International Journal of Current Engineering and Technology
E-ISSN 2277 – 4106, P-ISSN 2347 - 5161

Available at http://inpressco.com/category/ijcet

Research Article

Comparison of Locally Available Biomass Characteristics as a Gasification Feedstock

Prabin Haloi[Å*]

[Å]Department of Mechanical Engineering, Tezpur University, Tezpur, India

Accepted 11 August 2014, Available online 25 Aug2014, **Vol.4, No.4 (Aug 2014)**

Abstract

Fuel characteristics play a determining role in the use of a given feedstock for a particular application. So, its necessary that different properties of a biomass are known in order to pre-estimate its value and suitability as a fuel feedstock. The present work studies the properties of certain locally available biomass of north-east India and evaluates these as a gasification feedstock. Comparison has been made to obtain a better and efficient biomass fuel for a small-scale household gasifier. In this work, three locally available biomasses namely mixed-dry-leaves, rice straw and dry sugarcane residue (bagasse) are selected. Samples are prepared and tests performed as CHN, TGA, heating value, ash content volatile matter, moisture content to analyse the property behaviour of the biomasses. A 85E-1 AC/ML automatic calorimeter is used to calculate the calorific values of the three samples under study. For the ash and volatile matter content, a muffle furnace and a vertical tube furnace has been used. The CHN analysis is done using a CHN analyzer CHN5/0 of 2400 series and the TGA used a TGA-50 analyzer. Based on the comparative tests study and analysis, mixed-dry-leaves have turned out to be a better biomass feedstock.

Keywords: *Heating Value, CHN, TGA, Muffle Furnace, Small Household Gasifier*

Introduction

Energy demand and the search for viable sources of energy are seemingly to be on an uptrend. Major difficulties in the use of new energy sources and the methods of utilization are cost, pollution and transportation though but are not limited to. Under such circumstances, gasification has been seen as a promising alternative to satisfy this rapidly increasing energy needs. Use of cheap and easily available energy sources are few reasons for more and more divergence towards gasification. Gasification converts biomass into combustible gases that can be utilized for various heating purposes.Gasification is the partial oxidation of a carbonaceous material in a controlled manner. The product of gasification is a syngas that can be used as an energy source for various applications. The temperature requirement for syngas production is in the range of (600 – 1500)^{0}C with certain variations. The produced syngas composition depends highly on the nature and type of inputs (biomass) to the gasifier. The percentage chemical composition of H_2, CO, CO_2, CH_4, N_2 in the feedstock reasonably determines the composition and quality of the syngas. The gasification product finds use in many applications that includes gas engines, thermal applications in households, electricity generation, agricultural sectors, co-generation and more. Gasification involves drying zone, devolatilization zone, oxidation zone, ash cooling zone. Increases in the steam-to-air ratio increases the energy content of the syngas.

Commonly used biomass includes wood, charcoal, wood residues, agricultural residues, peat and such other. Locally and some easily available biomass can be used as a feedstock material for gasification conversion. There are differences in the chemical and physical properties of these fuel materials and may require different gasifier designs either existing or new. It’s important that the biomass feedstock materials to be used as gasification fuel must undergo proper tests and analysis of properties. Knowledge of the biomass properties and their variations under specific conditions can help select or design a definite gasifier for efficient operation and production of high quality producer gas. Gasifier feedstock materials which possess better fuel characteristics have high calorific value, low ash content, high fixed carbon content, low nitrogen percentage, low moisture content, high rate of gasification. Due to a number of advantages, a downdraft gasifier can be used for such biomasses.

In a gasifier (downdraft type), the pyrolysis products undergoes decomposition on passing through the high temperature oxidation zone. A number of media such as air, steam, oxygen and hydrogen can be used as gasifying agents. The choice of a particular medium depends on certain favourable factors of one over the other. An alternative approach was developed to illustrate biomass gasification in a ternary diagram using data from thermodynamic equilibrium modeling of air-blown atmospheric wood gasification (Martin Gra¨bner *et al*,

*Corresponding author: **Prabin Haloi**

2014). Investigation on the characterization of the thermal decomposition of two kinds of plywood with a cone calorimeter was made. The different stages of the thermal degradation are observed to estimate the ignitability and combustibility parameters of plywoods, and studied the gaseous emissions during the thermal degradation of the plywood (Talal Fateh. *et al*, 2014). Analysis on carbon and nitrogen in branch and stem and leaf samples and equations developed, estimated that biomass from diameter at breast height (dbh) or diameter at root collar (drc) were through regression. They applied these equations to blue oak data and found biomass and carbon estimates higher than FIA's (John F. Karlik. *et al*, 2014). Evaluation of different biomass canes to characterise and identify different types of high biomass genotypes obtainable from early generation hybrid populations were made. Sixty potentially high biomass genotypes with variable fibre content were screened from the MSIRI germplasm collection and were evaluated over two harvests to exploit the biomass of sugarcane crop for different enduses (D. Santchurn*et al*, 2014). A comparison of the char material produced by microwave and electrical heating at different temperatures showed that the char yield is lesser for the former type of heating when subjected to same temperature(Wang *et al*, 2009). A study of the physiochemical characterisation of torrefied biomass concluded that the properties improve at low temperature and shorter residence time (Ibrahim, Ramie H.H. *et al*, 2009).Effects of feedstock composition of eight grass varieties characterized by calorimetry, TGA, fiber and metal analysis were investigated and similar spectrum of chemical compounds of all samples obtained(Kelkar, S. *et al*, 2014). The study of the temperature rise and weight loss characteristics of wheat straw under microwave heating/irradiation in a fixed bed microwave reactor concluded that the feasibility to pyrolyze wheat straw in microwave fields by addition of small amounts of pyrolytic residue(Xiqiang Zhao *et al*, 2014).A study was made of the process of gasification, different kind of reactions and constructed one updraft gasifier considering two samples of wood chips and a sample of coconut shells for the performance analysis of the constructed updraft biomass gasifier. The pyrolysis, reduction and oxidation zone temperature were also monitored with the aid of K type thermocouples. The experimental analysis for these biomass samples showed that the coconut shell having the greater temperature for all the zones as compared to the other two, when the air velocity increases. Maximum temperature of the different zones for coconut shell represents the optimum amount of combustion. They further investigated the gasification and dispersion of Ni particles. The gas and hydrogen yield in this research kept increasing with the increase of Ni loading content. The well-dispersed Ni particles on Ni/MCM-41 catalysts could lower the coke generation which further contributed to promote their catalytic reactivity in wood sawdust gasification (P. Yadav *et al*, 2013). *Researchers* have investigated the structure and thermal kinetic analysis of CO_2 gasification reactivity, thermal behaviour and activation energies of sugar cane bagasse (SCB) chars prepared at 500, 800 and 900^0C using thermogravimetric analysis (TGA) under non isothermal conditions at different heating rates of 20, 30 and 40^0C min^{-1}.Their findings showed that the char reactivity is inversely proportional to the pyrolysis temperature and directly to a gasification heating rate. Comparison and analysiss of six energy crops (hemp, sugar beet, maize, triticale, grass/clover ley, winter wheat) for biogas production have been conducted and found varying performance regarding methane yield per hectare and energy input and costs in the production and supply of crops as biogas feedstock, the highest biomass and biogas yield was observed for sugar beet (Charlott Gisse´n, *et al*, 2007). Computational fluid dynamics studies have been made on Biomass Thermochemical Conversion to develop a CFD solution (Yiqun Wang *et al*, 2011).

Gasification Reactions: The principle gasification reactions are

$C + O_2 \rightarrow CO_2$
$C + (½) O_2 \rightarrow CO$
$C + CO_2 \rightarrow 2 CO$
$H_2O (g) \rightarrow CO + H_2$
$C+2H_2 \rightarrow CH_4$

The combustion reaction occurs in the presence of free oxygen, is highly exothermic, and very fast. The first two combustion reactions provide the energy necessary to sustain the endothermic gasification and other reactions. Other oxidation reactions are also exothermic. Gas phase reactions and other important secondary reactions occur under appropriate conditions (temperature, pressure) with the decomposition of heavy hydrocarbons and tars to carbon and low molecular gaseous products.

$CO + H_2O \rightarrow CO_2 +H_2$
$CO + 3 H_2 \rightarrow CH_4 + H_2O$
$CO + (½) O_2 \rightarrow CO_2$
$H_2 + (½) O_2 \rightarrow H_2O$
$Tar \rightarrow Char + Gas$ Tar thermal cracking
$Tar + H_2O (g) \rightarrow CO + H_2O+CH_4$Steam tar reforming

Experimental Procedure

Various tests are conducted for the analysis ofsuitability of the biomass to be used as a feedstock for gasification. The tests are performed and the results compared for the three biomass under study. The analysis were made based on the requirements of characteristics of gasification feedstock to yield a better syngas fuel.

Calorimetry

A 85E-1AC/ML automatic Bomb Calorimeter of make-Changsa K. Instruments Co. Ltd. has been used to calculate the calorific values of the biomass taken. The change in enthalpy per mole of a substance in a reaction between two substances is observed. The product of temperature change and specific heat give a measure of the energy change during the reaction. Ratio of this energy change to the number of moles in sample is a measure enthalpy change of reaction. The variations in the calorific values of the three biomass samples are illustrated using tables (Table 1) and combined bar diagram (Figure 1).

CHN Analysis

A CHN CHN5/0 Analyser of make Parkin-Almer, series 2400 is used for the ultimate analysis of the three sample biomass. The CHN elemental analysis determines the carbon, hydrogen, nitrogen in a biomass. The CHN analysis is carried out at high temperature combustion in an excess of oxygen. At the high temperature, the carbon in samples is converted to CO_2; H_2 to H_2O and N to N_2 or NO_x. Gas detection is done using chromatography, thermal conductivity and the elements are quantified with standard quantifying compounds. The elemental percentage for each sample of rice straw, sugarcane residue/bagasse and mixed leaves are shown in Table 2 and as pie chart (Figure 2, 3 and 4).

Proximate Analysis

The proximate analysis gives moisture content, volatile matter content (when heated to 950^0C), the free carbon remaining at that point, the ash (mineral) in the sample and the high heating value (HHV) based on the complete combustion of the sample to carbon dioxide and liquid water. The present work was carried out on three different equipments to find out the ash content, volatile matter content and the moisture content. The carbon content of the biomass was found out by mere calculations.

Ash content

A Muffle Furnace EN012QF of make Nascar & Co.WB., 4.0 kW, 2Ø /400V / (M 1000℃/W 950℃) /SL MF 1205 has been used to burn off the organic compounds by auto igniting the organic matter in biomass samples.

Volatile Matter Content

For volatile matter content, a vertical tube furnace, 3.5 kW/230V/1000℃ of make Nascar & Co., WB/SL, NC/0311.The heated length is divided into 3 zones.

Moisture Content

A universal oven with a maximum temperature of 300˚C is utilized to heat off the moisture content in biomass samples, thus calculating the amount of moisture in the samples in terms of weight.

Thermogravimetric Analysis (TGA)

In this analysis, the changes in the physical and chemical properties of biomass are measured either as a function of increasing temperature or time. The TGA analysis of biomass gives an estimate of the mass loss or gain due to decomposition, oxidation, or moisture loss. The TGA analysis determines the biomass contents in terms of organic and inorganic matters.

Here a TGA Analyser, TGA-50 of maker- Shimadzu is used for our purpose. The TGA was done in the air flow rate of 30ml/min and the sample weight was taken as 3.82 mg for sugar cane residue. This test is done to know how the weight varies with the increase in temperature in the gasification process. For straw the air flow rate is 30 ml/min and the sample is taken as 4.491 mg. For mix dry leaf the air flow rate is 30 ml/min and the sample is taken as 5.629 mg.

Result and Discussions

Calorific Value

The calorific value analysis of the three biomass samples shows that rice straw (dried) gives a higher calorific value in (J/gm) as compared to sugarcane bagasse and mixed dried leaves. The graph in fig. 1 shows that the calorific value of dry straw is highest and the sugar cane is lowest. The range is found to be 5.490 kJ/gm among the three samples. Thus from this property evaluation it seems dry straw possess a better fuel characteristics among the three biomass. The order of suitability is arranged in increasing order as sugarcane bagasse (dry) < mixed dry leaves < rice straw.

Table 1

Sample	Calorific Value (J/gm)
Sugarcane bagasse	17352.91
Rice Straw	22843.47
Mixed Dry Leaves	19946.19

Calorific value of the biomass

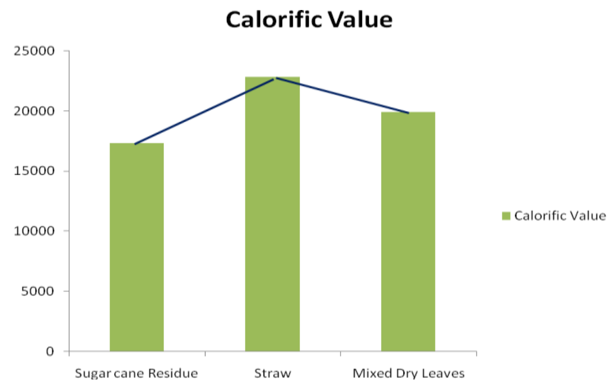

Figure 1: Bar Diagram of Calorific value.

CHN Analysis

The carbon percentage determined in the ultimate analysis is the carbon percentage present in the biomass samples as fixed and as volatile material. The pie diagram of CHN analysis of the three biomass feedstock showed that carbon percentage is highest in mixed dry leaves [43.34% (34.35% as volatile matter and 8.99% as fixed carbon)] and in dry sugar cane residue it is least among the three biomass. The graph in fig.8 it is observed that the fixed carbon percentage variation is less than 1%. In this comparison, mixed dry leaves seems to be a better option as a gasification feedstock. Yet, all the three biomasses may be considered due to the small differences in fixed carbon content. The carbon content is lesser by 0.5% for the sugar cane residue compared to dry straw and in mixed dry leaves it is nearly 0.4% higher compared to dry straw. As such the range of fixed carbon content is approximately 0.91%

The analysis also indicates a higher hydrogen percentage in case of dry rice straw (6.74%) whereas the H_2 percentage in the other two biomass samples found to be roughly the same (~6.24%). From the graphs (fig. 2, 3, 4) it is seen that nitrogen percentage in the sugarcane residue is the highest (2.8%) followed by dry straw (1.8%) and mixed dry leaves (1.34%). During the gasification, nitrogen forms NOx with oxygen which is toxic in nature, so a high value of nitrogen is undesirable and so is the biomass releasing it (Table 2).Thus in context of nitrogen mixed dry leaves is the better choice for feedstock among the three biomass.

Table 2

Sample	C (%)	H_2 (%)	N (%)	Others(%)
Sugarcane residue	42.43	6.24	2.8	48.53
Straw	43.27	6.74	1.8	48.19
Mixed Dry Leaves	43.34	6.24	1.34	49.08

CHN Analysis

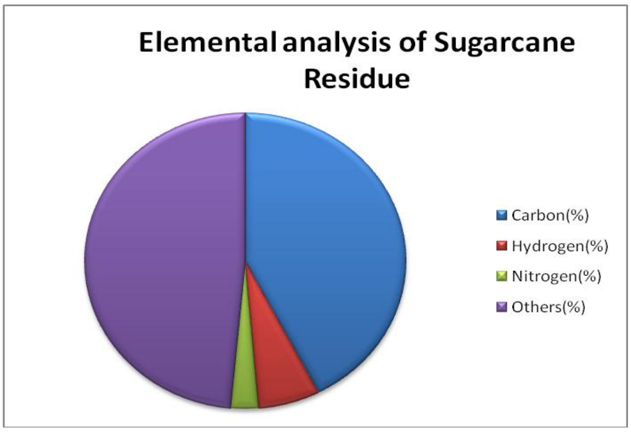

Figure 2: *Pie Chart of CHN Analysis ofSugarcane residue*

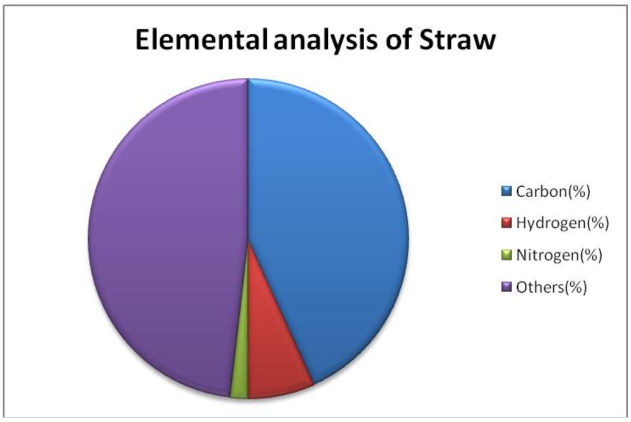

Figure 3: Pie Chart of CHN analysis of Straw

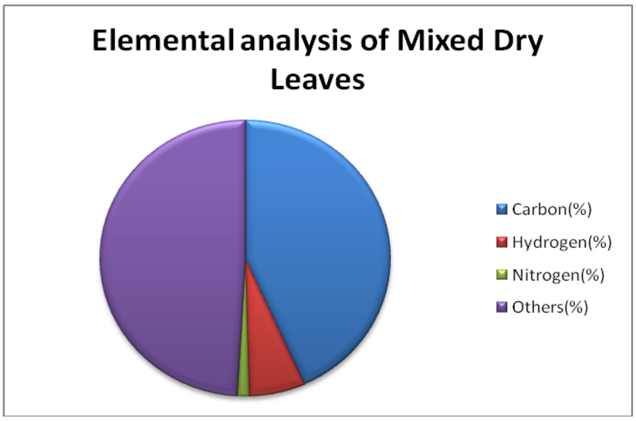

Figure 4: Pie Chart of CHN analysis of Mixed Dry Leaves

Proximate Analysis

Volatile matter is the component of the biomass except the moisture which is liberated from the fuel at high temperature in absence of air. Chemically it is mixture of short and long chain and aromatic hydrocarbons and a little amount of sulphur. The graph (*figure 7*) and Table 4 shows a reverse trend in the variation of volatile matter content between the biomass samples. The range in variation between mixed dry leaves and sugarcane residue is somewhat higher (nearly 10%). Thus dry sugarcane turns out to have highest volatile matter content biomass and seems to be the most suitable gasifier fuel among the three samples taken in terms of volatile matter content**.** Therefore, the order of suitability of the biomasses can also be put as, sugarcane bagasse (dry)> rice straw> mixed dry leaves. The above graph in fig 8 shows a similar trend in the variation of ash content among the three biomass samples as that of the moisture content. The range in variation between the least and the most is somewhat higher (nearly 9%). Thus sugar cane residue turns out to be a low ash content biomass and seems to be a less polluting gasifier fuel. For a downdraft type gasifier, the suitability of the three biomass considered will be in the order of decreasing trend as sugarcane bagasse (dry) > rice straw> mixed dry leaves. Likewise, their suitability for an updraft type gasifier arranged in a similar way shows the same trend as sugarcane bagasse (dry)> rice straw> mixed dry leaves when tested.

Table 3

Sample	Moisture (%)
Sugarcane bagasse	8.19
Rice Straw	8.74
Mixed Dry Leaves	9.86

From the graph (*figure 5*) and Table 3**,** it is observed that the percentage of moisture content is less than 1% for the sugar cane residue/bagasse compared to dry straw and in mixed dry leaves it is slightly higher than 1% compared to dry straw. As such the range of moisture content percentage variation is found to be less than 2%. Comparatively mixed dry leaves may require more amount of preheat for equivalent moisture removal time when the

Table 4

Sample	Ash Content (%)	Volatile Matter (%)	Fixed Carbon Content (%)
Sugarcane bagasse	1.57	90.15	8.28
Straw	5.15	86.26	8.59
Mixed Dry Leaves	10.41	80.60	8.99

samples are subjected to the same conditions for measurement of moisture content. In this comparison thus dry sugar cane residue is a better choice as a gasification feedstock. Referring to the moisture contents, both updraft and downdraft gasifiers may be suitable for the three biomasses under sequence can be arranged for both types of gasifiers as, mixed dry leaves> rice straw> sugarcane bagasse (dry).

Moisture Content

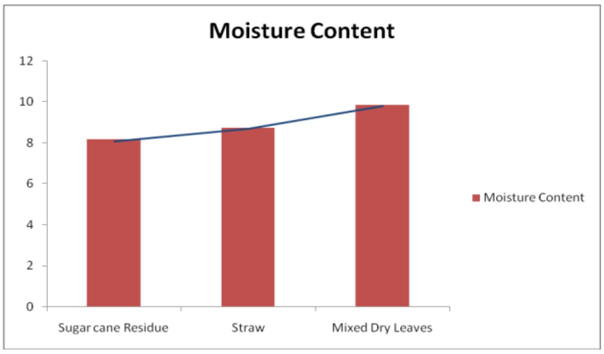

Figure 5: Bar diagram for moisture content in the biomasses

Proximate analysis of the biomass samples

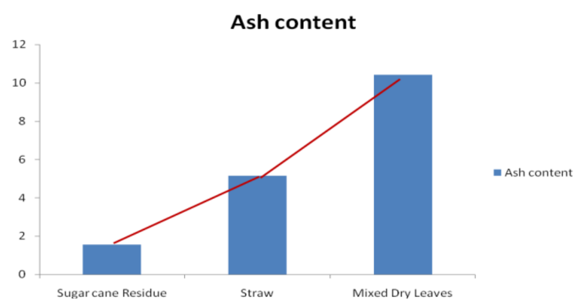

Figure 6: Bar diagram of ash content

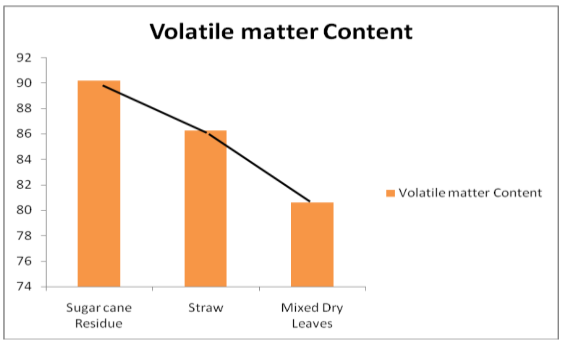

Figure 7: Bar diagram of volatile matter content

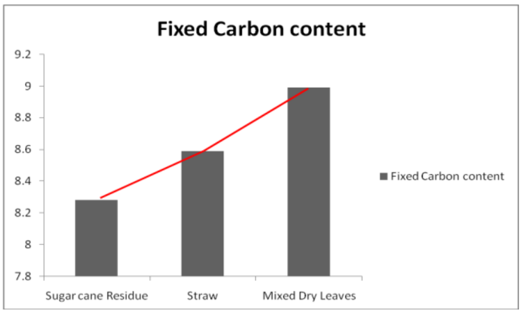

Figure 8: Bar diagram for fixed carbon content in samples

Thermo Gravimetric Analysis

From the curve of TGA analysis of the three samples, two types of graph are plotted namely the temperature-weight (T-W) graph and the time-weight (τ-W) graph. The common observation is that with temperature increase, the weight or mass of the sample gets decrease or vaporized. The T-W curves for the three samples shows variation in slope values under similar temperature ranges. In the range of 240^0C-350^0C, the vaporization rate is very high. For dry sugarcane residue the slope of the curve in the range of 15^0-270^0C is about 1.647x 10^{-3}, in the range of 270^0C - 350^0C the slope is about 0.026875 and in 350^0C-600^0C range it is about 4.416x10^{-3}.The slope of the curve for rice straw in the range of 32^0C-255^0C is about 2.201794x10^{-3}, in the range of 255^0C-350^0C the slope is about 0.0126 and in 350^0C -600^0C range it is about 7.6706x10^{-3}. For mixed dry leaves the slope of the curve in the range of 30^0C-223^0C is about 3.5699x 10^{-3}, in the range of 223^0C-367^0C the slope is about 0.01375 and in 367^0C-600^0C range it is about 5.8928x10^{-3}. From (τ-W) graphs, taking the mean slope we found that for sugarcane residue it is 1.03684 x10^{-3}, for dry straw it is 1.0477 x10^{-3} and for mixed dry leaves it is 1.3354 x 10^{-3}.The slope represents the rate of weight loss of the samples. The sample which has the highest slope will gasify faster than the others. So mixed dry leaves is a better choice.

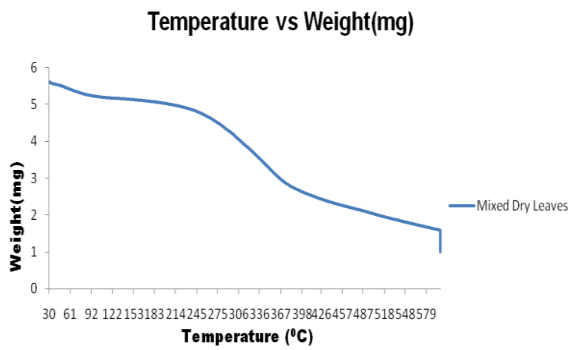

Figure 9: tempt. vs weight plot of mixed dry leaves

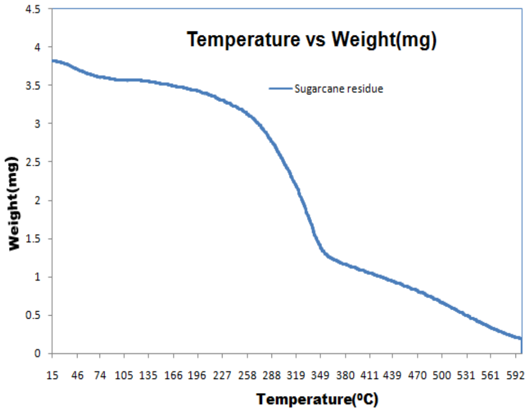

Figure 10: tempt. vs weight plot of dry sugarcane bagasse

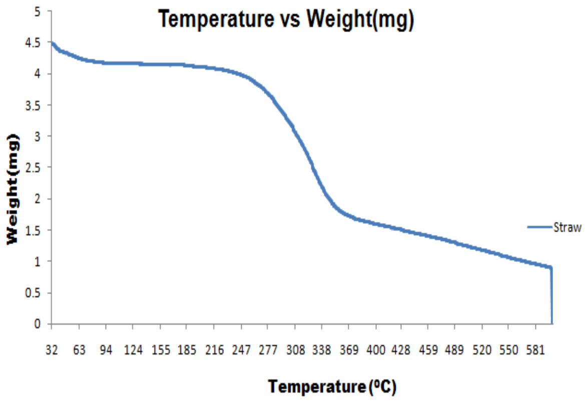

Figure 11: temperature vs. weight plot of dry Straw

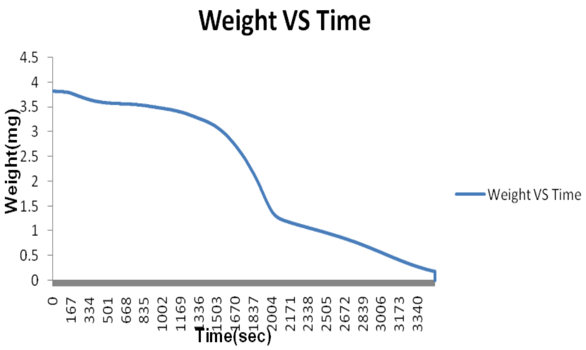

Figure 12: weight vs. time plot of dry sugarcane bagasse.

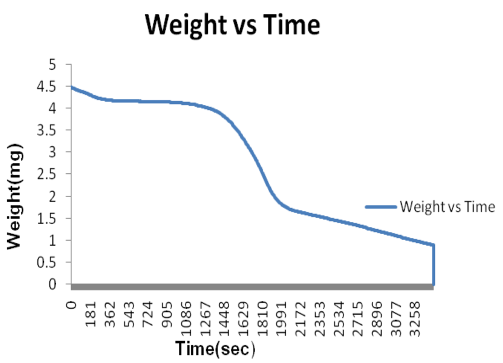

Figure 13: weight vs time plot of dry straw.

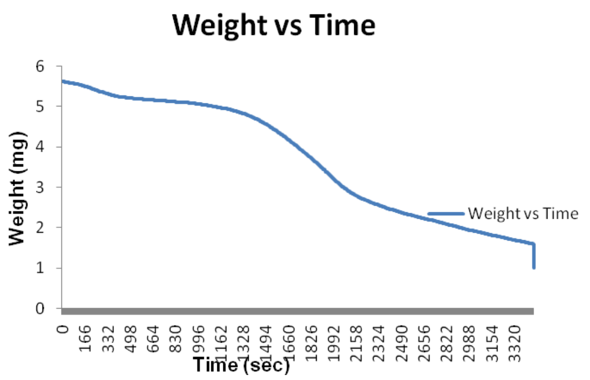

Figure 14: weight vs time plot of mixed dry leaves

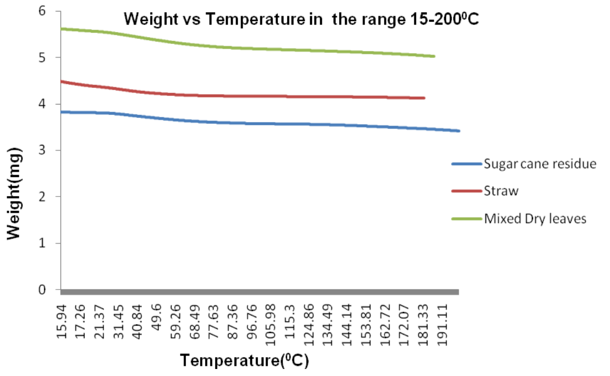

Figure 15: plot of weight variations in the tempt. range of 15^0C -200^0C

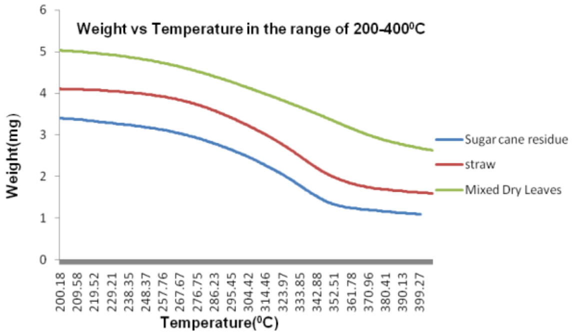

Figure 16: Weight variations in the tempt. range of 200^0C -400^0C

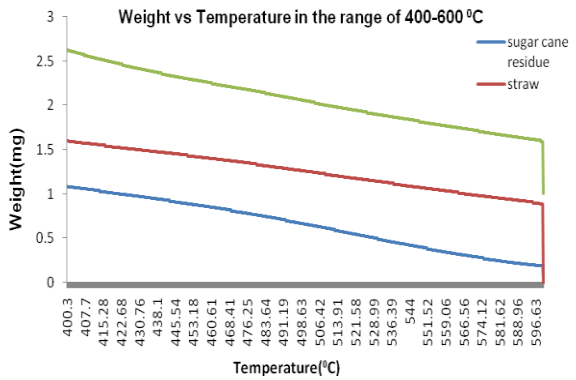

Figure 17: weight variations in the tempt. range of 400^0C -600^0C

Conclusion

The present day energy requirement is mostly met by the fossil fuels, whose reserves are on the verge of depletion. So the future generation energy requirements are to be met by some other means such as gasification.

In this work analysis have been made on three locally available biomass samples. The three samples taken are dry sugarcane residue, mixed dry leaves and dry rice straw. The biomass has been tested for use as a gasification feedstock. Based on comparative tests results it is seen that mixed dry leaves is favored by four tests and sugarcane residue by three tests and dry straw is favored by two tests. As such, mixed dry leaves are a suitable source for biomass gasification among the three samples for production of household syngas.

Dry rice straw has the highest calorific value (22843.47 joule/gm). From the proximate analysis, sugarcane residue/bagasse contains least ash content (1.57%) and moisture content (8.19%). Dry sugarcane residue has the highest volatile matter content (90.15%) and fixed carbon content (8.28%). In mixed dry leaves, carbon percentage (43.34%) is maximum and nitrogen percentage (1.34%) is least in context of CHN analysis.

The results of TGA shows that mixed dry leaves lose its volatile matter more rapidly than other two biomass.Based on the characteristics obtained from the various tests, the suitable gasifier will be selected which can efficiently be used for household fuel gas production. Since for an updraft gasifier, ash content should be below 15%, moisture content up to 50% and also it is less sensitive to particle size, it is more suitable for household gasification process.

Testing for other elements present in the biomass can be done to determine the empirical formula of the biomass sample. The empirical formula can be used to calculate the amount of syngas produced and the calorific value of the gas. More samples can be taken into considerations for the tests and their results can be analyzed to find more efficient biomass samples for household fuel gas production.

Acknowledgement

The Author acknowledges the help received during the progress of this work especially to the students, Mr. Sameer Dubey, Mr. Dhrubajyoti Sarma and Mr. Sanjay Gautam. The author is also grateful to the works done by authors of other research journal articles/case studies/books and reports published in this field that help me get a better review of literature.

References

Gra¨bner, M., Krahl, J., Meyer, B.(2014), Evaluation of biomass gasification in a ternary diagram, *Biomass and Bio Energy*, 64 (1), pp190-198.

Fateh, T., R, Thomas., *et al*(2014),Characterization of thermal decomposition of two kinds of plywood with a cone calorimeter, *Journal of Analytical and Applied Pyrolysis*, 107, pp 87–100.

Karlik, John F.,David C. Chojnacky.(2014), Biomass and carbon data from blue oaks in a California Oak Savanna, *Biomass and Bio Energy*, 62(1), pp 228 -232.

Santchum.D.,Ramdoyal.K., *et al*(2014), Evaluation & simultaneous selection of different types of high biomass cane, *Journal of Biomass and Bioenergy*, 61, pp 82-92.

Wang et.al(2009), Microwave pyrolysis of gas and char, *Bioresources*, 4(3), pp 946-959.

Ibrahim, Ramie H.H., Darvell, Leilani I *et al*(2013), Physiochemical characterisation of torrefied Biomass, *Journal of Analytical and Applied Pyrolysis*, 103, pp 21-30.

Kelkar, S., Li,Zhenglang., Bovee,J*et al*(2014), Effects of Feedstock composition and taxonomy on pyrolysis products, *Biomass and Bio Energy*, 64, pp 152-161.

Xiqiang Zhao, Wenlong Wang., *et al*. Temperature rise weight loss characteristics of wheat straw under microwave heating, Journal of Analytical and Applied Pyrolysis, Elsevier (2014); 107, 59-66

Yadav, P. *et al*(2013), Performance Analysis of the Constructed Updraft Biomass Gasifier for Three Different Biomass Fuels, *International Journal of Modern Engineering Research*, 01(04), pp 2249-6645.

Cobuloglu, H.Ibrahim.,*et al*(2014), A mixed-integer optimization model for the economic and environmental analysis of biomass production, *Biomass and Bio Energy*, 67, pp 8-23.

Stals, M. *et al*(2013), Characterization of activated carbons derived from short rotation hardwood pyrolysis char, *Journal of Analytical and Applied Pyrolysis*, 101(1), pp 199–208.

Yun,Y. *et al*(2009), Syngas Quality in Gasification of High Moisture Municipal Solid Wastes, *Plant Engineering Center, Institute for Advanced Engineering*, 633(2), pp 449-863.

Malik, A. *et al*2009), Utilization of Biomass as Engine Fuel, *Journey of Scientific and Industrial Research*, 68, pp 887-890

Joseph O Akowuah. *et al*(2012), Physico-chemical characteristics and market potential of sawdust charcoal briquette, *International Journal of Energy and Environmental Engineering* , 3, pp 20-26.\

NguyenBui.*et al*(2009), Calorific value and energy yield of Refuse Derived Fuel (RDF) from rice husk and plastic wastes, *Journal of Science and Technology*, 47(5A), pp 396-404.