

$$d_h = 192.5\ mm$$

I. Nozzle Design

The height of nozzle plane above the smallest cross section of the throat is a function of the throat diameter and can be evaluated from the chart.

$$\frac{h}{d_t} = 1.3$$

$$h = 71.5\,mm \tag{21}$$

Thus, the height of nozzle plane above the throat of the gasifier becomes 71.5 mm.

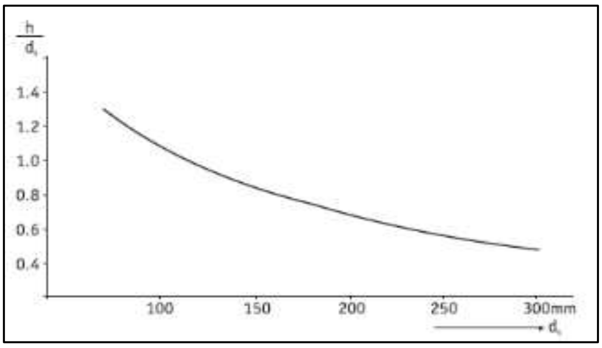

Fig. 4: Hight of Nozzle Plane above Throat for various Throat Diameters

$$\frac{h}{d_t} = 1.3$$

$$h = 71.5\,mm \tag{21}$$

Similarly, the ratio between the nozzle flow area and the throat area is a function of the throat diameter which is given from into the chart as,

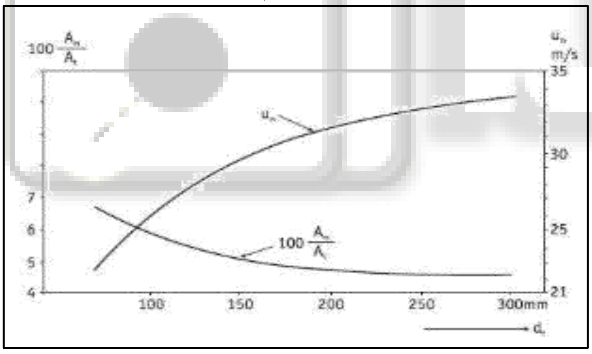

Fig. 5: Nozzle Area for Various Sizes of Gasifier Throat

$$\frac{A_n}{A_t} = 0.07$$

$$d_n = 14.55\,mm \tag{22}$$

Sivakumar et al. [12] suggested optimum results are obtained when the angle of inclination of the nozzles is between 10° and 25°. An inclination of 15° is used.

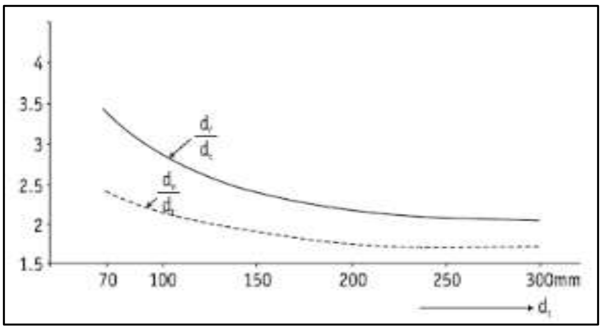

Fig. 6: Nozzle Tipring Diameter as a function of Throat Diameter

The nozzle tip ring diameter d_{nt} is also a function of the throat diameter as seen into the chart. The ratio between the nozzle tip ring diameter and the throat diameter is,

$$\frac{d_{nt}}{d_t} = 3$$

$$d_{nt} = 44\,mm \tag{23}$$

J. Air blast velocity

The air blast velocity (Vb) can be estimated by equating the volumetric flow rate of the producer gas through the throat to the volumetric flow rate of air through the nozzle.

$$Q_t = Q_n$$

$$0.016 = 6 \times \frac{\pi}{4} \times 0.014^2 \times V_b$$

$$V_b = 17.77\ m/s \tag{24}$$

K. Air Inlet & Outlet

The general range for air inlet velocity is 6 m/s to 10 m/s. The dimensions for the air inlet can be obtained using the continuity equation. By taking the velocity of air to be 6 m/s,

$$Q = A_i \times v$$

$$d = 18\ mm$$

Fig. 7: Laboratory Scale Downdraft Biomass Gasifier

V. PRELIMINARY TESTS CARRIED OUT ON THE BIOMASS FUELS

Sized wood and saw dust briquettes were used as the biomass fuel/feedstock for testing the performance of the manufactured biomass gasifier. Preliminary experiments were carried out on the biomass fuels to determine some of their properties which are critical to the operation of the gasifier. The properties that were determined include the densities, proximate analysis, ultimate analysis, calorific value etc.

A. Biomass Size

The size of the biomass like sized wood and saw dust have been measured by the guideline of ASABE standards S424.1 (American Society of Agricultural and Biological Engineers).

B. Measurement of Bulk Density & True Density of Biomass

The bulk and true density is calculated as the mass of biomass divided by the container volume. Three replicates were performed for each feedstock, Mohsenin, 1986 [14].

C. Proximate Analysis of Biomass

Proximate analysis is used for calculation of chemical composition of the residue including Moisture content, Ash content, volatile matter & fixed carbon.

The fuel moisture content (MC) of biomass is determined by drying the known weight of sample in hot air oven at 105 ± 2°C for 24 hours keeping the sample in Petri-dish till the constant weight is achieved [15].

Similarly, ash content is measured as oven-dried biomass sample kept in the silica crucible is placed in the muffle furnace at 750 ± 25 °C till constant weight is attained. The ratio of the final weight to the initial weight of the sample is the ash content of the moisture free biomass sample.

The volatile matter of biomass also can be measured as Oven-dried biomass sample is kept in the tared crucible. Two drops of benzene is added in it to displace air in the environment surrounding the sample. The crucible is closed with lid and placed in the muffle furnace and heated at 600 ± 10°C for six minutes and 900 ± 10°C for another six minutes. The loss in weight divided by the initial weight of biomass will provide the volatile matter on dry basis in the fuel.

D. Ultimate Analysis of Biomass

Ultimate analysis includes measurement of the carbon, hydrogen, nitrogen and nitrogen contents in the biomass.

The hydrogen and nitrogen content of the biomass can be easily determined from the Combustion method [16], Carbon content in the biomass can be determined by the Walklay and Black's method describing the estimation of the organic carbon of the biomass fuel was used for determination of carbon content of the biomass [17] and oxygen content is measured on mass basis of biomass contents.

E. Calorific Value of Biomass Fuel

The calorific value of biomass was measured using digital bomb calorimeter as per the standard measuring practice.

VI. Result & Discussion

The results for the determination of the properties of the biomass fuels are given in Table II.

Sr. No.	Physical Properties	Biomass Fuel Type	
		Sized Wood	Saw Dust Briquettes
1	Length, (mm)	56.54	25.33
2	Diameter, (mm)	26.45	65.54
3	Bulk Density, (kg/m3)	256.70	563.34
4	Moisture content, (%,w.b.)	10.25	10.02
5	Volatile Matter, (% d.b.)	78.02	72.13
5	Ash Content, (%, d.b.)	1.89	8.72
7	Fixed Carbon (%, d.b.)	21.09	19.15
8	Calorific Value, (kcal/kg)	4100	4080

Table 2: Physical Properties of Biomass

VII. Conclusion

A laboratory scale downdraft biomass gasifier was designed to deliver a mechanical power of 5 KW and thermal power of 18 KW. The design was largely empirical, that is based on past experience. The various geometric dimensions of gasifier like reactor diameter, reactor height, throat diameter, diameter of fire box, nozzle dimensions, air inlet and outlet etc. have been evaluated. Some operating parameters such as biomass consumption, air flow, superficial air velocity, air blast velocity are also calculated.

Raw biomass was chosen as sized wood and saw dust briquette for operation of downdraft biomass gasifier. all major properties like biomass size, bulk and true density, proximate and ultimate analysis, calorific value of biomass have measured and tabulated as suggested by some standard accepted methods. at the end, designed gasifier is fabricated by using stainless steel as a parent material.

References

[1] Twidell J, Weir T. Renewable Energy Resources. 2nd ed. Oxon: Taylor & Francis; 2006..
[2] Worasuwannarak N, Sonobe T, Tanthapanichakoon W. Pyrolysis behaviors if rice straw, rice husk, and corncob by TG-MS technique. Pyrolysis 2006;78:265-271.
[3] Yi S, Yonghao L. xperiment on rice straw gasification in a two-stage gasifier. Asia-Pacific Power and Energy Engineering Conference, 2009. APPEEC 2009; 2005, p. 1-4
[4] Iyer, P. V. R., Rao, T. R., Groover, P. D., Singh,N.P.,2002,"Biomass–Thermochemical Characterization,"ChemicalEngineering Department, Indian Institute of Technology,Delhi, pp. 9 – 16.
[5] Nor Afzanizam b. Samiran, Mohammad Nazri b. Mohd Jaafar, Chong Cheng Tung, Ng Jo-Han, 2014, "A Review of Biomass Gasification Technology to produce Syngas", Vol. 8, pp. 69-74.
[6] Somayeh Farzad, Mohsen Ali Mandegari, Johan F. Gorgens, 2016, "A critical review on biomass gasification, co-gasification, and their environmental assessments", Vol. 12, pp. 483-495.
[7] M.K.Chopra, Shrikant Ulhas Chaudhari, 2012, "Performance Of Biomass Gasifier Using Wood", International Journal of Advanced Engineering, Research and Studies, E-ISSN2249–8974, Vol. 1, pp. 204-206.
[8] Sunil P. Moharkar, P.D.Padole, 2012, "Design and Development of Downdraft Gasifier for Rural Area", International Conference on Emerging Frontiers in Technology for Rural Area.
[9] David D. Jones, Ajay Kumar and Milford A. Hanna, 2009, "Thermochemical Biomass Gasification: A Review of the CurrentStatus of the Technology" , Energies, ISSN 1996-1073.

[10] S.J. Ojolo and J.I. Orisaleye, Design and Development of a Laboratory Scale Biomass Gasifier, Journal of Energy and Power Engineering, Volume 4, ISSN 1934-8975, USA, 2010.
[11] Rice Husk Gas Stove Book, Alexis T. Belonio, Department of Agricultural Engineering and Environmental Management College of Agriculture Central Philippine University Iloilo City, Philippines 2005.
[12] S. Sivakumar, K. Pitchandi, E. Natarajan, Modelling and simulation of down draft wood gasifier, Journal of Applied Sciences 8 (1) (2008) 271-279.
[13] J. Venselaar, Design rules for down-draught gasifiers, a short review, IT Bandung, Indonesia, 1982.
[14] Physical Properties of Plant and Animal Materials, N.N. Mohesenin 1986.
[15] Jeandson da Silva, Roberta Martins, Marcio Aredes, Denisa Mendes de Souza, 2018, The Oven-Drying Method for Determination of Water Content in Brazil Nut" volume 34, n. 3, p. 595-602.
[16] Niveta Jain, Arti Bhatia, Himanshu Pathak,Emission of Air Pollutants from Crop Residue Burning in India, Aerosol and Air Quality Research, 14: 422–430, ISSN: 1680-8584 2014.
[17] Walkley A. and Black, LA. "An examination of the method for determining soil organic matter and a proposed modification of the chromic acid titration method". Soil Sci. 37, 29-38.

