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PROXIMATE, ULTIMATE AND THERMOCHEMICAL EFFICIENCY OF *TERMINALIA ARJUNA* FOR POWER GENERATION

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ABSTRACT

The increasing environmental pollution and depletion of fossil fuels have led to a search for ecofriendly, renewable, and sustainable alternative energy sources. Biomass is a promising alternative energy carrier that can be utilized instead of conventional resources. *Terminalia arjuna* is a fast-growing tree belonging to family combretaceae. The purpose of this paper is to study the proximate, spectral, thermal, ultimate and gasification properties of selected woody material for power generation. The proximate analysis of *Terminalia arjuna* is amenable for biomass-based power generation due to their ideal energy value (4168 Kcal/kg). The FT-IR assignments exhibit high volatility due to the presence of carboxylic, amine, and hydroxyl groups. Ultimate analysis showed that the selected woody material has major hydrocarbon content (12.59% & 67.36%) which is suitable for energy production. TGA and DTG decomposition demonstrates that the selected woody material can be used as a feedstock for thermochemical conversion process to produce biofuels with high efficiency. In 5kW/h downdraft biomass gasifier produce clean gas with higher heating value ensure the gasifier efficiency and the bioenergy potential of the selected woody material as a feedstock for energy conversion. In a holistic perspective, the results showed that *Terminalia arjuna* exhibited superiority in all energy properties that advance support to its amenability for energy utility.

Keywords: *Terminalia arjuna*, Calorific value, TGA, Producer gas, gasifier efficien

Introduction

Global primary energy consumption is expected to reach 7.32 1017 kJ by 2040, reflecting the rapid increase in energy demand brought on by population growth and globalization (Ahmad and Zhang, 2020). Generating more sustainable and clean renewable energy sources is best solution that might be used for solving these problems (Vikraman et.al., 2022). Because biomass is readily available everywhere, it can be used to produce power and biofuels, and it can be produced and used in a CO_2-neutral manner, modern biomass use is an exciting potential (Hanif 2018). *Terminalia arjuna* is a fast-growing tree having high biomass production potential and ability to grow on marginal and degraded lands (Hemant Kumar 2017**)**. It is there an important source of timber and it has potential elsewhere. *T. arjuna* grow fast to become 2–3 m tall in 3 years (Sanjeev 2019). It is mainly used as a fuel wood and act as a good sink of carbon stock (Baqir et.al., 2019). However, a thorough understanding of the physical, chemical, spectral and thermal characteristics of biomass is necessary to use it effectively for energy production. Gasification is a thermochemical process by which carbonaceous material can be converted to a synthesis gas by means of partial oxidation with air (Ren et al., 2019). Since investigation on gasification process operations to improve producer gas yield and composition is also a matter of concern, the gasification of a biomass using 5kw/h downdraft biomass gasifier to assess their suitability for use as power generation.

Materials and Methods

The selected woody material was collected from Agricultural college and Research Institute, Killikulam, Vallanadu Thoothukudi District, Tamilnadu, located at 8^{o}46 N latitude and 77^{o}42 E longitude and lies in south India. The collected woody material dried over sunlight until completely dried (around 20-25 days). Dried material was chopped in a household blender without any pretreatment. The chopped material is ground to a fine powder for characterization (Proximate analysis, Fourier Transform - Infra Red Spectroscopy (FT-IR), Energy Dispersive X-Ray analysis (EDAX), Ultimate analysis, Thermogravimetric and Differential Thermogravimetric analysis (TGA – DTG)). The 5kw/h down draft gasifier was used to analyze the sample and establish the gasifier efficiency, the wood consumption rate and charcoal of the sample. Gas analyzer (CEMS) was used to determine the syngas composition.

Result and Discussion

Proximate Analysis

Proximate analysis result is given in Table.1. The moisture content of selected woody material is (6.0%), well below the acceptable limit (<10%) for biomass gasification (Vikraman et al., 2022). According to the literature, low moisture content value is appropriate for pyrolysis and combustion process (Cai et.al., 2017). The ash content of the selected woody material is 1.08%, notably below the permitted range (< 2%), it is very advantageous for biomass to be used as a pyrolysis feedstock because it increases volatile matter and decreases fixed carbon (Yahaya et al., 2019). The volatile matter of *T. arjuna* is 84.15%, which could aid in the higher pro-duction of syngas (Suttibak and Chuntanapum, 2021). The fixed carbon content value obtained for the selected woody material is 8.77%. According to Nasser et al. (2016), the majority of the residues burn mostly as gaseous matter because low fixed carbon content may be linked to high volatile matter. The calorific value of selected woody material is 4168Kcal/Kg comparatively high with those reported by earlier workers **(**Saravanan et.al., 2013). The high calorific value which strongly favour's the gasification and the chosen woody material is good for the application of power generation (K. Abushgair et.al,2016).

Table 1: Proximate Analysis of *T.arjuna*

Species	Moisture (%)	Ash (%)	Volatile matter (%)	Fixed carbon (%)	Calorific value Kcal/kg
T.arjuna	6.0	1.08	84.15	8.77	4168

The proximate analysis results show that the selected woody material can be a feasible material for renewable fuel production through gasification.

FT-IR Analysis

The Fourier transform infrared spectroscopy (FTIR) was performed to classify the wood and to estimate the functional group present in the biomass by measuring the FTIR spectra in the 4000–400 cm^{-1} in the transmission mode. The FT-IR spectrum is shown in Figure 1 and the functional groups found in the selected woody material is listed in Table 2 based on literature (Goyal, and Goyal 2016). The adsorption band 3414 cm^{-1} attributed to O-H symmetric vibration, which confirmed the presence of water, phenol and aromatics compounds (V.

Chintala 2017). High volatility and flammability are confirmed by hydrogen bonding, which is present in this woody material. The O–H stretching Carboxyl acid assignment at 2921 cm^{-1} confirms the hemicellulose, cellulose and lignin which are responsible for volatility. Further peak 1738 cm^{-1} is generated due to C=O stretching vibrations, assign the presence of carbonyl group in the selected woody materials which yield, high volatility (Hirohata et.al.,2008). While peak 1630 cm^{-1} ascribed with N-H bend primary amines, showed the presence of aromatic amino groups suggest for combustion analysis (John coates 2000). The peak 1461cm^{-1} ascribed with CH_2 and CH_3 bending vibration attributed to the cellulose (Wang et.al.,2009). The enhanced carbonyl absorption peak at 1374cm^{-1} is assigned for C-N stretching aromatic amino group (Bodirlau et.al.,2007). Further peak 1243 cm^{-1} ascribed C-O stretching confirmed the presence of alcohol, ether, esters and carboxylic acid important for volatility (Mothe CG, De Miranda.,2009). The prominent peak of the chosen sample is 1056cm^{-1} represent the aliphatic ether and C–N stretching vibrations (Peng et.al.,2015). The finger print region, spanning from 900cm^{-1} - 600cm^{-1}, is characterized by unique absorption bands in the majority of the biomass samples. The peaks at 897cm^{-1}, 666cm^{-1} represent the C-H stretching out of plane and C-H bend alkyne represent the nitrate and sulfate group (Chen et.al., 2015). The FT-IR assignments exhibit high volatility due to the presence of carboxylic, amine, and hydroxyl groups (John Coates 2000).

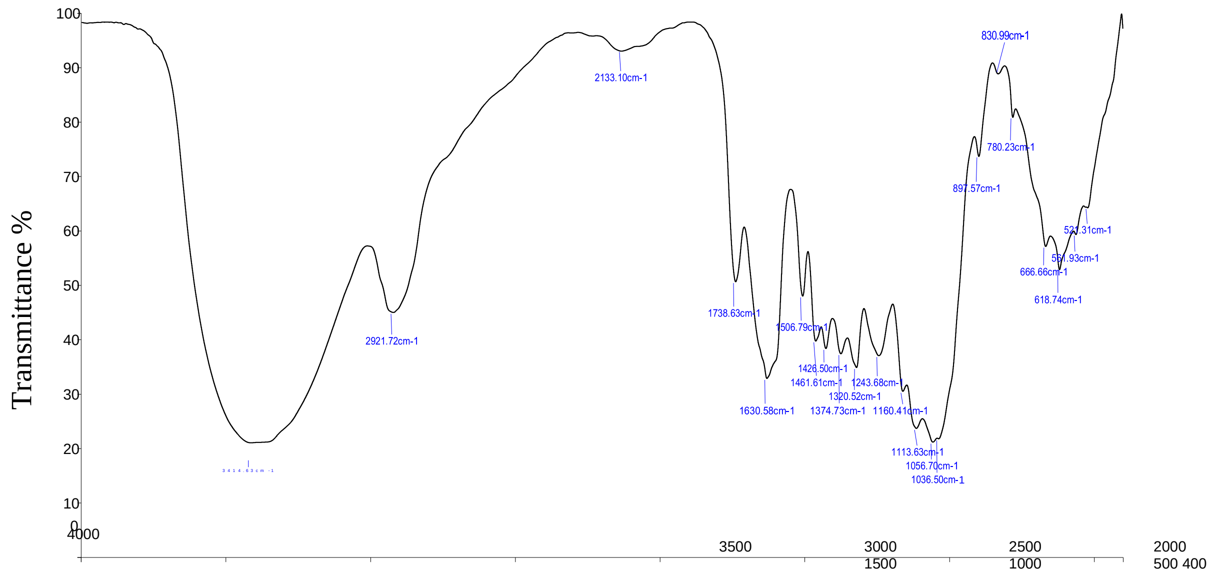

Fig. 1. FT-IR Spectrum of *T.arjuna*

Table.2. FT-IR Spectral assignments for *T.arjuna*

Wave number (cm^{-1}) *Terminalia arjuna*	**Assignments**
3414	O-H Stretch
2921	O-H Stretch Carboxylic acids
1738	C=O Stretch
1630	N-H bend primary amines
1461	CH_2 scissor vibration and CH_3 bending vibration
1374	C-N stretching of aromatic amino group
1243	C-O stretch
1056	C-N Stretching
897	C-H stretching out of plane
666	C- H bend alkyne

EDAX Analysis

Table 3 shows the elemental analysis of selected woody material. The result of the carbon element (C) present in terms of weight percentage for the selected woody material is 70.03%, which favors higher CO concentrations in the syngas (Martínez et al., 2020). The carbon and oxygen serve as the primary factors in determining the effectiveness of biomass fuels (Disco et.al.,2017). The oxygen value for the selected woody material is 29.67%. Moreover, the substantial biomass material yields greater heat energy in the process of thermochemical conversion, owing to its higher carbon element content (Seethalashmi, A.N., 2016). Lower concentration of minor elements such as 0.03% of N and 0.02% of S, will evaporate during combustion (Olli sippula et.al.,2009), which shows that the operation of a thermal conversion unit is in safer side.

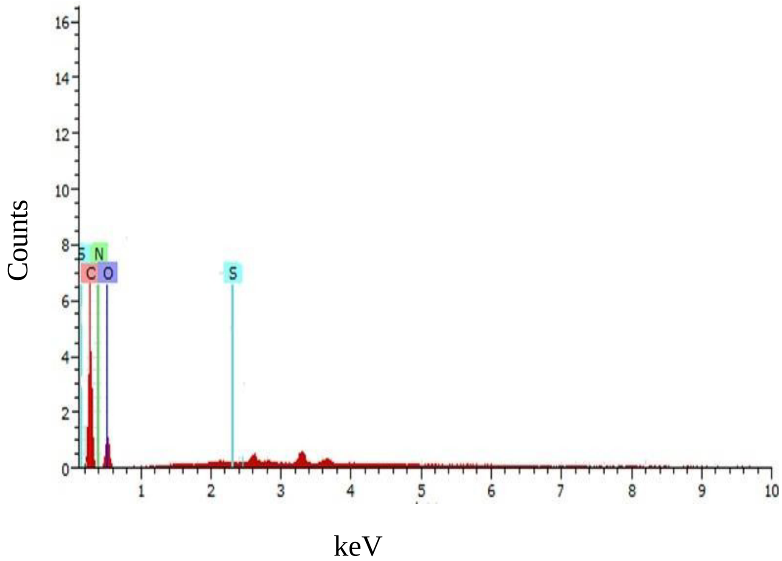

Fig:2. Elemental analysis of *T.arjuna*

Table 3: Elemental Analysis of *T.arjuna*

Element (K)	***T. arjuna* Mass (%)**
C	70.03
O	29.67
N	0.03
S	0.02

Ultimate Analysis

An essential component of assessing the qualities of biomass fuel is the ultimate analysis. This analysis calculates biomass sample percentages, including carbon, hydrogen, oxygen, nitrogen and sulphur, and their impact on combustion in boilers and environmental implications. From Table 4, the carbon content of the selected woody material is 67.36%. The hydrogen value of the selected woody materials is 12.59%. While the oxygen content in the selected biomass sample is 20.00%. The selected biomass material has a higher fraction of carbon, hydrogen and a smaller fraction of oxygen, which improves the characteristics of biofuels (Obernberger et.al.,2006). From these analyses selected biomass sample has higher proportion of carbon and hydrogen content which favor higher CO and H_2 concentrations in the syngas (Martínez et al., 2020). The low nitrogen content (0.03%) of the selected woody material indicates clearly that no toxic gases, such as NO_x or SO_x, will be released into the atmosphere during combustion (Parmar, 2017, Aldana et.al., 2015). It's essential to remember that the selected woody material has high hydrocarbon content, which qualifies them for use in power generation (Arumugasamy et.al.,2019).

Table 4: Ultimate Analysis of *T.arjuna*

Element (K)	*T. arjuna*
C	67.36
H	12.59
N	0.03
S	0.02
O	20.00

Thermogravimetric Analysis

Thermogravimetric analysis (TGA and DTG) is employed to investigate the thermochemical behaviour of selected biomass constituents during pyrolysis and combustion at temperature from 37°C - 880°C for *T. arjuna*, at a heating rate of 25°C/min with a continuous flow of pure nitrogen gas to ensure the necessary environment. Thermogravimetric analysis and Differential thermogravimetric analysis curves of the selected woody materials under pyrolysis conditions are shown in Figure 3 & 4. Previous studies on lignocellulosic biomass reveal four key stages of decomposition: moisture loss, lighter volatile, heavier volatile, and lignin decomposition. (Mehmood MA et. al., 2017). The percentage of weight loss during the stages are given in Table 5.

The first stage is the dehydration stage, which represents the moisture removal for the decomposition of biomass. Kumar et.al., 2019, said that the initial stage peak is occupying a smaller area, which means the mass loss percentage as well as moisture content are low in the biomass material. The initial stage temperature for the selected woody material is 221ºC (Fig.3). The mass loss of the first stage of the selected woody material is 6.24% (Table 5), which is responsible for the reduction of moisture content (Mohit Kumar et.al.,2022, Ashfaqahmed et.al.,2018).

The second stage corresponds to the lighter volatile generated by the decomposition of hemicellulose. Mohit kumar et.al.,2022 said that the second stage represents the active pyrolysis stage because of the thermal cracking of hemicellulose components of biomass. From figure 3, the active pyrolysis stage for our sample is 221°C - 437°C and the weight loss of the second stage is 82.95% (Table 5.). The finding of this study is comparable to those of other literature-reported studies (Ashfaqahmed et.al.,2018, Mehmood MA et.al.,2016) and confirms the presence of volatile matter.

The third stage corresponds to the heavier volatile generated by the decomposition of cellulose. Charusiria et.al.,2018 ascribed with the complex low volatile organic compounds are formed and released slowly from the lignocellulosic biomass in stage III, this stage also represents the active pyrolysis stage. From figure 3, the heavier volatile temperature for the selected woody material is 437°C - 611°C. The weight loss for the selected sample is 25.97% (Table 5). As a result, the thermal degradation in this stage occurs more strongly, compared to the second stage and the weight loss is lower. Thermal degradation obtained for our sample is similar to previous literature research findings (Marquez-Montesino Fet.al.,2015). The leftover mass at the end of the third stage indicates that biomass conversion into biochar has been completed. This phase is frequently referred to as the char-forming phase.

The fourth stage is the lignin decomposition generated by the decomposition of biomass. Throughout the process, the lignin degradation process is incredibly complex, gradual, and continuous (Chen Z et al., 2015). The fourth stage value for our sample is observed as 611°C - 826 °C and it seen as a tail in TG curves (Fig.3). This stage is referred as passive pyrolysis stage. Because the mass rate is significantly lower than that of individuals in the second and third stages. Less than 2% (Table 5) of the mass is lost during this stage. At this stage, decreases in mass loss rates indicate that the non-volatile components are burning and that the lignin components are slowly degrading. (Braga RM et. al., 2014). Based on the decomposition, it can be concluded that the chosen woody material has good conversion efficiency when used as a feedstock for thermochemical conversion process.

Table 5. Weight loss in different major stages in TGA curves of *T.arjuna*

Sample Name	Weight loss (%) Stage 1	Weight loss (%) stage 2	Weight loss (%) stage3	Weight loss (%) stage 4
T. arjuna	6.24	82.95	25.97	1.58

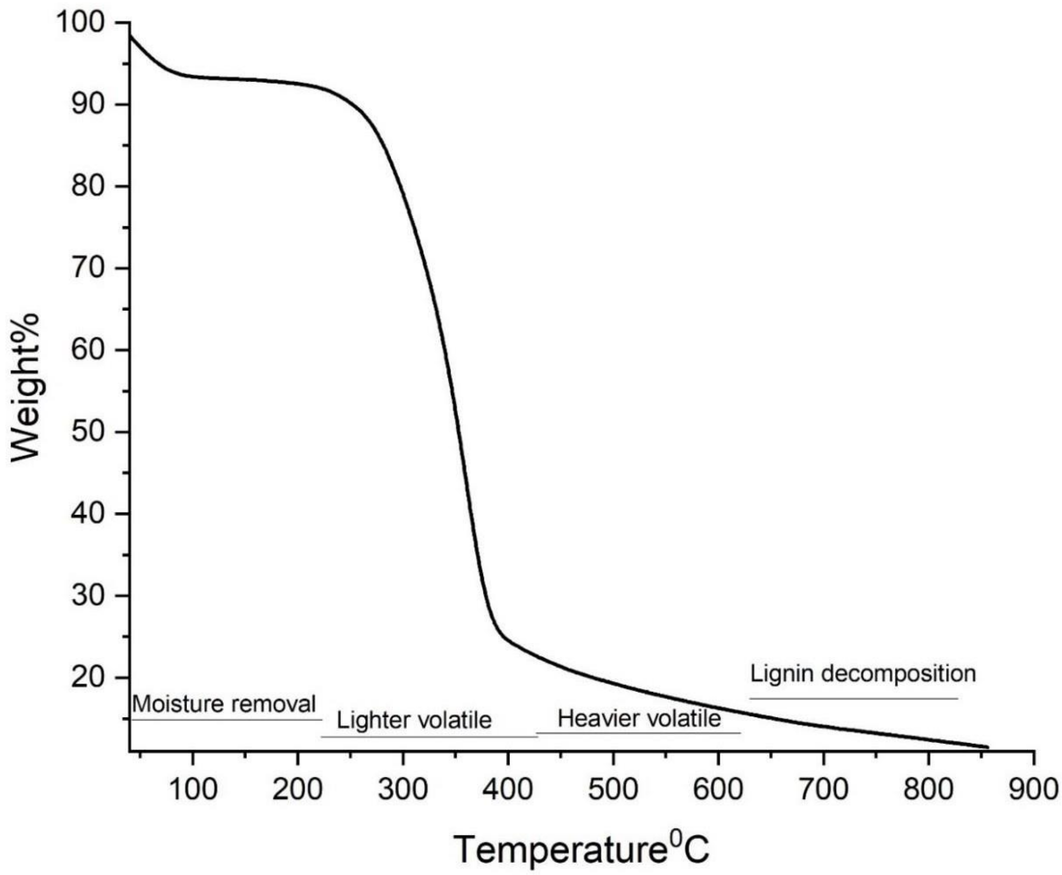

Figure 3: TGA of *T. arjuna*

Differential Thermogravimetric Analysis

The DTG curves provide information about the temperatures at which the greatest rate of weight loss occurred by the locations of the curve peaks.

The initial peak of the DTG curve shows that the mass loss is associated with the elimination of moisture content, or the dehydration stage. A loss of extremely small quantities of volatile substances can occasionally occur along with it (N.S.Yuzbasi, 2011).

The second peak is due to Lighter volatile degradation. The highest conversion temperature recorded during the second stage peak on the DTG curve appeared at 359^{o}C for *T. arjuna*, indicating the presence of hemicellulose. The third peak is heavier volatile, peak value is 492^{o}C, confirming the presence of cellulose (Ranjeet Kumar Mishra, 2019). Compared to the second and third peaks, the final peak experiences a significantly reduced rate of weight loss. The difference in the peak can be attributed to difference in the physical and chemical properties of biomass (Ritesh Kumar et. al., 2009). According to the literature, this area of biomass degradation corresponds to the final stages of cellulose decomposition, the breakdown of heavier volatiles, the breaking of C-C bonds, and the creation of char. According to Kumar et al., 2008, lignin breakdown has apparently persisted in this area.

The results of this study are consistent with the decomposition patterns of different biomass (Naik S et.al.,2010). The largest amount of biomass is transformed into biofuels during this stage of volatiles breakdown.

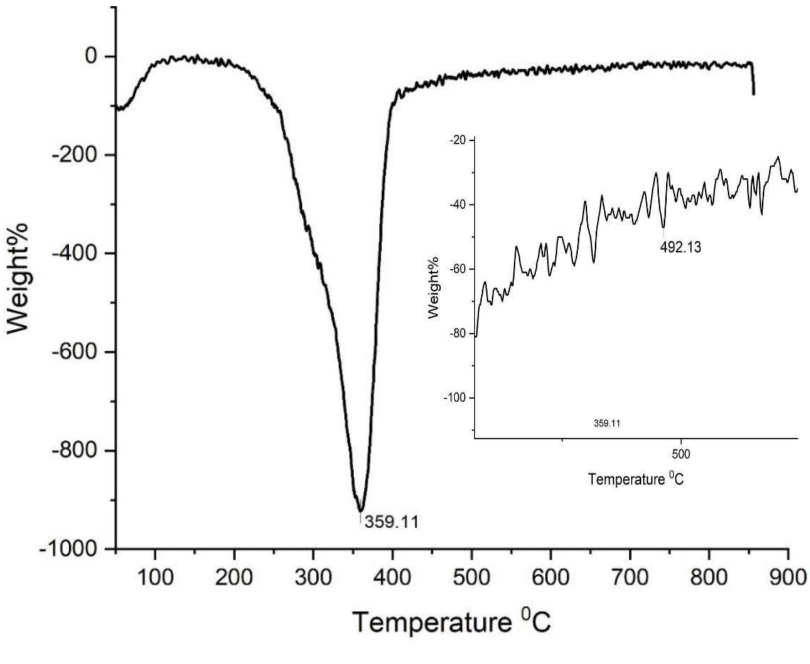

Figure 4: DTG of *T. arjuna*

Gasification Parameters and Thermal efficiency of selected woody material

The gasification parameters and thermal efficiency of the selected woody material is tabulated in Table 6. The generated power efficiency is calculated by taking the ratio of the input load and the output load. Electric power generation system development is reviewed with special attention to observe plant efficiency. According to the published research, the better downdraft gasifier efficiency is between 50 and 70 percent (Martinez et.al., 2012). The efficiency of the chosen woody material is 79%, which is greater than the stated value. Due to this the energy content of the producer gas is increased. Since, the charcoal value of the selected woody materials is less than 1% (0.132%) which, maximize the conversion efficiency of biomass into producer gas (Raman et.al., 2013). When a substance completely burns with oxygen under normal conditions, the amount of energy produced as heat is measured as the calorific value. The calorific value of the selected woody material is 18689kJ/kg. Hayati olgun et.al., 2011, reported that high calorific value leads low consumption of conventional fuel. The wood consumption is one of the important parameters to determine the rating of the gasifier. The wood consumption rate of the selected woody material is 5.800 kg/h. When a generator run in conventional mode alone 0.800 lr/h is consumed to produce output voltage is 223V. In dual fuel mode, when the producer gas is introduced to the engine, the speed governor automatically reduced the quantity of conventional fuel (Kumararaja 2016). Only 0.270 lr/h is consumed and the output voltage is 219V. In dual fuel mode, it is possible to conserve the diesel by replacing it with syngas is 0.530 lr/h. The result shows that the selected woody material is the most suitable option for reduction of conventional fuel for the power generation.

Table 6: Gasification parameters and Thermal Efficiency of the *T. arjuna*

Characteristics	***T. arjuna***
Generation power efficiency (%)	79
Charcoal produced (%)	0.132
Wood consumption rate (kg/hr)	5.800
Fuel (Diesel) consumption (l/hr)	0.270
Output voltage (volt)	219
Calorific value kJ/kg	18689

Producer Gas Composition

Table 7 shows Gas composition of Syn gas during non-conventional mode. The higher concentration of CO (20 – 25%) contribute to high syngas calorific value for gas engine applications and the gas-liquid fuel conversion process (Guo et al. 2014).

Table 7: Experimental values of the chemical composition of syngas – non conventional mode

Samples	Gas composition (%)						HHV (MJ/m^3)
	CO	H_2	CH_4	CO_2	O_2	N_2	
T. arjuna	24.78	14.76	2.30	13.52	1.08	48.52	5.3

During the gasification of the selected woody material, ambient air served as the gasification agent, and nitrogen gas (N_2) made up the majority of the other gases that entered the reactor with it. Literature said that the presence of high hydrogen (14.76%) and low methane (2.30%) are favorable for heating value and also suitable for power generation (Asadullah et al 2014, Qin et al., 2012). The CO_2 value of the chosen woody material is 13.52% notably below the permitted range 16% (Muhammad Afif Ariffin et.al., 2016). Higher heating value of the selected woody material is 5.3 MJ/m^3 ensures the gasifier efficiency (Yogesh parab et al., 2020).

Conclusion

The proximate analysis result of the current study apparently indicates that *T. arjuna* is amenable for biomass-based power generation due to their ideal energy values. The proximate analysis of the chosen sample suggests to utilize as fuel wood due to their superiority in chemical and thermal properties and recommends for energy purpose. The FTIR analysis confirmed the volatility of biomass fuel, due to the presence of carboxyl, amine and hydroxyl substitutional compound, which is responsible for pyrolysis. Elemental analyses confirm the presence of evaporated minor element with a high carbon content resulting in a high calorific value, which is beneficial for combustion. The CHNS analysis indicates that selected woody material with high hydrocarbon content tends to has higher concentrations of CO and H_2 in syngas. Based on TGA and DTG analysis study, all the selected woody material can be recommended as a feedstock for thermal conversion process due to their recommended decomposition results. The experimental study on selected biomass air gasification in a 5kW/h downdraft gasifier reveals that the chosen woody material can produce clean gas with higher concentration of carbon- monoxide and hydrogen which contribute high syngas calorific value for fuel conversion process. Hence it is strongly recommended that *Terminalia arjuna* can act as key component of future sustainable energy supply.

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