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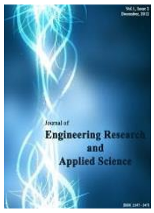

Thermal processing technologies for biomass conversion to clean fuels

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Abstract
Uncertain supplies of oil, climate change and attempts to increase the nation's fossil fuel independence are concerns that have evoked a renewed interest in alternative sources of energy. Biomass is one of the most important of these renewable energy sources. Biomass can be converted to energy in a variety of ways. In the thermochemical conversion technologies, gasification and pyrolysis have attracted compared to combustion, because of high efficiency and high yields. In this paper, we will be discussing substantial techniques and recent progress in combustion, pyrolysis and gasification techniques for the conversion of bioenergy into a effective way of energy, fuel and chemicals.

Keywords: Renewable energy; bioenergy; combustion; pyrolysis; gasification; clean fuels.

1. Introduction

World energy demand is constantly increasing. With more people using energy to Make better their existences, we estimate that global energy demand will be about 25 percent higher in 2040 than it was in 2015 [1]. Majority of energy demand is supplied from the conventional energy resources like oil, coal and natural gas. In recent years, disquiets over global climate change have strongly increased, and although fossil fuels have driven the development of the today's world, their sustained use is likely to guide widespread economic and environmental effects[2]. It is predicted that a large majority of world energy demand will be supplied from fossil fuels until 2040. Figure 1 shows this situation for primary energy sources. Since 2000 the energy resources have been multiply by two in developed countries but the demand is still upward movement. Uncertain supplies of oil, climate change and attempts to increase the nation's fossil fuel independence are concerns that have evoked a renewed interest in alternative sources of energy [3,4].

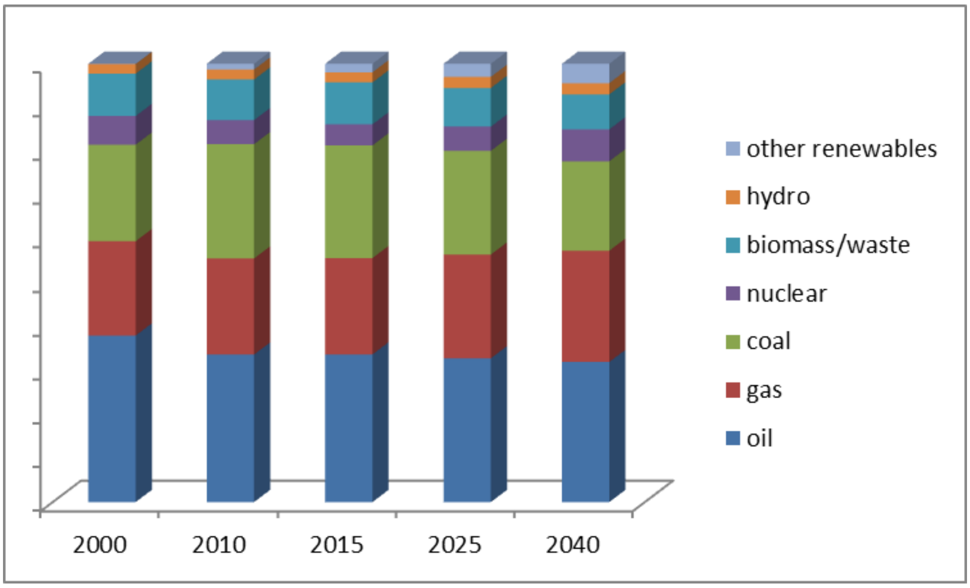

Figure 1. World primary energy demand for 2010-2040.

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Renewable energy is of expanding importance in convincing environmental and economic worries over fossil fuel utilization. As a sort of renewable energy, biomass is an appealing alternative energy to fossil fuels, owing to its neutral CO2 emissions [5]. Nowadays, about 97% of the fuels consumed by transport and passenger vehicles are petroleum-based. For that reason, the need for alternative fuels will be more and more important in the coming years. Several alternatives are possible [6].

Biomass is the fourth largest source of primary energy in the world (meaning 12% of the total energy consumption) and soaring to nearly 40% of it in some developing countries [7]. In 1800, 99% of the world's primary energy demand was provided by biomass. In 1861, with the construction of the first oil refinery in Baku, the use of biomass started to decrease. Unlike fossil fuels, biomass does not take much time to grow. Annually, a great amount of biomass grows by means of photosynthesis.

Biomass comes from many kinds of sources as shown in Figure 2. Biomass is thinking about the renewable energy source with the ultimate potential to contribute to the energy needs of all communities. Energy obtained from biomass derived from lingo-cellulosic can contribute remarkably towards the objectives of the Kyoto Agreement in lessening the greenhouse gases emissions and to the problems associated with climate change [8-10].

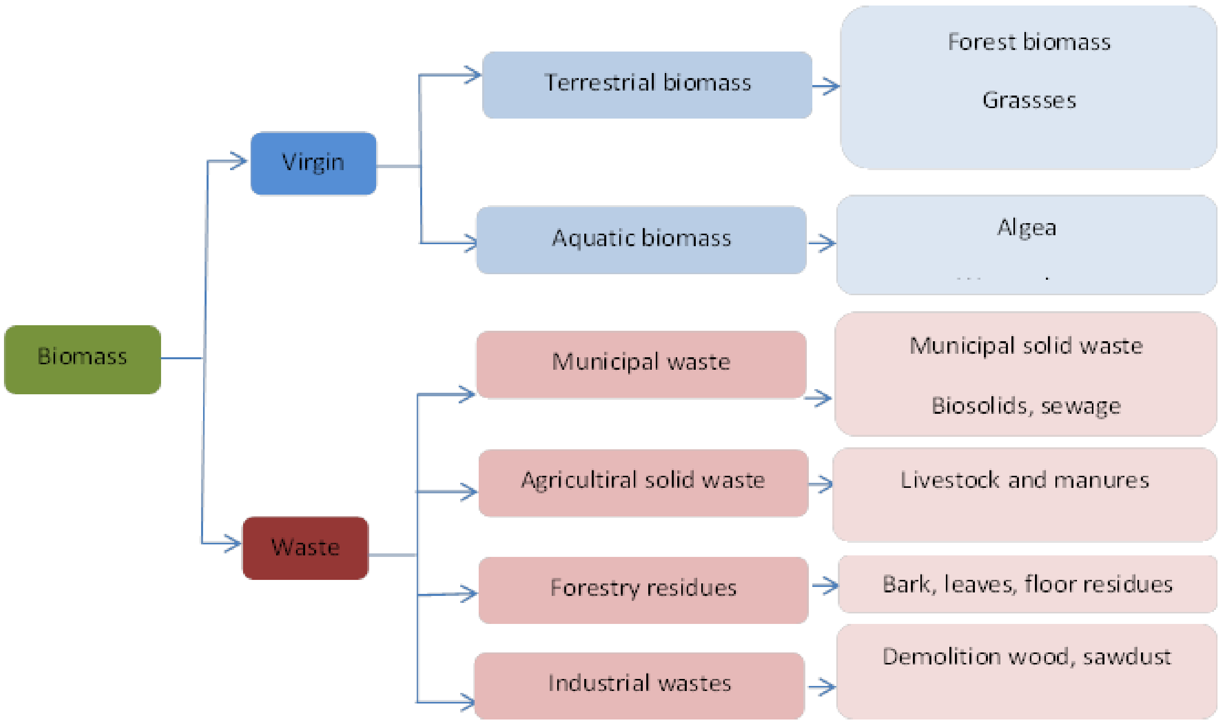


Figure 2. Sources of biomass.

Biomass can be converted to energy in a variety of ways. These routes are shown in detail in Figure 3. In the thermochemical conversion technologies, gasification and pyrolysis have attracted compared to combustion, because of high efficiency and high yields. Thermal conversion techniques applied to biomass are generally thought to be environmentally friendly (as CO2 neutral and pollutant emissions are very low when compared to coal) economical. Thermal conversion technologies are generally considered environmentally friendly (as biomass is CO2 neutral and its pollutant emissions are less pronounced in comparison to coal) and economically sound[11]. Bioenergy provides a great deal of socio-economic benefits as well as numerous environmental benefits [12]. Agricultural wastes contain less C and H and contain more inorganic elements such as N, S, Cl, K and Si compared wood. Therefore, the chemical composition of fuel must be analyzed substantially [13].

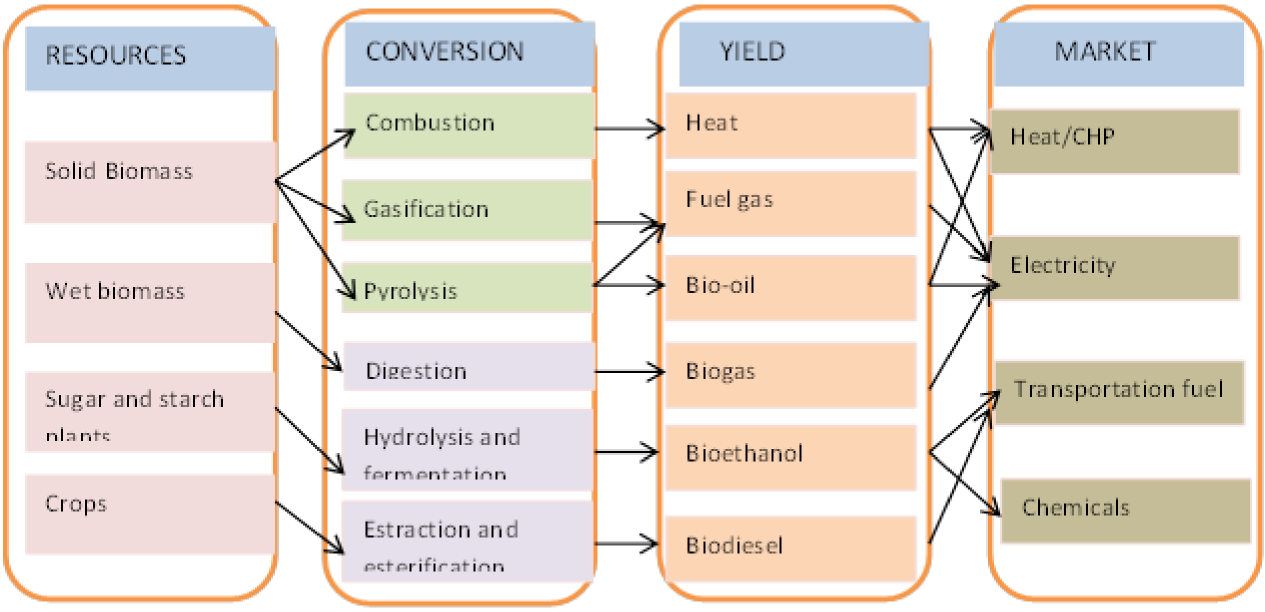


Figure 3. Conversion routes to biomass.

New technologies for biomass to energy burning can perform much better than conventional systems, but their improvements are progressing gradually. In this paper, it will focus on advance in thermal conversion technologies for biomass. We are focusing lingo-cellulosic materials, such as straw, hazelnut husk, wood, etc. and farm products such as corn, sugar cane, wheat, etc.

2. Thermal Processing of Biomass

2.1. Combustion

One efficient method to convert biomass to energy is by direct combustion [14]. Biomass can be directly burned to supply energy for heating and cooking purposes. Chemically, direct combustion is an exothermic reaction, consisted of two main products water and carbon dioxide between oxygen and lingo-cellulose in biomass. The energy resulting from this reaction is presently the largest source of energy consumption. Biomasses have a many kinds of small ingredients, such as Cl, S, P, N, and many kinds of metals. These properties of biomass cause several defiance to their use in biomass combustion [15].
Combustion of biomass accounts for a large majority of pollutants released into the atmosphere, which was prediction to contribute to a large share of particular matter (PM) emissions in different European countries [16]. PM's from biomass combustion are highly complex mixtures of chemical constituents. The emissions are largely dependent on the combustion parameters. To evaluate the combustion properties of biomass fuels, a large number of studies have been conducted [7, 13, 17-20]. Co-combustion is one of the most advantageous ways for effective use of biomass and waste for being an alternative to fossil fuels. Many difficulties are being faced for pulverized coal combustion to operate in co-combustion [21]. Co-combustion of coal and biomass reduces pollutant emissions, improves combustion performance and reduces fossil fuel consumption [22]. The biomass owing to the significantly different composition of coal shows different combustion characteristics, such as short combustion time and low ignition temperature, high volatile matter [23].

2.2. Pyrolysis

Pyrolysis has been greatly used for converting biomass into liquids and solids products among the thermo-chemical technologies [24]. The pyrolytic properties of biomass are controlled by the chemical composition of its major component, namely cellulose, hemicellulose and lignin and their minor component including organic extractives and inorganic minerals. Biomass pyrolysis represents heating the biomass to drive off the volatile matter and leaving behind the charcoal. Pyrolysis technology is one of the leading-edge technologies of bio-energy research that is currently and widely used in biomass conversion [25]. Pyrolysis is an encouraging thermochemical conversion technology that involves irreversible thermochemical decomposition of biomass in the absence of oxygen [26]. Unlike combustion, pyrolysis comes about in the total absence of oxygen, except in cases where partial combustion is allowed to provide thermal energy needed for this process. [27]. Based on the retention time and heating rate, pyrolysis is separated three main groups as slow, fast and flash pyrolysis. Table 1 summarizes the properties of pyrolysis main types. Biomass slow pyrolysis, particularly wood carbonization and distillation, has been used by humans for more than a thousand years [28]. Slow pyrolysis is a process in which heat is applied to the biomass in an oxygen-free environment in order to either partially or completely break down the complex lingo-cellulosic biomass. In slow pyrolysis, the vapor residence time from 5 to 30 min and lower heating rates about 5–20 °C/min and final temperature up to 500 °C results in formation of char, gas and 35%–50% liquid product [29]. In general, slow pyrolysis is utilized to maximize the solid yield, while fast pyrolysis is utilized to maximize the liquid yield.

Table 1. Typical product yields (dry wood basis) obtained by different modes of pyrolysis of wood[30].

Types of process	Temperature and time	Liquid, %	Char, %	Gas, %
Fast pyrolysis	Moderate temperature, short residence time	75	12	13
Carbonization	Low temperature, very long residence time	30	35	35
Gasification	High temperature, long residence time	5	10	85

Fast pyrolysis is a technology to manufactured desired products rapidly from biomass in an oxygen free environment. The liquid product obtained from fast pyrolysis is called bio-oil or biocrude, and this liquid usually contains valuable value-added chemicals [31]. Pyrolysis oil as known it is a complex mixture of water and many kinds of oxygenated organic compounds. Maybe this liquid used as energy source for engines, turbines, boilers and gasifiers or used as chemical feedstock. Table 2 gives some advantages of using bio-oil as a fuel [32]. Bio-oil is a dark brown fluid liquid and has an strong smoky smell indicating the presence of a complex hydrocarbons in large quantities [24,33]. Pyrolysis oil obtained from biomass waste is reported to be highly oxygenated, complex and chemically unstable [34]. Consequently, when bio-oil is used as fuel, it cannot generate SOx emissions, because plant biomass is included negligible amounts of sulfur. When bio-oil is used as a fuel in a gas turbine, it is much less abundant than nitrogen oxides that diesel fuel emits. The fast pyrolysis has many different reactor configurations such as a ablative systems, fluidized beds, stirred or moving beds and vacuum pyrolysis systems [35]. The types of pyrolyzer used in pyrolysis are shown in Table 3. Products obtained from pyrolysis depend on a number of parameters as physical and chemical characteristics, kind of the pyrolyzer, heating rate, pyrolysis temperatures, residence time in reaction zone and particle size of biomass sample.

Table 2. Some advantages of using bio-oil as a fuel.

Bio-oil is the lowest cost liquid biofuel, and its CO2-balance is clearly positive
Possibility of utilization in small-scale power generation systems as well as use in large power stations (co-firing)
Possibility to decouple solid biofuel handling from utilization (reduced capital and operation costs in utilization)
Storability and transportability of liquid fuels
High-energy density compared to atmospheric biomass gasification fuel gases
If light fuel oil is replaced, middle distillates are released to be used for transportation
Potential of using pyrolysis liquid in existing power plants

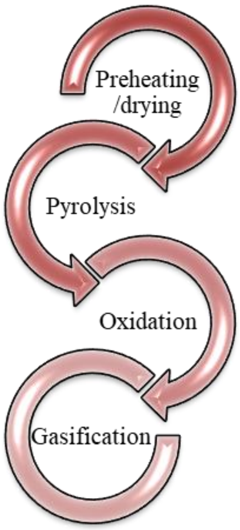
Table 3. The types of pyrolyzer used in pyrolysis.

Fixed-bed
Bubling-bed
Circulating fluidized-bed
Ultra-rapid
Ablative
Rotating-cone
Vacum

2.3. Gasification

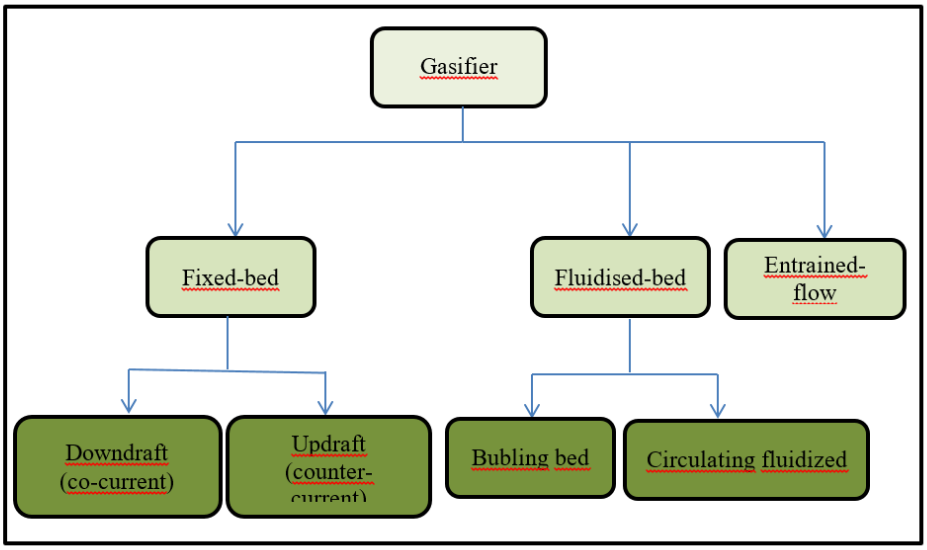
Gasification is the conversion of lingo-cellulosic biomass to a gaseous fuel by heating with a gasifying agent such as oxygen, air or steam. The lingo-cellulosic feedstocks are converted into gaseous products with partial oxidation. The gasification process takes place in four consecutive steps (Figure 4). The main components of biomass gasification in the produced gas are H2, CO and CH4. The composition of this produced gas depends on the operating conditions. These conditions also influence the product distribution and gas quality [36]. Although biomass gasification is a low-cost and low-emission plan for sustainable development, there are a few obstructions that can bring along serious operational problems, such as tar existence in gas products [37]. To improve the gasification of the biomass by virtually eliminating such problems, there are several routes. These are catalytic gasification, co-gasification and two stage-gasification. The most effective of which is co-gasification. Co gasification is a more economically viable compared to other methods and has a great potential for tar destruction [38]. High quality producer gas can be fed directly into an internal combustion engine (IC engine) or gas turbine to generate electricity and heat [39].

Figure 4. Patch of gasification.



Various gasifier technologies have been developed over many decades. A gasifier is the reactor vessel used for gasification processes. Gasification of biomass is usually performed in three types of gasifier, namely fixed-bed, fluidized-bed and entrained-flow gasifiers (Figure 5).

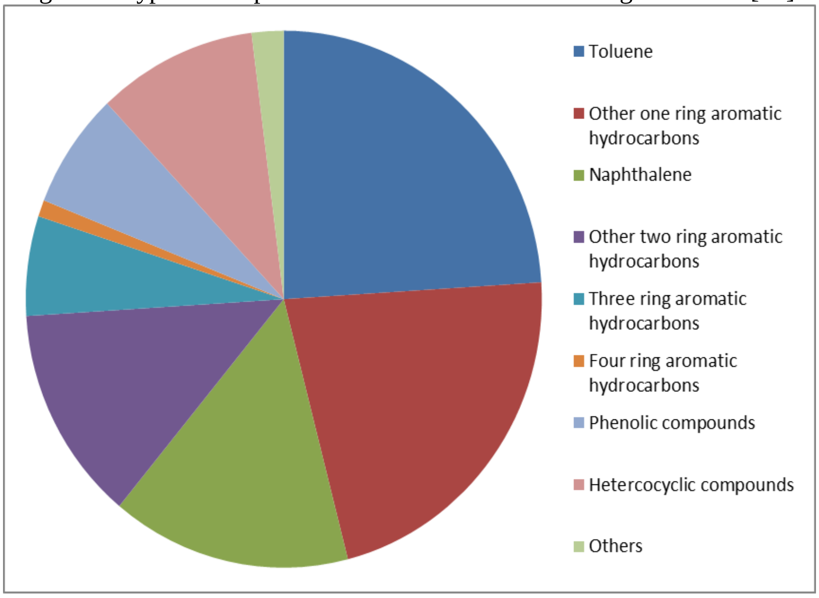
Figure 5. Types of gasifier used in gasification



The fixed bed gasifier is the simplest and oldest technology. In commercial markets, Fixed-bed gasifier is take into accounted as the first choice for small-scale gasification plants of less than 10 MW for regional power generation . The fixed-bed gasifier is sub-classified as updraft (counter-current) and downdraft (co-current), depending upon the direction and entry of airflow. The positioning of reaction distribution regions, i.e. drying, pyrolysis, combustion and reduction, in a fixed-bed reactor differ depending on the type of gasifier.

Among the technologies that can be used for biomass gasification, fluidized beds are emerging as the best due to their flexibility in terms of type of fuel and high efficiency [40]. In a fluidized bed reactor the fuel is fed in relatively from the top, onto the whole of the fluidized bed. The gasifying agent is supplied in the form of a fluidizing gas fed in from the bottom of the reactor [41].

Figure 6. Typical composition of tars obtained biomass gasification [42].



Products obtained in may be divided in to a solid phase and a gas/vapor phase. The solid phase consists of ash and un-reacted char. The un-reacted char forms less than 1% of the ash. The gas/vapor phase can be divided into two groups as a gas phase (syngas) and a condensable phase (tar) [43]. Since the gasification process is comprised of several complex chemical reactions and subsystems, the quality of producer gas and tar content depends on several factors, such as biomass feedstock, reactor design, operating conditions, catalyst and gas cooling and cleaning techniques [44]. The typical composition of tar obtained from the gasification of the biomass is given in Figure 6. The gaseous product through two-stage catalytic cracking reactors to produce clean gas with very low contents of tar, sulphur, nitrogen and halogen compounds, suitable for use in motors, turbines or fuel cells.

3. Conclusions

Renewable energy interest is increasing day by day, due to the environment and security of energy supply. Bioenergy, derived from lignocellulosic materials (wood and other plants) is very important for sustainable energy strategies, particularly when converted to modern energy carriers such as electricity and liquid and gaseous fuels. If biomass energy were “modernized”-that is, if it were produced and converted efficiently and competitively into more convenient forms such as gases, liquids, it might be more widely used. Based on the retention time and heating rate, pyrolysis is separated three main groups as slow, fast and flash pyrolysis. For pyrolysis the product yields vary, depending on the particular feedstock composition, residence time, particle size, heating rate and reactor temperature. Fast pyrolysis liquid has a higher heating value of about 17 MJ/kg as produced with about 25% wt. water. While this liquid is referred to as “bio-oil”, it will not mix with any hydrocarbon liquids. Gasification is not a combustion process. Gasification is a conversion process, produced more precious products from lingo-cellulosic materials. Gaseous products are obtained from carbonaceous materials by both gasification and combustion processes. At gasification, emissions of sulfur and nitrogen oxides are minimized compared to combustion, because of the cleanup of syngas.

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