JOURNAL OF BIOPROCESSING AND CHEMICAL ENGINEERING

Journal homepage: http://scienceq.org/Journals/JBCE.php

Research Article Open Access

Gasification and Combustion of Biomass for IC Engines

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Received: November 24, 2014, Accepted: December 26, 2014, Published: December 26, 2014.

ABSTRACT

Due to increasing environmental concerns especially related with the use of fossil fuels, new solutions to limit the greenhouse gas effect are continuously sought. Among the available alternative energy sources to mitigate greenhouse emissions, biomass is the only carbon-based sustainable option. Biomass is recognized to be the major potential source for energy production. There are ranges of biomass utilization technologies that produce useful energy from biomass. Gasification is one of the important techniques out of direct combustion, anaerobic digestion - Biogas, ethanol production. Gasification enables conversion of these materials into combustible gas (producer gas), mechanical and electrical power, synthetic fuels, and chemical. The gasification of biomass into useful fuel enhances its potential as a renewable energy resource. This paper gives a comprehensive review of the techniques used for utilizing biomass, experimental investigation on biomass fuels, characterization, merits, demerits and challenges faced by biomass fuels.

Keyword: Biomass combustion, Biomass gasification, IC engine, Producer gas, Gasification characteristics

INTRODUCTION

Today biomass is seen as the most promising energy source to mitigate greenhouse gas emissions [1]. Large scale introduction of biomass energy could contribute to sustainable development on several fronts namely, environmental, social, and economical [2]. World energy supplies have been dominated by fossil fuels for decades (approximately 80% of the total use of more than 400 EJ per year) [3]. Today biomass contributes about 10 to 15% (or 45 ± 10 EJ) of this demand. On average, in the industrialized countries biomass contributes some 9 to 14% to the total energy supplies, but in developing countries this is as high as one-fifth to one-third [4]. In quite a number of these countries, biomass covers even over 50 to 90% of the total energy demand. It should be noted, though, that a large part of this biomass use is non-commercial and used for cooking and space heating, generally by the poorer part of the population. Modern production of energy carriers from biomass (heat, electricity and fuels for transportation) or biofuels contributes a lower, but significant 7 EJ [5]. The utilization of biomass within the European Union (EU) has strongly increased over the last decades, and the ambitions of the EU for the use of biomass are high.

With respect to global issues of sustainable energy and reduction in emission of greenhouse gases, biomass is getting increased attention as a potential for power generation. Biomass is not yet competitive with fossil fuels. Fossil fuel contributes to the major part of world's total energy consumption. According to the World Energy Assessment report, 80% of the world's primary energy consumption is contributed by fossil fuel, 14% by renewable (out of which biomass contributes 9.5%) and 6% by nuclear energy sources [6].

Biomass gasifiers are being developed around the world today to produce CO_2 neutral energy. Gasification is a thermo chemical process where biomass is converted into a combustible producer gas. The main components in producer gas are N_2; H_2; CO; CO_2 and CH_4, and it is often used as fuel in an internal combustion (IC) engine. Gasification of woody biomass has been a well-known technology for more than five decades [7]. This paper gives a comprehensive review of the techniques used for utilizing biomass, experimental investigation on biomass fuels, characterization, merits, demerits and challenges faced by biomass fuels.

Biomass Utilization Techniques

There are wide ranges of biomass utilization technologies that produce useful energy from biomass. The commonly used techniques for utilizing biomass are elaborated below.

Direct Combustion

The energy produced by direct combustion process is heat and steam. Despite its apparent simplicity, direct combustion is a complex process from a technological point of view. High reaction rates and high heat release and many reactants and reaction schemes are involved. In order to analyze the combustion process, a division is made between the place where the biomass fuel is burned (the furnace) and the place where the heat from the flue gas is exchanged for a process medium or energy carrier (the heat exchanger). Properly designed industrial biomass combustion facilities can burn all types of above listed biomass fuel. In combustion process, volatile hydrocarbons (C_xH_y) are formed and burned in a hot combustion zone. Combustion technologies convert biomass fuels into several forms of useful energy for commercial and/or industrial uses. In a furnace, the biomass fuel converted via combustion process into heat energy. The heat energy is released in the form of hot gases to heat exchanger that switches thermal energy from the hot gases to the process medium (steam, hot water or hot air) [7]. Direct combustion systems are of either fixed bed or fluidized-bed systems. Fixed-bed systems are basically distinguished by types of grates and the way the biomass fuel is supplied to or transported through the furnace. In stationary or travelling grate combustor, a manual or automatic feeder distributes the fuel onto a grate, where the fuel burns. Combustion air enters from below the grate. In the stationary grate design, ashes fall into a pit for collection. In contrast, a travelling grate system has a moving grate that drops the ash into a hopper.

Biomass Gasification

Biomass gasification is other thermo chemical conversion process utilizing the following major feedstock: wood, agricultural waste, municipal solid waste. Chemical process of gasification means the thermal decomposition of hydrocarbons from biomass in a reducing (oxygen-deficient) atmosphere. The process usually takes place at about 850°C. Because the injected air prevents the ash from melting, steam injection is not always required. A biomass gasifier can operate under atmospheric pressure or elevated pressure. The resulting gas product, the synthetic gas, contains combustible gases - hydrogen (H_2) and carbon monoxide (CO) as the main constituents; by-products are liquids and tars, charcoal and mineral matter (ash or slag). In general, the gasifying agent can be air, oxygen (O_2) or oxygen-enriched air. For biomass gasification, air is normally used as oxidant (oxygen as the oxidant agent is preferred in high capacity fossil fuel gasification systems) [7]. The biggest advantage of gasification is the variety of feed stocks as well as products. The produced synthetic gas can be utilized not only as the fuel for power generation but also as the feedstock for chemical industry.

Anaerobic Digestion

Anaerobic digestion can be used to produce valuable energy from waste streams of natural materials or to lower the pollution potential of a waste stream. Biogas plant has a self-consumption of energy to keep the sludge warm. This is typically 20% of the energy production for a well-designed biogas plant. Anaerobic digestion is a complex biochemical reaction carried out in a number of steps by several types of microorganisms that require little or no oxygen to live. During the process of biogas, principally approximately 65% methane (CH_4) and about 30% carbon dioxide (CO_2), is produced [7]. The amount of biogas produced varies with the amount of organic waste fed to the digester and temperature influences the rate of decomposition. Several different types of bacteria work in stages together, to break down complex organic wastes, resulting in the production of biogas. Controlled anaerobic digestion requires an airtight chamber, called a digester. The mixture of CH_4 with CO_2 is making up more than 90% of the total biogas composition. The remaining gases are usually smaller amounts of H_2S, N_2, H_2, methylmercaptans and O_2.

Ethanol Production

Starch content of biomass feed stocks like corn, potatoes, beets, sugarcane, wheat, barley, and similar can be converted by fermentation process into alcohol (ethanol). Fermentation is the biochemical process that converts sugars into ethanol (alcohol). In contrast to biogas production, fermentation takes place in the presence of air and is, therefore, a process of aerobic digestion. Ethanol is easier to transport and store than hydrogen, fuel reforming (using a chemical process to extract hydrogen from fuel) may be a practical way to provide hydrogen to fuel cells in vehicles or for remote stationary applications. Latin America, dominated by Brazil, is the world's largest production region of bio-ethanol. As the value of bio-ethanol is increasingly being recognized, more and more policies to support development and implementation of ethanol as a fuel are being introduced.

Among all the alternatives of technology used, gasification is the best suitable alternative in view of the following points [7]:

- ❖Gasification offers high flexibility in terms of various biomass materials as feedstock.
- ❖Gasification has thermo-chemical conversion efficiencies in the range of 70% to 90%, which is highest among various alternative.
- ❖Gasification output capacity, especially in the high output ranges, is controlled only by availability of adequate feed materials rather than technical consideration.
- ❖The area requirement for gasification equipment is lowest per unit output of energy in the form of heat and/or electricity.
- ❖The gasification equipment has high turn down ratios comparable to biogas and higher than steam turbine systems.

Biomass Gasifiers

The production of generator gas (producer gas) by gasification is partial combustion of solid fuel (biomass) which takes place at temperature of about 1000°C. The reactor is called a gasifier. The combustion products from complete combustion of biomass generally contain nitrogen, water vapour, carbon dioxide and surplus of oxygen. However in gasification where there is a surplus of solid fuel (incomplete combustion) the products of combustion are combustible gases like Carbon monoxide (CO), Hydrogen (H_2) and traces of Methane and non-useful products like tar and dust. The key to gasifier design is to create conditions such that (a) biomass is reduced to charcoal and, (b) charcoal is converted to CO and H_2 at suitable temperature to produce. Basically gasifiers are classified as fixed bed and fluidized bed type gasifiers similar to fixed bed or fluidized-bed systems in combustion technology. Since there is an interaction of air or oxygen and biomass in the gasifier, fixed bed gasifiers are classified according to the way air or oxygen is introduced in it. There are two types of gasifiers: downdraft and updraft. These are also called cocurrent and countercurrent, respectively. And as the classification implies updraft gasifier has air passing through the biomass from bottom and the combustible gases come out from the top of the gasifier. Similarly, in the downdraft gasifier the air is passed from the tuyers in the downdraft direction. With slight variation almost all the gasifiers fall in the above categories. The fuel, its final available form, its size, moisture content and ash content, dictates the choice of one type of gasifier over other.

Gasification is a highly complex chemical process. Bridgewater described the gasification sequence as drying and evaporating processes of biomass followed by pyrolysis, and finally oxidation and reduction. Almost any carbonaceous or biomass fuel can be gasified under experimental or laboratory conditions. However, the real test for a good gasifier is not whether a combustible gas can be generated by burning a biomass fuel with 20-40% stoichiometric air but that a reliable gas producer can be made which can also be economically attractive to the customer. Towards this goal the fuel characteristics have to be evaluated and fuel processing done.

Gasification and Combustion Experiments

A large number of researches were carried out with biomass as a replacement of internal combustion (IC) engine fuel by researchers from various parts of the world. A summary of these experimental results is given below.

The capability of using different types of solid or liquid fuels has led to the study of downdraft gasifiers today. In many engineering applications, equilibrium calculations are useful to predict the outcome of the system being studied. Thus, equilibrium is the first approach used to predict the outcome of the gasification process in downdraft gasifiers. Mendiburu et al. [8] developed a non-stoichiometric equilibrium model to study parameter effects in the gasification process of a feedstock in downdraft gasifiers.

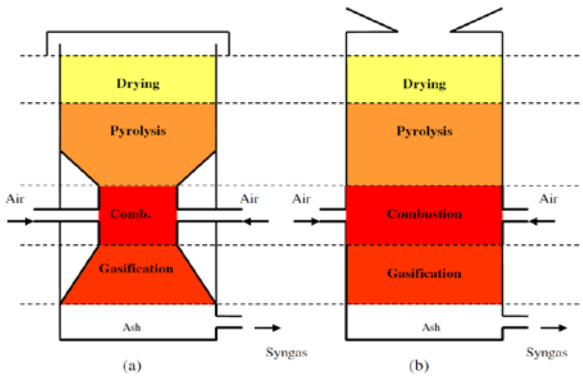

Fig. 1. General scheme of downdraft gasifiers: (a) Stratified and (b) Imbert.

Downdraft or countercurrent gasifiers obtain their name from the flux characteristics of the feedstock and the gasification agent. The feedstock enters at the top of the apparatus, while the gasification agent enters into a lower section of the gasifier. Products of pyrolysis and combustion flow downward. The hot gas then moves downward over the remaining hot char, where gasification takes place [9]. The minimum temperatures required to gasify the most refractory part of almost any biomass are about 800-900 °C. According to Reed and Das [10], two kinds of downdraft gasifiers can be identified: Downdraft Imbert gasifiers and Stratified Downdraft Gasifiers, which are also called Open-Top Downdraft Gasifiers. The main differences between these gasifier units are related to their geometry. Downdraft Imbert gasifiers are characterized by a throated combustion zone and different diameters for pyrolysis and gasification zones, while Open-Top Downdraft Gasifiers are characterized by a constant diameter throughout the gasifier body [11]. Fig. 1 shows the general layout of these two kinds of downdraft gasifiers. Downdraft gasifiers have been tested in compact cogeneration systems for producing electricity and hot and cold water [12]. Another study [13] shows that the ecological efficiency of a downdraft gasifier coupled to an internal combustion engine is about 80%.

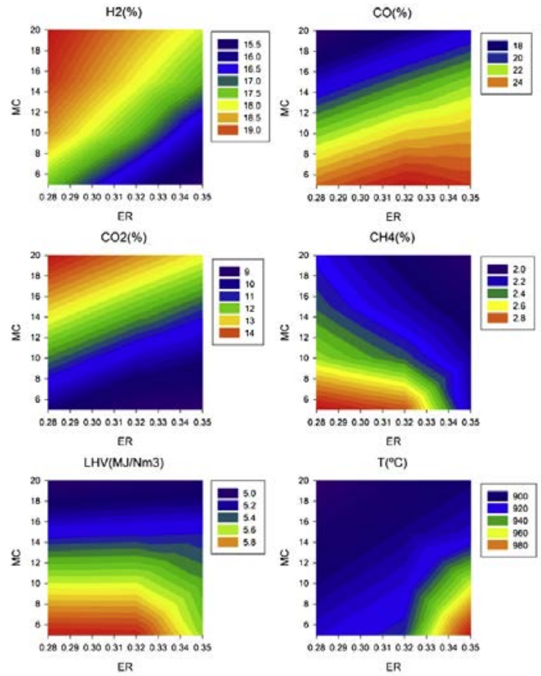

Fig. 2. Influence of ER and MC on synthesis gas composition and LHV for 60 min gasification time.

The results obtained for a gasification time of 60 min and for different values of ER and MC are depicted in Fig. 2. In general, if the MC was held constant, the increase of the ER value produces the decrease of the H_2, CH4 and CO2 contents, while at the same time the CO content increases slightly, producing a synthesis gas with lower LHV and the process shows higher gasification temperatures. On the other hand, if ER was held constant, the increase of MC content produces increments in the H2 and CO2 contents, while at the same time reducing the CO and CH4 contents, producing a synthesis gas with lower LHV and the process shows lower gasification temperatures. Regarding the H_2 and CO_2 contents, their highest values were obtained for MC = 20% and ER = 0.28, while the highest content of CO was obtained for ER = 0.30 and MC = 5%, increases of MC and departure of ER from the vicinities of 0.30 yield lower CO contents, a similar behavior is presented by the LHV. The CH_4 content has its maximum in MC = 5% and ER = 0.28. The maximum gasification temperatures were obtained for MC = 5% and ER = 0.35.

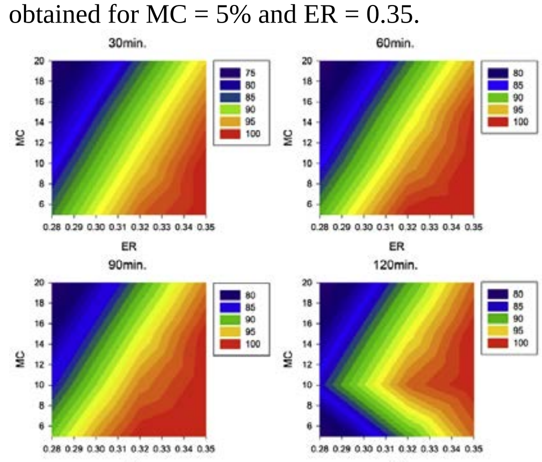

Fig. 3. Influence of gasification time on carbon conversion efficiencies.

In Fig. 3, the carbon conversion efficiencies, obtained for four different gasification times, are presented. When the gasification time is increased the carbon conversion efficiency is also increased, thus the tendency is to reach 100% of carbon conversion, but the ER and MC also represent an important influence, the minimum carbon conversion efficiency was obtained for the minimum gasification time, the minimum ER and for the maximum MC. In the studied case a reasonable carbon conversion efficiency of more than 90% can be achieved for MC below 10% and ER above 0.30.

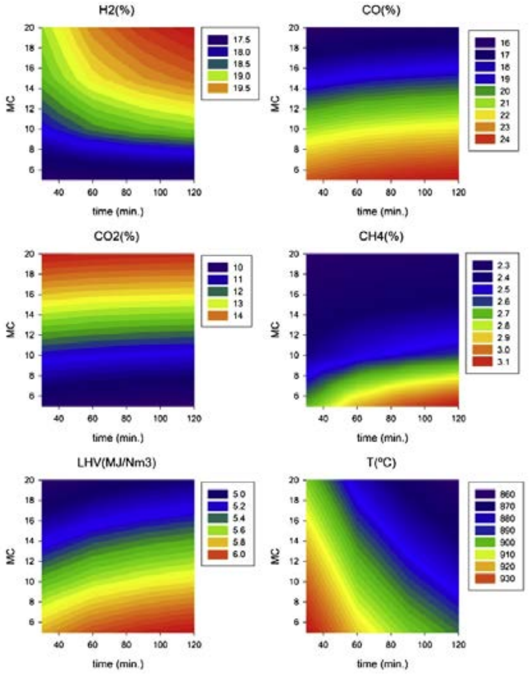

Fig. 4. Influence of gasification time on synthesis gas composition and LHV for ER = 0.30.

In Fig. 4 the synthesis gas composition, obtained for a fixed equivalence ratio (ER = 0.30) and for different MC contents and gasification times, is presented.

If MC was held constant at a value of 5%, the increments in the gasification time produce increments in CO content, CH_4 content and LHV value, while the gasification temperature decreases and the H_2 and CO_2 contents slightly decrease.

If MC was held constant at 15%, the increments in gasification time produce increments in H_2, CO and CH_4 contents and LHV value, while the gasification temperature decreases and the CO_2 content slightly decreases.

If gasification time was set at 120 min, the increment in MC contents produces increments in H_2 and CO_2 contents, while the gasification temperature and the LHV decrease, and also the CO and the CH_4 contents decrease.

The influence results of gasification efficiencies are presented in Fig. 5. The ER value was set at 0.32 and it is observed that increments in gasification efficiency produce a synthesis gas with higher H_2, CO, CH_4 contents and LHV values, while at the same time producing lower CO_2 content and gasification temperatures. The increment in gasification efficiency implies that the products are closer to equilibrium and at equilibrium it is observed that the H_2 and CO contents are the highest that could be obtained from a gasification process. Lower carbon conversion efficiencies result in higher temperatures obtained from the model, together with lower contents of H_2 and CO.

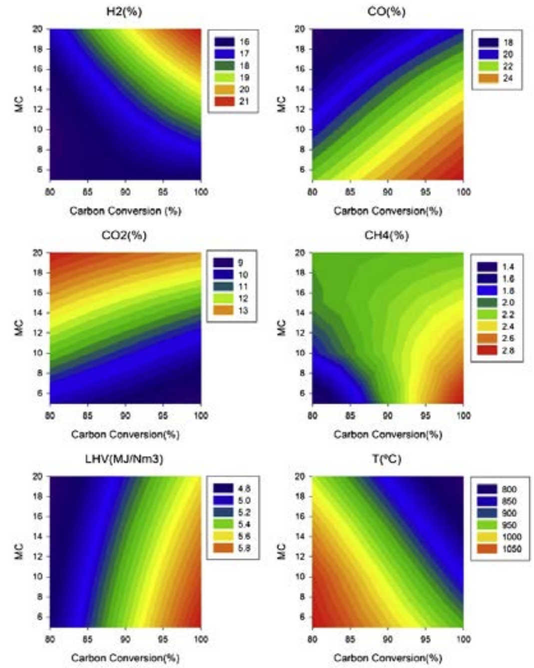

Fig. 5. Influence of carbon conversion efficiency on synthesis gas composition and LHV for ER = 0.32.

The experimental results can be summarized as follows:

- ❖ The influence of four input parameters was assessed, these parameters were: the equivalence ratio (ER), the moisture content (MC), the gasification time, and the carbon conversion efficiency (η_{CC}).
- ❖ It was found that increments in the equivalence ratio (ER) enhance the carbon conversion efficiency while at the same time reduce the LHV of the synthesis gas. For this reason it is preferable to maintain the ER just above 0.30 and give the gasification process enough time to achieve good carbon conversion efficiency. Also it was found that the CO_2 content slightly decrease when ER is between 0.28 and 0.35, which means that this is a good operation interval.
- ❖ It was also found that increments in the moisture content (MC) enhance the H_2 production in detriment of the LHV of the synthesis gas and also in detriment of the carbon conversion efficiency, for these reasons is recommended moisture contents lower than 15%.
- ❖ The gasification time has an important influence on the carbon conversion efficiency, together with the moisture content and the equivalence ratio, carbon conversion efficiencies above 90% are obtained for moisture content of 10%, equivalence ratios of 0.32 and gasification times starting of 30 min or more.

Advantages, Challenges and Technical Difficulties

From the review of literature available in the field of biomass usage, many advantages are noticeable. The following are some of the advantages of using biomass as fuel with diesel in I.C. engine [14].

- ❖ Agricultural waste obtained domestically helps to reduce costly energy imports.

- ❖Development of the biomass usage machinery would strengthen the domestic, and particularly the rural, agricultural economy.
- ❖It is biodegradable and non-toxic.
- ❖It is a renewable fuel that can be made from agricultural crops and or other feed stocks that are considered as waste.
- ❖It contains no aromatics.
- ❖It has a reasonable cetane number and hence possesses less knocking tendency.
- ❖Environment friendly due to absence of sulphur content.
- ❖No major modification is required in the engine.
- ❖Personal safety is improved (flash point is higher than that of diesel).
- ❖It is usable within the existing diesel infrastructure (with minor or no modification in the engine).

Challenges

The major challenges that face the use of Biomass as I.C. engine fuels are listed below [15, 16].

- ❖The price of biomass is dependent on various factors like availability, transportation, and drying, etc.
- ❖Feed stock homogeneity, consistency and reliability are questionable.
- ❖Storage and handling is difficult (particularly stability in long term storage).
- ❖Flash point in blends is unreliable.
- ❖Compatibility with I.C. engine material needs to be studied further.
- ❖Acceptance by engine manufacturers is another major difficulty.
- ❖Continuous availability of the particular type of biomass needs to be assured before embarking on the major use of it in I.C. engines.

Technical Difficulties

The major technical areas (with respect to the use of biomass as fuels in I.C. engines), which need further attention are listed below [17, 18].

- ❖Development of less expensive quality tests.
- ❖Emission testing with a wide range of biomass feed stocks.
- ❖Studies on developing specific markets such as mining, municipal water supplies, etc. which can specify bio-diesel as the fuel choice for environmentally sensitive areas.
- ❖Co-product utilization like ash produced in a beneficial manner.
- ❖Efforts to be focused on responding to fuel system performance, material compatibility and low fuel stability under long term storage.
- ❖Continued engine performance, emissions and durability testing in a variety of engine types and sizes need to be developed to increase consumer and manufacturer confidence.
- ❖Environmental benefits offered by biomass over diesel fuel needs to be popularized.
- ❖Studies are needed to reduce cost and identify potential markets in order to balance cost and availability.

CONCLUSIONS

Many experimental works were carried out by using producer gas derived biomass as I.C. engine fuel substitutes in various countries. These results have shown that thermal efficiency was comparable to that of diesel with small amounts of power loss while using producer gas. The particulate emissions of producer gas are lesser than that of diesel fuel with a reduction in NO_x and producer gas from biomass gave performance characteristics comparable to that of diesel. Hence, they may be considered as diesel fuel substitutes. The use of producer gas derived from biomass as I.C. engine fuels can play a vital role in helping the developed world to reduce the environmental impact of fossil fuels.

REFERENCES

1. M. Junginger, E. de Visser, K. Hjort-Gregersen, J. Koornneef, R. Raven, A. Faaij, W. Turkenburg, Technological learning in bioenergy systems, Energy Policy, 34 (18) (2006), pp. 4024-4041.
2. C.N. Hamelinck, R.A.A. Suurs, A.P.C. Faaij, International bioenergy transport costs and energy balance, Biomass Bioenergy, 29 (2005), pp. 114-134.
3. M.M. Hoogwijk, A.P.C. Faaij, R. van den Broek, G. Berndes, D. Gielen, W.C. Turkenburg, Exploration of the ranges of the global potential of biomass for energy, Biomass Bioenergy, 25 (2) (2003), pp. 119-133.
4. A.P.C. Faaij, Biomass combustion, Encyclopedia of Energy, 1 (2004), pp. 175-191.
5. A.P.C. Faaij, Bio-energy in Europe: changing technology choices, Energy Policy, 34 (3) (2006), pp. 322-342.
6. A.A. Khan, W. de Jong, P.J. Jansens, H. Spliethoff, Biomass combustion in fluidized bed boilers: potential problems and remedies, Fuel Process. Technol., 90 (2009), pp. 21-50.
7. A. Malik and S.K. Mohapatra, Biomass-based gasifiers for internal combustion (IC) engines-A review, Sadhana, 38 (2013), pp. 461-476.
8. A.Z. Mendiburu, J.A. Carvalho Jr., R. Zanzi, C.R. Coronado, J.L. Silveira, Thermochemical equilibrium modeling of a biomass downdraft gasifier: Constrained and unconstrained non-stoichiometric models, Energy, 71 (2014), pp. 624-637.
9. H. Tang, K. Kitagawa, Supercritical water gasification of biomass: thermodynamic analysis with direct Gibbs free energy minimization, Chem. Eng. J., 106 (2005), pp. 261-267.
10. T.H. Jayah, L. Aye, R.J. Fuller, D.F. Stewart, Computer simulation of a downdraft wood gasifier for tea drying, Biomass Bioenergy, 25 (2003), pp. 459-469.
11. M. Dogru, A. Midilli, C.R. Howarth, Gasification of sewage sludge using a throated downdraft gasifier and uncertainty analysis, Fuel Process. Technol., 75 (2002), pp. 55-82.
12. S. Jarungthammachote, A. Dutta, Equilibrium modeling of gasification: Gibbs free energy minimization approach and its application to the spouted bed and spout-fluid bed gasifiers, Energy Convers. Manage., 49 (2008), pp. 1345-1356.
13. S. Shabbar, I. Janajreh, Thermodynamic equilibrium analysis of coal gasification using Gibbs energy minimization method, Energy Convers. Manage., 65 (2013), pp. 755-763.

14. L.J.R. Nunes, J.C.O. Matias, J.P.S. Catalão, A review on torrefied biomass pellets as a sustainable alternative to coal in power generation, Renewable Sustainable Energy Rev., 40 (2014), pp. 153-160.
15. K. Tekin, S. Karagöz, S. Bektaş, A review of hydrothermal biomass processing, Renewable Sustainable Energy Rev., 40 (2014), pp. 673-687.
16. D. Baruah, D.C. Baruah, Modeling of biomass gasification: A review, Renewable Sustainable Energy Rev., 39 (2014), pp. 806-815.
17. M. Asadullah, Biomass gasification gas cleaning for downstream applications: A comparative critical review, Renewable Sustainable Energy Rev., 40 (2014), pp. 118-132.
18. F.L. Chan, A. Tanksale, Review of recent developments in Ni-based catalysts for biomass gasification, Renewable Sustainable Energy Rev., 38 (2014), pp. 428-438.

Citation: Junjie Chen and Longfei Yan (2014) Gasification and Combustion of Biomass for IC Engines. J. of Bioprocessing and Chemical Engineering. V2I2. DOI: 10.15297/JBCE.V2I2.05