Application of Pyrolysis and Hydrothermal Liquefaction Process to Convert Bio-Fuel from Biomass

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Abstract. Rapid increase in demand of fuels creates the challenge for scientific community. The fossil fuel resources are declining day by day. So, biomass derived fuel starts to feel an exquisite alternative option, by reason of it develop from residual cooking oil, animal fats, or vegetable oils, etc. In present work biomass is converted into bio-fuel by the process of pyrolysis and hydrothermal liquefaction. But if it is compared with fossil fuel some undesirable properties have been found such like high oxygen content high water content, high corrosiveness and high viscosity etc. Directly biofuels cannot be used in IC engine due to their unwanted content in the fuel. Therefore upgrading of bio-fuel is needed to improve its properties for liquid fuels by the pre-treatment process of biomass. The purpose of biomass pre-treatment is the degradation of cellulose phibrils, lowering their crystallization and polymerization levels, hemicelluloses separation and degradation of cellulose. However application to this bio-fuel have been needed to enhance its properties for CI engine fuel using blending for direct use in engine application.

Key words: Bio fuel, Biomass, Hydrothermal liquefaction, Pretreatment, Pyrolysis,

1. Introduction
In oil consumption India is the third leading country in the world. In India transport sector consumed, nearly 99.6% of petrol and 70% of diesel. Crude oil consuming in India in 2016 was 249 million tons, while the 41 Mt crude oil produced in 2016. It represents 80% of its demand was fulfilled by import and only 20% by its production in India [1-3].

India imported total crude oil in the year 2016 - 17, 2017-18 and 2018-19 was 213932, 220433, 226498 Metric tons which had cost $70196 million, $87803 million, $111915 million respectively [4]. This shows that there is the continuous increase of burden on Indian economy. In India It is estimated that 92% of its oil demand would import till 2030, Due to the gap in supply and demand is continuously increasing because of domestic oil production from few years is static [5]. Due to extraordinary efforts of India for development of renewable energy in recent years; new capability of fossil fuels and renewable investment was first time topped in 2017. Including 9.1% power from hydro power plant, only 15.5% electricity was generated from renewable energy in 2017. For promoting renewable electricity, India begin back its electricity act in 2003. In 2015, India has decided to have 175 GW by 2022, including, 100 GW of solar power plant, 10 GW of bioenergy, 60 GW of wind energy power plant, and 5 GW of small hydro power plant. This will be substitute for 70 GW of electricity produced from coal. Total capacity of India at present time is around 350 GW together with crude oil and low-carbon plants [6]. Because of increasing dependency on imports of oil and concerns regarding climate,
India must hold bio fuel production on its own. Biofuels can solve the problem of greenhouse gas emissions and the uncertainty of the supply of fossil fuels to a great extent.

1.1 Available Biomass Feedstocks

All areas have individually generated biomass feedstocks from forest, agriculture, energy crops, and urban homes. A broad range existing of biomass feedstocks, where plants or animals can exist. Moreover, most feedstock’s can be transformed into heat, electric, liquid fuels, and bio based products. To meet energy level, local needs and objective of transportation fuel, biomass can be adapted widely as an energy resource due to its flexibility in nature and widespread availability. Some most common example of biomass feedstocks are:

1.2 Global Biomass Resources

1.2.1 Dedicated Energy Crops – Energy crops are those crops which is growing slowly for production of energy and are not eatables. These are low-cost and low-maintenance crops. The liquid, solid, or gaseous fuels may be abstracted from these crops the form of bioethanol, char, or biogas. These fuels are used to produce electricity or heat energy. Energy crops are divided into two types.

1. Herbageous Crops (bamboo, timothy, wheatgrass, miscanthus, sweet sorghum, switch grass, tall fescue, kochia…etc.) –

2. Woody Crops (eucalyptus, green ash eastern cottonwood, poplar, sweet gum, willow, silver maple, sycamore, and black walnut … etc.) [7].

1.3 Wastes – Wastes are those materials, which are unusable or unwanted. Any substance which is defective, worthless, and discarded after primary use is called waste. In the past, wastes was shifted directly in agriculture field as a fertilizer after curing, this is a result of environmental and water pollution. Due to this, waste management is essential, which is responsible for further motivation for conversion of waste-to-energy. Anaerobic digestion is the most appropriate technique of transformed these wastes into a useful form of energy; which provides biogas that can be burnt directly for cooking. The wastes may also be converted into energy by the process of pyrolysis. In this process liquid fuel is the primary energy source abstracted from waste and is used in internal combustion engines as fuel, to produce electricity. These are the types of wastes used for convert waste-to-energy.

Wastes from Animal: - poultry waste, cow dunk, tallow
Wastes from Household: - institutional, household, and commercial waste
Wastes from Industries: - Waste from organic chemicals and pharmaceutical, food and beverage processing waste, paper processing waste, tannery, and pulp [7].

1.3.1 Residues Or Leftover – After withdrawing crops from the plant the left material which is no use further are called residue. There are two types of residues. 1. Agricultural residues: The materials which are left in an agricultural land after the crop has been harvested are agricultural residues. Stem, leaves, husk, shell, pulp, weeds, leaf litter… etc. are the examples of agricultural residue. The residue can be directly ploughed into the field or burned first. It can be used as animal fodder and soil improvement, fertilizers, and in the production of biofuels. Due to the great value of carbohydrate and starch. Crop residues can be considered as an appropriate feedstock to produce biofuels. 2. Forestry residues: Forestry residues may be primary or secondary type. Primary forestry residues are thinning or final felling of branches, stumps. These are examples of treetops, bark, sawdust, etc. The Sub-products and
co-products of industrial wood-processing operation are known as Secondary residues, like: - sawdust, bark, wood chips, sawmill slabs, etc. [7].

2. Materials and Methods

2.1 Conversion of Biomass into Energy Form

For waste to energy conversions a number of processes present. The most conversion method used of these are thermal conversions, bio-chemical and chemical conversions. Selection of waste to energy conversion method depends on the quantity and quality biomass. Each method of them has its individual limitations and advantages.

2.1.1 Thermal Conversions: The thermal conversion processes available for the thermal treatment of solid wastes are pyrolysis, gasification, and incineration etc. By the use of these thermal conversion processes different by-products are produced, as shown in Figure: 1; and these products are treated by different energy and substance recovery systems [8].

![Thermal conversion process and products [8]](image)

2.1.2 Pyrolysis: Pyrolysis process have Many advantages like: (a) significantly decrement of bulk wastes approx 50 to 90%, (b) production of fuels like: - liquid fuel, solid fuel, and gaseous fuels. (c) Chemical feedstock for plant and transportable fuel is obtained. (d) Eco friendly (e) it is an appropriate process to convert waste into energy. (f) The investment costs of the pyrolysis process is comparatively less than that of the incineration process. It is an indirect gasification process. Pyrolysis process is done in the absence of oxygen or in the presence of inert gases as the gasification agent [9]. Different pyrolysis processes have been described in short. The heating rate in the conventional pyrolysis process is slow and liquid, solid and gaseous products come out in significant portions [10]. The vapours formed in the process can be removed continuously. But the fast pyrolysis is accompanying tar, at low temperature range 800–1300 K, and gas, at high temperature range approx 1000–1350 K. In present, the preferential
technology used is flash pyrolysis at high temperatures with very short retention time. The fast pyrolysis process is precisely further defined as the thermolysis process. In this process the material or biomass is quickly heated to high temperature in the absenteeism of oxygen [11].

Table 1 Operating parameters used for different pyrolysis process [12]

| Operating parameters          | Conventional pyrolysis | Flash Pyrolysis | Fast pyrolysis |
|------------------------------|-------------------------|-----------------|----------------|
| Particle Size (mm)           | 5-50                    | <0.2            | <1             |
| Heating Rate (k/s)           | 0.1-1                   | >1000           | 10-200         |
| Solid Residence Time (s)     | 300-3600                | <0.5            | 0.5-10         |
| Pyrolysis Temperature (K)    | 550-900                 | 1000-1350       | 800-1300       |

2.1.3 Gasification: In the first stage of gasification process biomass is combusted partially to carry out char and gasses and consequently decreases the product gasses like CO2 and H2O in to CO and H2. Mostly gasification process can be defined as the thermo chemical change of a liquid or solid carbon-based material (feedstock) into a combustible gaseous product in the presence of oxygen or the supply of a gasification agent (such as air, carbon dioxide, subcritical water, etc.). Other hydrocarbons and some methane are also generates in the gasification process, Depending on the design of the reactor and operating conditions of gasification [14]. The combustible gas contains CO, CH4, CO2, H2O, H2, and find higher quantities of hydrocarbons [15].

If the process do not take place in the presence of an oxidizing agent, it is called indirect gasification and needs an external energy source for complete the process (Figure: 2 and 3) [16, 17]. Due to gasification agent, feedstocks are quickly converted into gas with many heterogeneous reactions [18-20]. A gasification system is made up of three basic elements: (1) For producing the combustible gas a gasifier is used; (2) To remove harmful compounds from the gases the gas clean up system is required; (3) Energy recovery system is required for collecting and using heat energy through controlled combustion of waste material. A suitably uniform carbon-based material is used in a gasification process for a proper and efficient gasification. Some wastes cannot be treated in the gasification process due to too-much oxygen content in the biomass. These oxygen is removed via dehydration method and high hydrocarbon content gas is obtained. If the oxygen content exceeds the certain value, the process transformed, gasification to combustion. In the gasifier reactor conversion of feedstocks takes place in the form methane, biogas or propane etc. The three main types of gasifier reactor is used in the gasification process: (1) fluidized bed, (2) fixed bed and (3) indirect gasifier. The gasification process is a potential substitute for the waste conversion by the thermal treatment process of homogeneous carbon-based material and for pre-treated heterogeneous material.
Figure 2. Block diagram of Gasification and pyrolysis processes [9]

Figure 3. Direct and indirect gasification processes [9]
Table: 2 Pyrolysis gas Composition from MSW. [13]

| Constituent | Amount, Vol.% | Calorific Value, kcal/Nm³ |
|-------------|---------------|---------------------------|
| CH₄         | 11-14         | 3400-3500                 |
| CO          | 35-37         |                           |
| H₂          | 36-38         |                           |
| CO₂         | 15-17         |                           |

2.2 Waste to Energy Conversion through Biochemical: Transformation of biomass into different products like: biogas, organic acids, butanol etc. by using of enzymes of bacteria and other microorganism are called Biochemical conversion processes. Mostly cases, micro-organisms are used for the conversion Process: fermentation, anaerobic digestion, and composting. Anaerobic digestion is helpful to reduce the quantity of organic waste material and recovering energy. Mainly, potential feedstock for anaerobic digestion is an organic fraction of an MSW. Mostly, the organic materials is digested in the digester and the gases from this may be utilized as a transportation fuel or may be used for heating purpose. However non-recyclable and nonorganic fraction from the waste may be either gasified or incinerated. In the process of decomposition, the temperature increases and could touch as high as 60-70 °C and starts to fall after 1–2 months. Though the fermentation process goes for a long period of time and a number of gases are produced, containing small volumes of H₂S and CO. During anaerobic digestion process, methane is produced. Methane gas can be ably transformed into methanol. Steps usually engaged in the anaerobic digestion process [21]. In controlled anaerobic digestion has been estimated that one ton of solid waste yields 2–4 times much methane in 3 weeks compared to one ton of waste in a landfill will produce in 6–7 years [22, 23]. In biochemical conversion the organic matter of wastes are biodegradably fractionated for contribution to energy output.

3. Appropriate Products from Biomass

Through biochemical conversion Ethanol produced from the waste. It is the largest volume biofuels produced in the current scenario. In the process of biochemical conversion the yeast ferment sugar from starch and sugarcane in to ethanol. Today’s ethanol is produced from corn-starch or sugarcane. Cellulosic biomass sources like trees, grasses, and agricultural waste can make biochemical conversion technique as a more fruitful [24].

3.1 Biofuels: Many types of energy like heat; biofuels etc. can be produced from biomass. In this conversion of biomass to energy bio-fuel is the most appropriate energy withdrawn in current scenario; helping to improve the greenhouse gas emissions and disburden demand for petroleum products in the transportation sector. Ethanol produce from sugarcane, maze corn and starch, and biodiesel produced from oil palm, soya and jatropha impact the current market scenario of biofuels, but most of the companies movement towards second generation of biofuel which is produced from non-edible feedstock or wastes produced from different resources in place of energy crops. This biofuels contain bio-butanol, methanol, cellulosic ethanol, and some synthetic gasoline/diesel equivalents. It is the merely available clean, renewable energy source in the field of transportation sector.
3.2 **Biogas**: Production of biogas from available biomass resources can be a good alternative of energy because it contributes to the demand and supply of the energy and the reduction of GHG emissions. Biogas conversion technology provides an exquisite route for the utilization of different wastes to meet energy need. The technology for converting biogas from biomass have a set of benefits, such as decreases in pathogenic diseases, improvement of ecology in the rural areas, and optimisation of the consumption of energy in rural areas. Biogas is produced under anaerobic conditions through biodegradation of organic wastes in the presence of bacteria.

| Biogas Constituent | %    |
|--------------------|------|
| Methane            | 50-70|
| Nitrogen           | 2-4  |
| Carbon dioxide     | 25-45|
| Water Vapors       | 0.5-1.5|
| Others             | 5-15 |

3.3 **Bio-Char**: Bio char, char and charcoal all three carbonaceous materials are produced through pyrolysis method. Any type of carbonaceous residue from pyrolysis or natural fires are called char. And after the pyrolysis of animal dung or vegetable waste the carbonaceous material obtained is called charcoal. Bio char is produced from pyrolysis of biomass at specific temperature. Bio char is used in boiler furnace direct as a fuel, and it can also be used in agricultural field to improve soil properties and crop productivity.

4. **Existing MSW Handling Scenario in India**

Municipal solid waste management (MSWM) in developing countries is a significant problem. In the developing countries, the waste generation is almost similar in composition but due to changes in the climatic condition, industrial, cultural, and infrastructural and some of the legal factors, the waste generation may vary. Municipal solid waste management (MSWM) turn out to be drastic in India, due to uncontrolled pollution rate and rapid urbanization. Now Indian cities are generated 8 times more solid waste than they did in 1947. The current population of India’s is about 1,380 million will continued the growth rate of 1.02–0.99% per annum. Out of this, 35% of the population lives in urban areas. Presently the solid waste generation as by products from municipal, agriculture, industrial and mining, annually is about 960 million tons. It is estimated that increment of solid waste generation per capita is about 1 % to 1.33 % annually [25]. Figure: 4 shows the municipal solid waste management (MSWM) system in India [26].
Figure 4. Municipal solid waste management (MSWM) systems in India [26]
5. Pre-treatment of Biomass

According to the purpose, pre-treatment method may be categorized in four types: drying, thermochemical treating, cell disruption, and targeted fractionation. There is a different methods can be combined and few categories are superimposing. Most of the biomass conversion methods and properties are well-known but still explored in aspects such as, use as a green solvents, energy demand and process escalation. The excerption of significant biomass pre-treatment depends on their cost-efficiency. The all four category of biomass pre-treatment are described briefly in below.

5.1 Drying: Drying process mainly consist of removal of water content from the biomass by the heat transfer and water diffusion [27]. The chemical decomposition and microbial may be reduced due to low water content, and stabilization of biomass during drying process. Although the other phenomenon can turn up the components of biomass and the cell structure may be affected because of denaturating and mechanical effects. Subsequent processing can have consequences, ranging from increased digestibility to protein precipitation, cell collapse, and enzyme deactivation. When biomass is subsequently obtained from valuable products like enzymes or vitamins, a slow and gentle drying process is required, literally due to it produces executable porous biomass with small modification of the molecules [28]. Cryodesiccation can be a worthy selection for drying biomass. The drying temperature and rate of drying can be higher during drying process. Recent study shows that spray drying can improve cell porousness, due to an expansion effect in drying process.

5.2 Thermochemical Conversion: Thermochemical conversion process integrate with pyrolysis and hydrothermal liquefaction (HTL). Both the processes are appropriate to produce biofuel from biomass, including gaseous, solid and liquid fuels. During HTL process wet biomass is heated in pressurized system in lower temperature ranging from 250 to 350˚C to avoid phase change. The process gives liquid and solid fractions. During pyrolysis process biomass is heated temperature up to 800 ˚C in the absence of oxygen and at atmospheric pressure. At different temperature in the pyrolysis process obtained all three phases fuels in appropriate proportions. All these three phases must be used as a fuel after further processed. Proteins and carbohydrates rich biomass are also converted to bio oil by the thermochemical process. HTL and pyrolysis both processes required appreciable energy, but the net energy balance can be positive. It is figured that HTL and pyrolysis can recovered 85-91 % and 75-80 % respectively, of the energy content from the biomass.

5.3 Cell Disruption: This pre-treatment method involves several steps that permeate, diffuse, disrupt or dissolve cell membrane or the cell wall. By the use of physical, chemical or mechanical techniques cells of biomass particles are disrupted. The cytomembrane, a fluid, lipid dual-layer with 4-5 nm roughly, is an eclectic barrier that defend internal structure and relatively easy to thermally wreck or dissolved [29-30]. The wall of cell is comparably permeable for small molecules, however most microalgae are thick and strong usually 200 nm [31, 32].The mechanical distraction of the cell wall shows internal macro-molecular organelles and components, and its hydrolysis is required if components of cell wall are to be used. CRUSHING OF BIOMASS IN POWDERED FORM: already dried biomass can be grinded by the methods, using common for other minerals or biomass. In the process of grinding the energy transfer and consumption to the product vary with the particular biomass.
5.4 **Targeted Fractionation or Solubilization**: This pre-treatment methods includes that dissolve elements of the biomass, similarly to specific cell disruption, but producing extracts that can be furthermore processed for purification or fermentation. This process is quit flexible because of the molecular targets diversity. This processes can required a primary biomass disruption process. For the production of high-yield products like: low polarity components and bio-oil, with vitamins and carotenoids. To generate byproduct or fermentable fraction by this pre-treatment method using slower hydrolysis method instead of mechanical cell disruption. The slow hydrolysis process for fractionation is slow but can increase the profitability of the bio-refinery. There is a specific set of take-out solvents permitted by regulations for food ingredients and foodstuffs. As per 2009/32 directives From European commission describes permitted for solvent extraction. Other solvents like: dichloromethane, hexane and methanol must be substantiated against the intended use [33].

5.5 **Pre-treatment Selection and Process Integration**: By following some guidelines there are lot of options for processing may support in the growth of new procedure in the selection of pre-treatment operation:

- Safety and legislation are also important, especially when uses of reagents and solvents, and amount of residue permitted in the products.
- A new procedure must be assessed and enhanced regarding yield, cost environmental impact and throughput at each iteration.
- Few thumb rules are apply when there is no precedent in processing specific micro-algal biomasses.
- A procedure should be made on the basis of previous effective approaches and improve the technique.
- Energy extraction and cost are crucial, but integration of byproducts are also essential and may increase the profitability.

6. **Conclusion**

The following conclusion can be drawn from the study is as:-

- The current study is based on the second generation of biofuel production, which is produced from non-edible feedstocks.
- Pre-treatment through drying of biomass can improve cell porousness due to an expansion effects.
- During thermochemical pre-treatment process the biomass is heated in pressurized system in temperature range between 250 °C to 300 °C to avoid phase change.
- In cell disruption pre-treatment method, the cell of biomass may be break 4-5 nm approx.
- The composition of gasses obtained through pyrolysis process contains as: \( \text{CH}_4=11 \text{ to } 14 \% \), \( \text{CO}= 35 \text{ to } 37 \% \), \( \text{H}_2= 36 \text{ to } 38 \% \), and \( \text{CO}_2= 15 \text{ to } 17 \% \).
- The preferential technology used is “Flash Pyrolysis” at high temperature range 1000-1350 °C, with very short retention time less than 0.5 seconds.
- During waste to energy conversion through biochemical, the decomposition temperature reaches as high as 60-70 °C for long period of time, 1 to 2 month.
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