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FUEL CHARACTERISTICS OF SOME INDIGENOUS PLANTS

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ABSTRACT

It is well known that fossil fuel combustion has tremendous negative impact on ecology and global climate. It is non renewable as well. The present rate of technological and economic growth of a country may be unsustainable due to rapid consumption of fossil fuel like crude oil, natural gas or coal. Thus people search for viable renewable energy sources like biomass, hydropower, geothermal energy, wind energy, solar energy, etc from time to time. Surplus biomass application for partial substitution of conventional fuel both in heat and power mode is an attractive option for developing country like India. It is normally techno-economically viable for most of small scale industrial process heat generation or allied applications. Biomass contains Carbon, Hydrogen, Oxygen, Nitrogen negligible amount of Sulphur. Biomass energy conversion can be achieved through several thermo chemical processes such as combustion, pyrolysis and gasification, etc. The present work investigates the fuel characteristics of some selected locally available fast growing plants such as Bamboo (*Banbuseae Tulda*), Gulmohar(*Delonix Regia*), Neem(*Azadirachta Indica*), *Dimaru* (Ficus Lepidosa Wall) and Sisham(*Delbergia Sissoo*). The lower heating value of different samples were found to vary from (15.95 – 18.40) MJ kg^{-1} on dry basis by automatic bomb calorimeter. From preliminary gasification study of this biomass (moisture ≤ 15 % w.b.) in a laboratory scale down draft biomass gasifier, it responded well for gasification. Some more long duration gasification studies may be required before recommending these indigenous fast growing plants for commercial scale gasification in some prospective industries.

Key words: Biomass, Calorific Value, Renewable Energy, Gasification, Combustion.

1. INTRODUCTION

Biomass is considered as renewable energy source. It has substantial region specific potential to contribute for energy needs of modern society. Therefore biomass may be used for both the developed and developing economies world-wide.

Today's rapid growth in population has led to the consumption of fossil fuels which are present in limited reserves. The use of fossil fuels has considerable negative impact on the environment. At the other hand, biomass energy is more suitable for agricultural applications than other renewable energy sources like solar, wind, geothermal, etc. It had been extensively used for transportation and on farm system during world war second [1]. Gasification of biomass which is an efficient thermo-chemical conversion processes producing a gas that can substitute fossil fuels in high efficiency power generation, heat or combined heat and power (CHP) applications. It can also be used for the production of liquid fuels and chemicals via synthesis. Biomass gasification means incomplete combustion of biomass in sub stoichiometric air fuel ratio resulting in production of combustible gases consisting of CO, H_2 and traces of CH_4. This mixture is called producer gas. Producer gas can be used to run IC engine (both CI and SI), boilers and gas turbine and domestic purposes. For energy production, the major concern about syngas is its heating value, composition and possible contamination.

2. LITERATURE REVIEW

2.1 Biomass as a fuel

Biomass is the nature's gift to mankind with major energy constituent carbon produced by action of photosynthesis. It stores solar energy in presence of sunlight. It is renewable, widely available and has potential to provide significant employment in rural areas. Biomass has important implications for design of biomass gasifier or biomass fired or co-fired furnace. Biomass is easier to gasify than coal in the sense that lower operating temperatures are required to achieve same gasification rates and degree of conversion from solid to gas. Most importantly biomass has negligible quantity of sulphur compared to coal.

Biomass composed primarily of the complex compounds such as cellulose, hemicelluloses and lignin. Cellulose has normally its same chemical structure in all types of biomass. Cellulose chains aggregate into crystalline structure that gives wood its mechanical strength. Unlike cellulose, hemicelluloses do not form a crystalline structure, but is amorphous. Lignin is a complex amorphous, randomly linked, high molecular weight, ringed structure that helps bind the cellulosic fiber together.

2.2 Biomass Types

Many researchers characterize the biomass in different ways but one simple method is to define four main types namely [2]:

- Woody plants
- Herbaceous plants
- Aquatic plants
- Manures

Woody biomass are those which are by product of management, restoration and hazardous fuel reduction treatments, including trees and woody plants (i.e. Limbs, tops, needles, and other woody parts, grown in forests, woodland, or range of land environment).

Herbaceous biomass is derived from plants that have a non-woody stem and which die back at the end of growing season. It includes grains or seeds crops from food processing industry and thereby products such as cereal straw. Herbaceous biomass is considered as especially important because it can be used for electricity or heat production as well as liquid bio fuel production. Hence after appropriate processing this biomass may be used to propel cars or commercial vehicles to partially substitute fossil fuel based transport sector.

Aquatic plants are those which are adapted to living in aquatic environments. Aquatic biomass relevant for bio fuel productions mainly concerns algae. Other aquatic plants are also sometimes referred to as possible source of biomass, but in general only algae are considered to have potential for bio fuel production in large quantities for a realistic alternative to fossil fuel sources [3].

Growing environmental concerns coupled with high energy prices have lead to a renewed interest in using feed lot biomass also known as manure. The best approach to using animal wastes (manure) for power depends on amount of moisture and non biodegradable solid material including dirt mixed with manure to be used as a feedstock.

Biomass moisture content is primary factor which determines the type of conversion process to be used for biomass. High moisture content such as herbaceous plants sugarcane involving fermentation whereas dry biomass such as woodchips, is more economically suited for gasification, pyrolysis and combustion. For wet biomass conversion processes, cellulose/lignin ratio can play a significant role, while for a dry biomass the calorific value, proportions of fixed carbon and volatiles, ash/residue content and alkali metal content must be taken into account for. Therefore, some biomasses are suitable for nearly all of the conversion technologies while some other biomasses are suited for some specific conversion technologies to generate heat and power [4].

2.3 Biomass Properties

It is the inherent properties of the biomass source that determine both the choice of conversion processes and subsequent processing difficulties that may arise [2]. Generally the following material properties are important to be taken into account.

2.3.1 Moisture Content

Woody biomass (dry) and low moisture content herbaceous biomasses are the most efficient biomass sources for thermal conversion. It has two types: intrinsic moisture content and extrinsic moisture content. Intrinsic moisture content is not influenced by weather effects while extrinsic moisture contents include the influence of prevailing weather conditions during harvesting.

2.3.2 Calorific Value

The energy content of a fuel material denotes the calorific value (CV) or the heat value when it is completely combusted in oxygen environment. This can be expressed in of the two ways namely gross calorific value (GCV) and net calorific value (NCV). GCV is defined as the heat released during combustion per mass unit fuel under the constraints that the water formed during combustion is in liquid phase. The water and flue gas have the same temperatures as the temperature of the fuel before combustion. NCV is defined as the heat released during combustion per unit mass of fuel under the constraints that the water formed during combustion is in gaseous phase and that the water and the flue gas have same temperature as the fuel prior to the combustion.

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The heat content of fuel type can vary significantly depending upon climate and soil in which the fuel is grown, as well as other conditions. HHV is independent of the conversion process, while LHV varies from one conversion process technology to other [4].

Coal contains (75-90) % carbon while biomass carbon content is about 50 % carbon only. This means the heating value of biomass is much lower than coal. Significance of the O: C and H: C ratios on the CV of solid fuels can be illustrated using a Van Krevelen diagram Fig. 1 [5]. Higher proportion of hydrogen and oxygen reduces the energy value of biomass fuel than fossil fuel (coal). As the age of coal increases inside coal mine, its calorific values supposed to be increased. It is also observed that most of the first growing plants have lower carbon contents than their counterpart slow growing ones. It is because of the fact the carbon fixation in the biomass takes time by solar energy until the plant sufficiently matured.

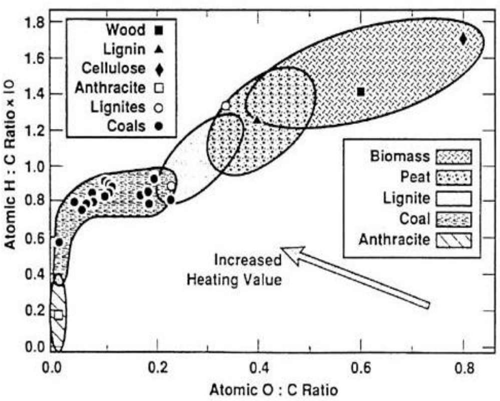

Figure 1: H/C and O/C ratio for several solid fuels (Van Krevelen diagram).

The gross calorific value of biomass fuels usually varies between (18-22) MJ kg^{-1} (db). The following empirical relation may be used to compute GCV of a typical biomass [10].

$$GCV = 0.3491X_C + 1.1783X_H + 0.1005X_S - 0.0151X_N - 0.1034X_O - 0.0211X_{ash}\ [MJ\ kg^{-1}\ db] \qquad (1)$$

Where X_i is the contents of Carbon, Hydrogen, Sulphur, Nitrogen, Oxygen and ashes in wt % (wb) and it is clear from the formula that C, H and S contribute positively for heating value and N, O and ash contents affect negatively to the heating value.

The net calorific value may be calculated from the following correlation.

$$NCV = GCV\ [(1 - \frac{w}{100})] - 2.44\frac{w}{100} - 2.444\frac{h}{100}8.936(1-\frac{w}{100})\ MJ\ kg^{-1}\ wb \qquad (2)$$

Where w is moisture content of fuel in wt % (wb) and h is concentration of hydrogen in wt % (db).

2.3.3 Fuel Size and Density

The size and density of biomass fuel particles is also important. They affect the burning characteristics by affecting the rate of heating and drying during the combustion process. The wrong size fuel will have an impact on the efficiency of the combustion process and may cause jamming or damage to the handling equipment. Smaller size fuel is easier to use in automatic feed system and also allows for finer control of the burn rate by controlling the rate at which fuel is added to the combustion chamber.

The density of processed product impacts on the fuel storage requirements, the sizing of material handling system. It also dictates how the material is likely to behave during subsequent thermo-chemical or biological processing as a fuel or feed stocks.

2.3.4 Chemical Properties

The chemical properties of the different kinds of solid bio fuels affect their thermal utilization and thus the combustion and flu-gas cleaning technologies. Wood fuels contains usually low amount of nitrogen, sulphur and chlorine. With the exception of bark, they are also characterized by low ash content. The alkali metal content of biomass i.e. Na, K, Mg, P and Ca, is especially important for any thermo chemical conversion processes. The reaction of alkali metal with silica present in ash produces a sticky mobile liquid phase, which can lead to blockages of air ways in the furnace and boiler plant [2].

The ash is the non-combustible organic residue that remains after burning. The residue represents the amount of non-biodegradable carbon present in biomass. In biochemical process this residue will be greater than the ash content in thermo-conversion processes, because the residue represent the carbon which cannot be degraded further biologically but which can be burnt thermally [4].

2.4 Different Energy Conversion Methods

The conversion of biomass into energy can be achieved using various different routes, each with specific advantages and limitations. There are three main energy conversion processes from biomass. They are namely, thermo-chemical, biochemical and mechanical conversion processes. Mechanical conversion technologies are suitable for few biomasses. Different thermo-chemical and biochemical technologies are suited for a wide range of biomass materials. Thermo-chemical conversion processes are independent of climatic conditions and mostly complete utilization of wastes biomass takes place. Whereas biochemical conversion processes susceptible to ambient temperature, and so forth such as anaerobic digester and production of secondary wastes such as biomass sludge also arises

However for hydrocarbon fuel production thermo-chemical conversion processes are seems to be more effective. Fig.2 shows the utility of products obtained by some thermal biomass conversion processes. The present section will investigate thermo-chemical conversion processes as follow:

2.4.1 Combustion

Combustion is the oldest and still most widely used way to convert biomass to energy. Combustion can ideally be defined as complete oxidation of fuel. Theoretically the ratio of air to fuel required for complete combustion of the biomass, defined as stoichiometric air fuel ratio that is 6:2 to 6.5:1, with the end product being CO_2 and H_2O. However for complete combustion of biomass excess air up to 150 % may be used. Controlled excess air gives rise to complete combustion of biofuel but it reduces the maximum adiabatic combustion temperature. Direct combustion of biomass can generate shaft power by use of steam turbine. Therefore it is not possible to generate electricity by combustion of biomass in IC engine. But biomass gasifier can be used preferably in dual fuel engine or 100 % gas engine. Combustion is unfavorable in purpose to produce liquid or gaseous fuel.

2.4.2 Pyrolysis

Pyrolysis is a high temperature endothermic, irreversible phenomenon which takes place in absence of O_2 and in presence of some inert atmosphere like N_2. Pyrolysis produces liquid and gaseous fuel. In other words, it is partial drying of biomass in absence of air to remove volatiles and water. Now a day, there are many pyrolysis techniques like catalytic pyrolysis; plasma pyrolysis and microwave pyrolysis are gaining momentum. Therefore it is becoming economically viable for fuel recovery. However various factors like unavailability of cheap catalyst, high temperature requirement in plasma pyrolysis and unavailability of sufficient carbon footprint in microwave pyrolysis, serves as a restriction which give rise to high production cost through these processes.

2.4.3 Gasification

Gasification is the process of incomplete or controlled combustion of biomass. It takes place at sub-stoichiometric conditions with air to fuel ratio being 1.5:1 to 1.8:1 only. The corresponding equivalence ratio for effective gasification is (0.2-0.35). The gas obtained is called producer gas which is combustible in gas burner. Gasification is highly efficient technique than pyrolysis because it uses partial oxidation to dry and pyrolyze the biomass that leads to improvement in overall efficiency. The product gases can be used in internal combustion engine after cleaning and cooling or gas turbines, boilers and domestic purposes. It is necessary to have reduced moisture contents (< 20 % w.b.) of biomass particularly for down draft gasifier applications.

Various parameters have influence on gasification process reaction and product distribution. For example, feedstock particle size, moisture content, pressure heating rate, temperature and temperature profile and residence time may have to be taken into account. A 10 kW thermal output gasifier (Make: Ankur Scientific and Energy Technology (P) Limited) is available for experimentations. The Fig.3 shows a 10 kW (thermal) woody biomass gasifier for gasification purposes.

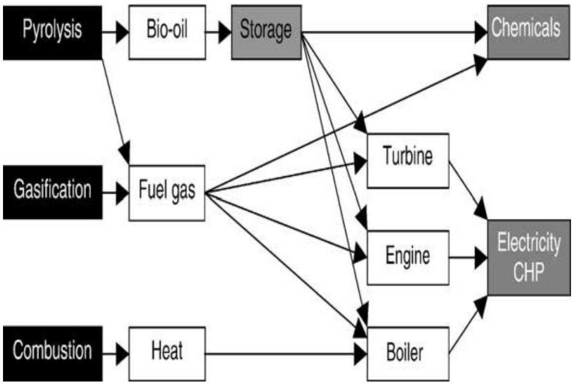

Fig. 2. Products from thermal biomass conversion.

Fig.3 Woody biomass gasifier (10 kW)

2.4.4 Torrefaction

During torrefaction, the biomass properties are changed to obtain a much better feed quality for combustion and gasification applications. During the process, the water and superfluous volatiles are removed, and the biopolymers (cellulose, hemicelluloses and lignin) partly decompose giving off various types of volatiles. The final product is the remaining solid dry blackened material which is referred to as "terrified biomass" or bio-coal. The torrefaction improves fuel quality, increases the fixed carbon content and energy density with both temperature and time.

2.4.5 Thermal Liquefaction

Compared to pyrolysis liquefaction has greater yields and the liquid product has higher energy content and lower O_2 content, which makes final product more stable. Liquefaction produces mainly liquid and some amount of gaseous components at a temperature and pressure range of (250-350) ^oC and (700-3000) psi, in presence of alkali metal salts as catalyst. The mechanisms of liquefactions reactions lack sufficient description about role of catalyst. In the past some researchers have proposed possible mechanisms for Na_2CO_3 and K_2CO_3 for biomass liquefaction [7-9]. In comparison to torrefaction, thermal liquefaction yields fuel in the line with petroleum products along with several high value chemicals. However, liquefaction could not be successful at commercial scale because of the factors such as lower overall yield of oil [between (20-55) % w/w] compared to pyrolysis, inferior oil quality, requirement of catalyst or other solvents [6].

3. MATERIAL AND METHODS

Five biomass samples namely *Bamboo* (BanbuseaTulda), *Gulmohar* (Delonix regia), *Neem* (Melia Azedarach L), *Dimaru* (Ficus lepidosa wall) and Sisham (Delbergia sissoo) are considered for determination caloric value. This tree are locally abundant and most importantly they are fast growing. Dried samples were collected, grinded in the form of powder. The calorific values of the samples were obtained in an adiabatic constant volume bomb calorimeter (Make: Changsha, China, Model: 5E-AC8018, Range: Maximum 40 MJ kg^{-1}, Temperature Resolution: 0.0001, Analysis time: 15 min). The proximate analysis of the sample was done as per ASTM standards. The parameters namely moisture content (ASTM D3172-73), volatile matter (ASTM D3175-73) and ash content (ASTM D3174-73). The ultimate analysis of the specimens was done with CHN Analyzer, [Model PR 2400 Series II Perkin Elmer].

Samples were prepared in woody chipping machine for gasification in down draft 10 kW gasifier. From the preliminary study, it was observed that yield of producer gas is comparable to the gasification of commercially available hard wood.

4. RESULTS AND DISCUSSIONS

The results obtained from proximate and ultimate analysis has been presented in Table 1 and Table 2 for five locally available biomass samples in Assam.

Table 1: Proximate analysis of some biomass

Feedstock	**Volatiles % db**	**Ash % db**	**Fixed carbon % db**	**Moisture % wb**
Bamboo	80.30	4.50	15.20	15 %
Gulmohor	81.25	5.50	13.25	15 %
Neem	81.75	5.60	12.65	15 %
Dimaru	82.00	5.80	12.20	15 %
Sisham	80.00	4.6	15.4	15 %

Table 1: Ultimate analysis of biomass

Feedstock	**C % by weight db**	**H % by weight db**	**N % by weight db**	**O % by weight db**
Bamboo	48.39	5.86	2.04	39.21
Gulmohor	44.43	6.16	1.65	41.90
Neem	45.10	6.00	1.70	41.50
Dimaru	44.85	5.98	1.65	41.84
Sisham	45.85	5.80	1.60	40.25

The lower hating value of bamboo sample was measured as 18.4 MJ kg^{-1}, Gulmohor 16.20 MJ kg^{-1}, Neem 16.60 MJ kg^{-1}, Dimaru 15.95 MJ kg^{-1}, Sisham 17.15 MJ kg^{-1}. It has been observed that lower heating value was maximum for bamboo species compared other woody biomass for same moisture contents.

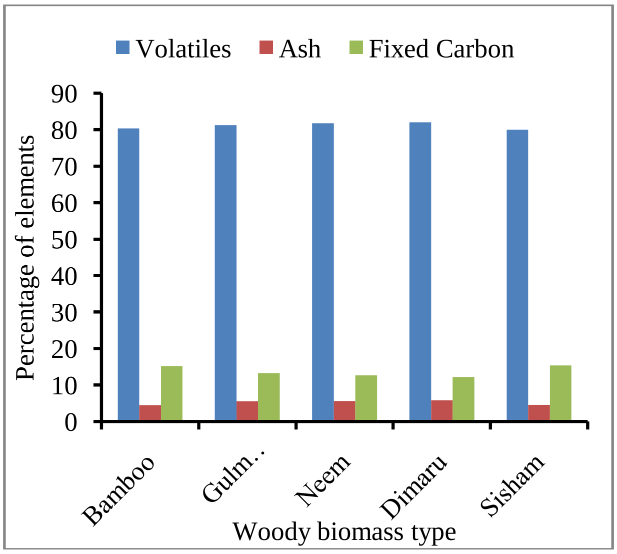

Fig.4 Compositional variation of different biomass

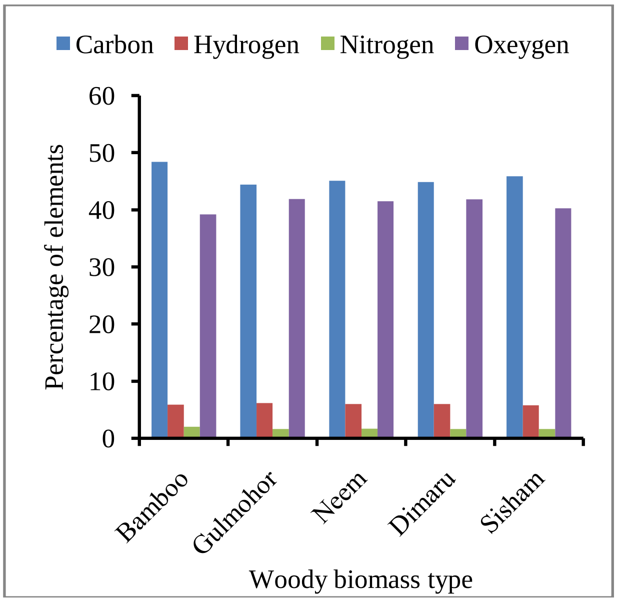

Fig.5 Elemental composition of different biomass

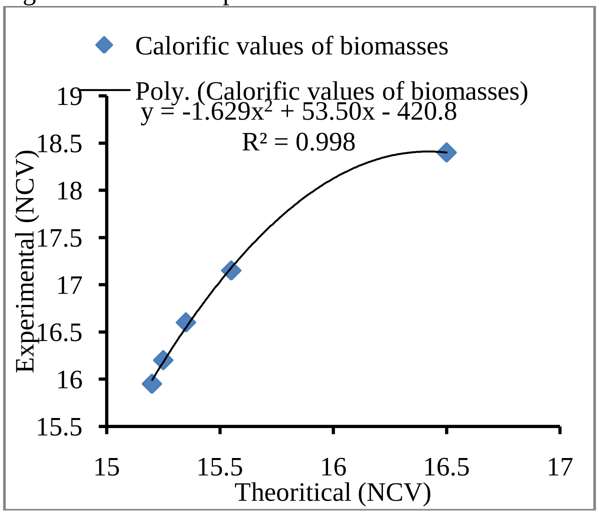

Fig.6 Comparative studies of theoretical and experimental (NCV)

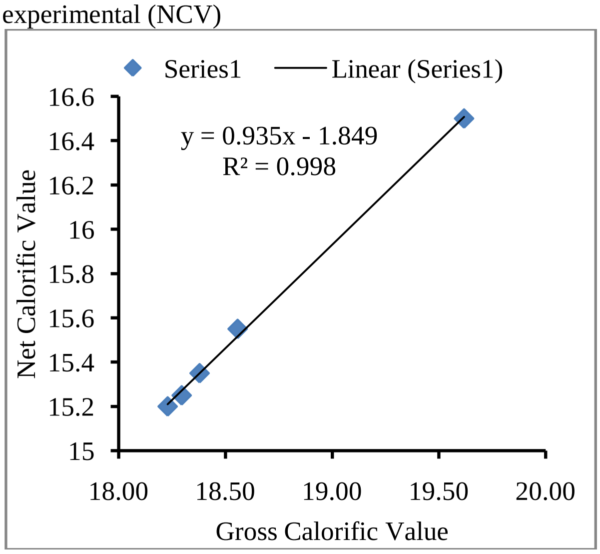

Fig.7 Variation of gross and net calorific values.

Fig.4 shows compositional variation of different biomass obtained from proximate analysis data. Volatiles matter for all the samples were obtained near 80 % from experiments. Variation of carbon, hydrogen, nitrogen and oxygen contents in the said biomasses have been presented in Fig.5. It is clear that carbon content of bamboo sample was highest. The other woody samples had carbon content almost equal.

Fig.6 represents variation of theoretical net heating value and experimental values for the all samples. The relationship may be best described with the curve fitting expression:

$$[NCV]_{exp.} = -1.692(NCV)^2_{theor} + 53.50(NCV)_{theor}) -420.8 \quad (3)$$

Fig.7 shows variation of gross calorific value with net calorific value. It is clear from curve fitting that the relationship between the two variable follow liner relationships given by the Eq. (4). The relationship between net calorific value and gross calorific value is linear with slope equals to 0.935.

$$NCV = 0.935GCV -1.849 \quad (4)$$

5. CONCLUSIONS

- The present paper investigates the fuel characteristics like combustion, pyrolysis, and torrefication, gasification characteristics. Different calorific values of certain biomass plants have been evaluated theoretically and experimentally.
- Woody plants, herbaceous plants and grasses are the main type of interest for producing energy, with attention focused on the C_4 plant species.
- It was observed that bamboo samples had highest calorific values (18.4 MJ kg^{-1}) and Dimaru had minimum (15.95 MJ kg^{-1}) for same moisture. Out four main types of woody biomass Shisum gave maximum calorific value (15.15 MJ kg^{-1}).
- Gasification of these chipped feed stocks gave producer gas yields similar to commercially available wood gasification as per manufacturer specification.
- An appropriate fuel characterization is of great relevance in order to adapt suitable combustion and flue gas cleaning technology to the fuel accordingly and to control acceptable quality deviations for a certain biofuel.

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