Life cycle assessment on biofuel production from biomass gasification and syngas fermentation

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Abstract. Biomass is gaining popularity in research for the development of new renewable and eco-friendly energy sources. Since lignocellulosic biomass, resources are ample and renewable. One of the methods to convert biomass into usable gaseous fuel is gasification process. Gasification is a very simple process to convert solid fuels into gaseous fuels. It can be used to gasify even low-grade agricultural solid residues to combustible gases to meet the energy requirements in a decentralized manner. Since gasification results in fewer pollutant emissions, it is also an environmentally clean way of utilizing fuels. In this proposed study, comparative life cycle Assessment will be performed for power generation from biomass downdraft gasification and syngas fermentation for biofuel synthesis in two stages. The present investigation is to analyse the Prosopis Juliflora biomass waste intended for ultimate, calorific value and proximate analysis and to evaluate their characterization as feedstock for utilization in gasification process. In the first stage, the feedstock is first fed into downdraft gasifier from top to bottom, followed by a sequence of operation namely drying, pyrolysis, oxidation, and reduction for syngas generation. The synthesis gas derived from biomass downdraft gasification often contains additional components such as tar, acetylene, ethane and ethylene. The impurities available in the synthesis gas causes a potential scaling in the ways and by inhibiting microbial catalyst, which involves a cellular low growth and poor yield in product. Some recent studies reported that syngas has been converted into liquid fuel by using Fisher trophic synthesis, but it requires a catalyst. So, in the second stage the syngas fermenter with the capacity of 7-L would be designed and fabricated for the continuous production of 1 g/L biobutanol from purified syngas using the mixed culture mainly consists of C1 fixing homoacetogenic and C4-producing butyrate microorganisms or butyrogens. The produced syngas can also be used directly as a fuel for Solid Oxide fuel cell applications.

Keywords: Prosopis Juliflora; Gasification; Syngas; Life cycle Assessment; Fermentation

1. Introduction
In recent years the global is facing major energy crisis due to diminution of fossil fuels and mounting ecological anxieties. To overcome increasing energy demand research have been focused on the utilization of renewable energy resources [1]. Among several renewable sources, Biomass is, abundant, cheap biocompatible carbon neutral and has been used to produce chemicals, energy, and fuels. In almost 50 years worldwide potential of biomass energy will be approximately 35 to 1136 EJ/yr [2]. This energy content will be equal to 200 billion of barrels of oil which will be sufficient enough to compensate global energy demand up to 2040[3]. Conversion technologies of biomass can be classified into four categories: combustion, biochemical, agrochemical and thermochemical processes depending on biomass characteristics and the requirement of the end product and its applications [4]. Meanwhile, the thermochemical process further classified into gasification, pyrolysis and combustion. Combustion technique is used to provide heat and power commercially practiced all over the world. But it is not popular due to low efficiency and causes environmental pollution. Pyrolysis can be defined as thermal decomposition of any biomass feedstock without the supply of oxygen [5]. Biomass gasification is the thermochemical conversion of solid biomass into combustible and non-combustible gases under partial
air supply for the stoichiometric condition. The gaseous products mainly consist of hydrogen (H\textsubscript{2}) carbon monoxide (CO) and a lesser volume of carbon dioxide (CO\textsubscript{2}), methane (CH\textsubscript{4}) and hydrocarbons (C\textsubscript{2}+) [6]. The quality of producer gas depends on several factors such as reactor design, operating condition, and purification techniques. According to the literature [7], the gasification process is performed when the moisture content is below 35%. When the biomass feedstock possesses the moisture content in the range of 25 to 60 % and if it is fed into the gasifier will result in energy losses in the overall system. Hence it is recommended for pre-treatment or dried before sending to the gasifier and moisture content should be in the range of 10 to 20% [8]. Tar is the major concern in the gasifier system. it may present as vapor phase in the gasifier and condense in liquid tar while cooling the gas [9]. In downdraft gasifier tar formation is less due to combustion zone follows pyrolysis zone in the reactor system [10]. The residence time is also shorter due to biomass feedstock moves faster due to gravity and drag force being aligned in the same direction. The present work focuses on using biomass species which is abundantly available in India, United States, south Arabia and African countries that is Prosopis Juliflora (PJ) [11]. PJ belongs to the family Leguminosae, genus Prosopis it can capture CO\textsubscript{2} from the atmosphere and can grow up to 10 m [12]. The zero emission and wider availability usually makes it as biomass fuel at international standard [13].LCA is described in the ISO standards 14040. It is one of the several methods for calculation of environmental impacts caused by the product or any process and service [14]. A mixture carbon, hydrogen and carbon dioxide is used as carbon and energy source and then converted into fuels and chemicals by microorganism [15].

2. Material and Methods

2.1. Selection of feedstock for investigation
The Prosopis Juliflora plant consist of a perverted trunk as well as springy branches having long and strong spikes. This plant can grow in different types of soils for example sandy, rocky, saline and alkaline soils. The roots of this plant breaches to a great depth in the soil. The stems of approximately 25 mm in diameter were collected in and around college premises of NIT Tiruchirappalli, Tamilnadu, south India.

2.2. Ultimate analysis
The elementary analyser various ELIII functions according to the principle of the combustion of catalytic tubes in oxygenated CO\textsubscript{2} atmosphere and high temperatures. The combustion gases are released from foreign gases (for example halogenous volatile). The preferred measuring components are separated from each other using specific and successively given columns of adsorption with thermal detector of conductivity (TCD). Helium (He) is used of rinsing and carrier gas. Win var software were used with accurate measurement of 0.05 % with analysis time of 10 to 14 min.

2.3. Proximate Analysis
The proximate analysis was performed in the tubular furnace. initially 1 mg sample was weighed and placed in the furnace for 1050 C for half an hour and the it was weighed for estimation of moisture content. Same sample was then placed in the furnace for 9250 C for 7 min at the nitrogen atmosphere. Sample was weighed to estimate the volatile matter. Finally, ash content was estimated by keeping the sample in the furnace for 5750 C for 5 hrs. Fixed carbon was calculated by the difference (100-M\%+V.M\%+Ash %).

2.4. Calorific value Analysis
To determine the calorific value of sample, initially the dried biomass sample is weighed for 5 mg and it is kept inside a bomb which is a heavy-duty stainless steel. The sample is exploded electrically inside bomb which is wrapped with oxygen. The temperature difference is resulted in the water bath adjoining the bomb due to complete oxidation of the compound. The rise in temperature is measured using digital sensor and constant volume heat of combustion is measured. By pelletizing sample and igniting inside
oxygen bomb calorimeter the CV of dried biomass sample (0.5 mg) was determined. Few repetitive experiments have been conducted to obtain the accuracy of ±2% maximum which is tolerable for experiments.

2.5. Syngas fermentation
An increase in energy demand, new technologies have been developed for the production of bio-butanol, which finds application as an additive in motor fuels, and several value-added products, using biological technologies. One of such technologies is the use of syngas to produce butanol using a syntrophic culture of two different anaerobic microorganisms. The syngas will be produced through down draft gasification using biomass waste. The preliminary study was conducted with 1 kW downdraft gasifier. In this, 3 kg of waste biomass was loaded into the gasifier which results in the production of 6.6 m$^3$/kg of syngas having the calorific value of 16 MJ/m$^3$. The quality of the syngas will be analysed by the gas analyser after passed through various cleaning and filter system to remove impurities, H$_2$S, and other unwanted gases. The syngas fermenter with the capacity of 7-L would be designed and fabricated for the continuous production of 1 g/L biobutanol from purified syngas using the mixed culture mainly consists of C1 fixing homoacetogenic and C4-producing butyrate microorganisms or butyrogens. This methodology is preferred because of enhancement in the yield of butanol and flexibility in operation.

2.6. Life cycle Assessment methodology

2.6.1. Definition and Scope of the Analysis
Description of environmental aspects of the syngas fermentation and gasification of biomass like formation of tars, emissions of heavy metals and toxic elements and emissions of polyhalogenated aromatic compounds.

2.6.2. Boundary system and Analysis of related legislation
Initially various components involved in the system must be defined before analysing the boundary of the system. Sub suits involved in the system that have productive purpose regarded as separate components. Policy and regulatory frameworks create the market push and market pull needed to develop bioenergy production currently, there is a lack of policies and incentives to support development, particularly at the smaller scale.

2.6.3. Selection of environmental performance indicators
The assessment of gasification and biofuel production process should be evaluated by using separate indicators. Indicators summarize the relevant information about the system. A precise evaluation is performed due to the collection of raw data and relation between them.

2.6.4. Inventory Analysis
The relevant input and output data from gasification and biofuel production process are collected and quantified for LCA analysis. Various Inputs and outputs parameters and products data from biofuel production process and gasification of biomass. Structure the system flow of our functional units namely gasification and pyrolysis in the field of materials, energy, product output.

2.6.5. Environmental Impact Assessment
The environmental impacts and functional unit associated with the system are easily identified and evaluated by the LCA impact assessment. There are various tools and separate software are used for performing the life cycle impact assessment.
Life Cycle Assessment

Significant findings can be obtained from comparing the results with mathematical modelling and experimental results. Sensitivity analysis will be performed to identify the parameters which has major impact on the results obtained from the functional unit.

3. Results and Discussion

3.1. Ultimate analysis

The ultimate analysis of Prosopis Juliflora is given in the table. Carbon content of biomass sample is 47.96 %, an increase in the heating value may results. Some of the carbon constitutes volatile matter and char. During pyrolysis hydrogen will be as volatile matter of 6.614%. Nitrogen content is 0.293% significant source of NOx pollutants. Sulphur is also negligible with 0.539% source for SOx pollutants. The difference is the oxygen content which reduces heating value.

| Carbon | Sulphur | Hydrogen | Nitrogen |
|--------|---------|----------|----------|
| 47.96% | 0.539%  | 6.614%   | 0.293%   |

3.2. Proximate analysis

Proximate analysis of a biomass provides the percentage of biomass that burns in a gaseous state (volatile matter) is 72.65%, ash content is 7.24%, moisture content of 3.24% and fixed carbon of 16.87%. if biomass with greater volatile content results in increased gas production.

| Moisture | Volatile Matter | Ash | Fixed Carbon |
|----------|-----------------|-----|--------------|
| 3.24%    | 72.65%          | 7.24% | 16.87%      |

3.3. Accessing calorific value by ultimate analysis

The heating value using ultimate analysis is determined by using dulong and Boie equation [18]. Dulong equation is[16]

$$HHV \left(\frac{kJ}{kg}\right) = 33823 \times C + 144250 \times \left(H - \frac{0.8}{8}\right) + 94195$$

(1)

The equation is not preferable since Prosopis Juliflora has less than 10% oxygen content. But in case of Prosopis Juliflora oxygen content is greater than 10%. Hence Boie equation is suitable for finding heating values of fuel and it expressed as

$$HHV \left(\frac{kJ}{kg}\right) = 35160C + 116225H - 110990 + 6280N + 10465S$$

(2)

Where mass fraction like C, H, N, S and O obtained by ultimate analysis of respective biomass species’ oxygen has negative co-efficient since it reacts with carbon and hydrogen to for carbon dioxide(CO$_2$)and water (H$_2$O).

Table 3. Comparison of calorific value between prediction and experimental values using ultimate analysis.
### 3.4. Assessing calorific value by estimating from proximate analysis

Based on proximate analysis Cordea et al. [19] investigated estimation of calorific value for biomass fuels on dry basis. Correlation equation used to find heating values are based on literature [16].

\[
HHV = 354.3FC + 170.8VM
\]  

\[
M + VM + FC + ASH = 100
\]  

Where HHV denoted as higher heating values, VM represents volatile matter, and FC represents fixed carbon these values estimated from the proximate analysis of the biomass sample *Prosopis Juliflora*.

Using the equation 4 HHV has been estimated and compared with investigational results. Mean absolute error has calculated using predicted and experimental results.

\[
MAE = \frac{HHV_{predicted} - HHV_{experimental}}{HHV_{experimental}}
\]

Table 4. Comparison of calorific value between prediction and experimental values using proximate analysis.

| Biomass          | Experimental calorific value (MJ/kg) | Predicted calorific value (MJ/kg) | Mean Absolute Error % |
|------------------|-------------------------------------|----------------------------------|-----------------------|
| *Prosopis Juliflora* | 17.91                                | 17.77                            | -0.78                 |

### 3.5. Downdraft gasification of Biomass

Biomass gasification used for generation of producer gas by burning biomass under restricted air supply. In gasification the feed stock is first fed into downdraft gasifier from top to bottom, followed by sequence of operation namely drying, pyrolysis, oxidation and reduction for syngas generation. Design of reactor is vertical; therefore, the four zones are arranged vertically in sequence. Drying can be done inside the gasifier itself, biomass is heated up to 100 °C. In pyrolysis process due to the unavailability of air biomass is thermally degraded into char and tar. Heat flows from the oxidation zone to drying zone and pyrolysis zone. Air is used as gasifying medium. Carbon dioxide is formed by reacting carbon in the form of char. Oxidation of hydrogen forms water. The final zone is the reduction zone were carbon monoxide is formed by reacting with carbon dioxide. Hydrogen and carbon monoxide are formed by reacting steam with carbon. Methane (CH₄) is formed by reacting char with hydrogen. During water gas shift reaction hydrogen and carbon dioxide are formed by reacting carbon monoxide with water. Combustible gases in the producer gas are formed during reduction process. The syngas comprises of hydrogen and carbon monoxide which is produced in this process.
Product syngas composition
The quality of syngas produced is affected by many parameters especially feedstock and design of gasification reactor. The heating value of producer gas is in the range of 4 to 5.5 MJ/Nm$^3$. The small of amount of gas is collected in a tedler bag which is then analyzed in gas chromatograph using nitrogen as a carrier gas. The determined gas composition is shown in the figure 3.

![Figure 1. Schematic of Downdraft gasifier reactor](image)

![Figure 2. Composition of producer gas](image)

The combustible gas like hydrogen gas (H$_2$) composition is around 21.59% and carbon monoxide (CO) is around 25.27 and methane (CH$_4$) is around 22.34. Due to uncontrolled supply of air carbon dioxide (CO$_2$) is around 26.35 %. Acetylene (C$_2$H$_2$) is around 0.43 % and ethane (C$_2$H$_6$) is around 4.01 %.

4. Conclusions
The Prosopis Juliflora having higher volatile matter content and less ash content of 72.65 and 7.25% respectively. Ultimate and proximate analysis were used to formulate the calorific values of biomass. The predicted result using Boie equation shows good agreement with experimental result. The calorific value of Prosopis Juliflora was found to be 17.91 MJ/kg which shows that it can be potential feedstock for biomass gasification. The gasification of Prosopis Juliflora in downdraft gasifier exhibits higher CO$_2$
of 26.35 % which is due uncontrolled flow of air. The gas chromatograph results revels that more amount of CH₄ was formed due to availability of excessive carbon content.

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