A REVIEW OF EMERGING THERMAL BIOMASS PRETREATMENT TECHNIQUES WITH REGARDS TO BIOMASS AVAILABLE IN THE UTTARAKHAND REGION

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Abstract—**Biomass is a versatile, ubiquitous energy resource that could be used as a sustainable energy source in multiple forms. However, it is beset by several limitations such as heterogeneity, lower bulk density, lower energy density, hygroscopic behavior, and fibrous nature that inhibit optimum energy utilization. Several techniques and methods are employed to reduce and ameliorate some of these major limitations. This paper serves to review some of the emerging thermal biomass pretreatment techniques, viz. Torre faction (thermal), pyrolysis (thermo-chemical) and palletizing (mechanical) with regards to biomass available in the Uttarakhand state of North India.**

Keywords— **Biomass, Palletizing, Pyrolysis, Torrefaction**

I. Introduction

Biomass is a broad term that includes any organic materials derived from plants or animals, forest and agriculture sector [1]. According to the Energy Statistics of International Energy Agency 2009, energy derived from biomass contributed around 10% of the world's total primary energy supply [2]. Biomass in India has been historically used for cooking and heating purposes. However, with the advancement in technologies, particularly in pretreatment techniques, biomass can now be utilized for electricity generation as well [3], with the conversion of biomass to biofuel being facilitated via different thermal, chemical and biological processes.

There are two sources of biomass: primary sources that include forest, agricultural resources and secondary sources that include industrial wastes derived from primary sources. Common examples include beech wood [4], bagasse [5] woody biomass [6,7], straws [8], seedcakes [9] and municipal solid waste (MSW) [10,11]. In this paper, a total of 15 different types of biomass feedstock specifically present in Uttarakhand region have been reviewed.

A. Biomass Constituents

Biomass is constituted of three principal compounds, viz. Cellulose, Hemicellulose and Lignin. Cellulose is the main constituent of biomass. It is a glucose polymer consisting of linear chains with an average molecular weight of approximately 100,000g per mole [12].

Hemicellulose is a heterogeneous polymer composed of five-carbon and six-carbon monomeric sugars, with an average molecular weight of 30,000 [13]. Lignin can be regarded as a group of amorphous, high molecular weight, chemically related compounds. The building blocks of lignin are believed to be a three-carbon chain attached to rings of six carbon atoms, called phenyl-propanes [14]. These constituents are commonly expressed as a percentage, constituting the lignocellulosic content of biomass. The lignocellulosic content serves as an effective indicator of the energy available for utilization in various biomass content. Table 1 shows lignocellulosic content of different biomass available at Uttarakhand region [15-21].

Feedstock	Carbon (%)	Hydrogen (%)	Oxygen (%)	Nitrogen (%)	Ash (%)
Sugarcane					
Rice straw					
Industrial waste paper	48	6.2	45.1	0.4	
Wheat straw	48.5	5.5	3.9	0.3	4
Tea waste	48.6	5.5	39.5	0.5	1.4
Barley straw	45.7	6.1	38.3	0.4	6
Solid cattle manure					
Hard wood	33.5 **10.1.1.**	3.7	35.8	0.1	
Softwood	37	3.9	34	0.1	

Table 1: Lignocellulosic content of different biomass feedstock

B. Properties of Biomass

Although a wide variety of biomass derived from an even wider variety of sources exist, there are several general properties that are exhibited by most types of biomass. These include:

- Low energy density/heating value (low fixed carbon content ~45%)
- High moisture content (~50%)
- High volatile matter content (~70%)
- Low ash content; high alkali metal content (Na, K) (low Cl content compared to herbaceous biomass)
- More oxygen content (needs less air for stoichiometric combustion)
- Hygroscopic (absorbs moisture)
- Non-uniform (wide range of shapes, sizes and types)

A comprehensive review of various physical and chemical properties exhibited by selected biomass available in Uttarakhand region is shown in Table 2 and 3 respectively.

C.Issues with Biomass

Energy harnessing from Biomass is hampered due to several underlying issues. Biomass has low calorific value, high moisture content and low energy density. Low calorific values, coupled with lower energy density than conventional fuels results in lower efficiencies in energy generation, when compared to other energy resources for similar fuel mass and other factors. Biofuels also have non-homogeneous combustion properties (Fixed C, VC, inorganic constituents, moisture, calorific value), resulting in operational difficulties for combustion processes. Also, due to wide variations in sizes, shapes and types, storage and handling of biomass is arduous and impractical in some cases[22-24].

Feedstock	Density (kg/m^3)	Moisture content (%)	Ash content (%)	Volatile matter (%)	Fixed carbon (%)	Calorific value Kcal/kg
Sugarcane	1198		3.2-5.5	-	-	4400
Rice straw	200	6	4.3	79	10.7	2500
Industrial waste paper	800-1500	7-9	3.8-8.5	82-86	1-3	4444
Wheat straw	1233	16	4	59	21	3440
Tea waste		8.3	4	65.5	21.3	4976
Barley straw	210	30	6	46	18	3511
Solid cattle manure						
Wood	1186	20	0.4-1	82	17	3500

Table 2: Physical properties of selected different biomass feedstock

The physical properties of biomass do not fare any better. Along with poor grindability [25], the hygroscopic nature (property of absorbing moisture during storage) of biomass results in immense storage concerns [26]. Also, biomass has demonstrated several post combustion, ash related problems. Although coal generally has much higher ash content, still biomass ash is more prone to slagging & fouling, resulting in a higher frequency of maintenance operations and environmental concerns.

Feedstock	Lignin%	Cellulose%	Hemicellulose%
Bagasse	23-32	19-24	32-48
Rice straw	18	32.1	24
Leaves	0	15-20	80-85
Industrial waste paper	5-10	60-70	10-20
Wheat straw	15-20	33-40	20-25
Rye straw	16-19	33-35	27-30
Walnut shell	52.3	25.6	22.7
Tea waste	40	30.20	19.9
Barley straw	14-15	31-34	24-29
Banana waste	14	13.2	14.8
Swine waste	NA	6	28
Solid cattle manure	2.7-5.7	1.6-4.7	1.4-3.3
Hard wood	18-25	40-55	24-40
Softwood	25-35	45-50	25-35

Table 3: Chemical properties of selected different biomass feedstock

II. Biomass Pretreatment

A. Torrefaction

Torrefaction is essentially a thermal treatment process. When biomass is heated between 200-300°C, alterations in the physical characteristics of biomass are produced, resulting in creation of high quality biomass as end product. The heat treatment procedure resolves issues with traditional biomass to some extent, resulting in up gradation of biomass quality and alteration in combustion behavior. As a result, torrefied batch of biomass can be efficiently used in a co-firing power plant [27-30]. Torrefaction is motivated mainly for thermochemical conversion process because of its ability to increase hydrophobicity, grindability and energy density of biomass. In addition to this, torrefied biomass after mechanical compression could be used to replace coal in the metallurgical process, and promoted as an alternative of charcoal.

B. Advantages of Torrefaction

Torrefaction improves the physical characteristics of biomass and thus the overall economics of the biomass utilization process for energy production. Also, the torrefied product is a homogeneous fuel with higher energy and lower moisture content. It makes biomass hydrophobic thereby making transport and material handling less expensive & easier. A significant loss of energy due to re-absorption of moisture in biomass (pellets) is saved, as torrefied biomasses have no decomposition behavior. This results in a longer storage life without fuel degradation [31,32]. Torrefied biomasses also have low O/C ratio, which results in higher yield during gasification and less smoke producing compounds [30].

C. Disadvantages of Torrefaction

A major disadvantage of torrefaction is that the volume of torrefied biomass is reduced only slightly, around 10-20% lower than the dried feedstock. Moreover, despite exhibiting higher calorific values, energy density is not improved significantly (around 5 GJ/m^3) in torrefied biomass. Another disadvantage is loss of energy content due to torrefaction. Although small, some of the energy content in original biomass is lost (nearly 10%). Torrefaction also does not reduce corrosive deposits on boiler tubes (all ash components of biomass are still present in torrefied biomass). A lack of understanding of process performance, properties of torrefied product and composition of volatiles also has inhibited acceptance of torrefaction in the energy sector. Despite of its numerous advantages there is no commercial torrefaction unit in operation yet. [29,33-36]

D. Pyrolysis

Pyrolysis is thermo-chemical treatment of biomass to obtain liquid biofuel. The process of pyrolysis of organic matter is complex and consists of both simultaneous and successive reactions when organic material is heated in a non-reactive atmosphere. In this process; thermal decomposition of organic components in biomass starts at 350 °C–550 °C and goes up to 700 °C–800 °C in the absence of air/oxygen [37]. The long chains polymer in biomass breaks down into smaller molecules in the form of gases, condensable vapors (tars and oils) and solid charcoal under pyrolysis conditions. Rate and extent of decomposition of each of these components depends on the process parameters of the reactor (pyrolysis) temperature; biomass heating rate; pressure; reactor configuration; feedstock; *etc.*

E. Advantages of Pyrolysis

Production of bio-oil through fast pyrolysis has received more attention in recent year due to the following potential advantages [38-40]:

- Renewable fuel for boiler, engine, turbine, power generation and industrial processes;
- Low cost and neutral CO_2 balance;
- Utilisation of second generation bio-oil feed stocks and waste materials (forest residue, municipal and industrial waste, *etc.*);
- Storability and transportability of liquid fuels;
- High energy density compared to atmospheric biomass gasification fuel gases;
- Possibility for separating minerals on the site of liquid fuel production to be recycled to the soil as a nutrient;
- Secondary conversion to motor-fuels, additives or special chemicals;
- Primary separation of the sugar and lignin fractions in biomass with subsequent further upgrading.

F. Disadvantages of pyrolysis

The disadvantages of early pyrolysis technology include slow production, low energy yield and excessive air pollution. Therefore, technology development to recover the maximum possible energy from a particular type of biomass is continuing as an important step towards a profitable investment. [41]

G. Palletizing

Palletizing is the conversion of woody biomass under the action of mechanical forces to small wood pallets. These pallets can be used directly for firing purposes. The most common biomass pelletized for fuel is wood, mainly from sawdust, wood chips and shavings. Wood pellets are also used on a commercial scale.

H. Advantages of palletizing

Pallets are dust free thereby reducing dust pollution and minimizing particle emission. They have more efficient form of combustion than biomass. They have increased bulk density, which favor storage and transportation problems

I. Disadvantages of palletizing

Preparations of pellets from biomass have some disadvantages. The fuel has less calorific value than coal, and therefore large quantity of pellets are required to achieve a similar effect. This raises issues related to transportation and the availability of larger storage areas, regular combustion equipment control and ash removal. Pellet production also consumes more energy than the direct burning of unprocessed biomass. [42]

CONCLUSIONS

Biomass has very high energy potential. However, certain aforementioned limitationslike low energy density, low bulk density, heterogeneity, hygroscopic behavior and the fibrous nature of biomass result in the transportation difficulties, storage problems, and the spontaneous decay of biomass. Such problems could be substantially avoided through the pretreatment processes. The increasing hydrophobicity of biomass through the torrefaction pretreatment process could make it acceptable for storage of biomass. Reducing the fibrous nature could increase the grindability of biomass that leads to a homogenous, spherical, and fine particle size distribution.

The pelletization after the torrefaction produces more uniform and hydrophobic products compared with that from the raw biomass. However, the process is hampered by a higher compression energy requirement and production of easily breakable pellets.

Thermo-chemical treatment of biomass resulting in biofuel is also a viable technique. The liquid fuel thus obtained from pyrolysis can be used directly in engines. However, due to lower fuelyield and slow production this method is not as economically viable as torrefaction.

Emphasizing on the Uttarakhand region where ample biomass is available, with the modern technologies especially pretreatment processes, energy harvesting from biomass can be done very efficiently. Among the three pretreatment techniques viz. torrefaction, pyrolysis and palletizing, that the paper identifies for high-energy biomass utilization, significant benefits can be gained. However, this can only be achieved through further research and development so that optimization for local feedstock can be achieved.

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