Review Article

A REVIEW OF BIOMASS ENERGY IN INDIA AND ITS DENSIFICATION

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ABSTRACT:

Of lately, with a limited supply and growing cost of fossil fuels, biomass as a renewable energy source has started to look economical. Apart from the cost, there is tremendous push to lower the greenhouse gas emissions to avoid the adverse effects of climate change. In utilizing biomass as an energy source, densification is an important step, where the biomass is compacted to increase its energy density, thereby decreasing its storage and transportation cost. In this paper, a detailed analysis of various densification technologies, along with densification mechanism is outlined. The effect of variables such as temperature, pressure, feed stock etc on the densification and durability of the biomass is discussed. Also, the pretreatments methods to increase densification behavior are explained. Based on this study densification methods for various biomass feedstock is suggested for efficient utilization. Finally, new characterization techniques are proposed to understand the materials properties of the biomass.

KEYWORDS: Biomass densification, Densification systems, Pretreatment, Biomass energy

INTRODUCTION:

The commercial energy requirement of India increased at a rate of 6% per year during the period 1981-2001(Planning Commission 2002, Govt. of India) [1]. The per capita energy consumption is still low compared to other developing countries. However, the Planning Commission of India estimates that by 2030 the energy requirement would be nearly 800 GW, which is nearly 5 times the current capacity. According to a report[2] during period 1970-2006 coal, oil and natural gas consumption has increased by 5, 7 and 48 times respectively, similarly electrical consumption has also increased from a level of 44 to 440 TWh. Renewable energy sources can potentially offer a viable option to address the future energy demands in India.

Apart from filling in the demand-supply gap, renewable energy offers enormous social and environmental benefits. Among all the available renewable energy resources such as hydro, solar, wind and biomass energy, the latter provides the benefit of low cost distributed energy source. It is worthwhile to look into utilization of biomass as an energy source, particularly in countries like India, where nearly 60% of the population is involved in agro businesses, contributing up to 17% of the gross domestic product (GDP). Although, the technology to convert biomass to energy has been known for a while the efficiency of these processes are very low, which is preventing its wider consumer adaptation.

Overall India produces 686 MT crop residue biomass on annual basis of which only 352 MT is currently used as energy source. About, 234 MT are wasted, which can be utilized for energy generation[4]. The forecasted annual bioenergy from wasted crop residue biomass is 4.15 TJ, equivalent to 17% of India's total primary energy consumption[5, 6]. Tumuluru et al 2010 [7] reported that wood wastes, agriculture straws and grasses are the most prominent candidate for biomass energy source provided the energy conversion is in efficient manner. The common biomass feedstock for power generation in India includes sugarcane bagasse, rice husk, straw, cotton stalk, coconut shells, soya husk, coffee waste, jute wastes, groundnut shells, saw dust etc[8]. A variety of biomasses have been tested for bioenergy generation including woody biomass[9] and loose biomass such as rice husk [10], cashew nut shell [11], areca nut [12], sugarcane residue [13].

One of the major barriers to the widespread use of biomass is the lower energy content than traditional fossils fuels, which means that more fuel is required to get the same amount of energy. When combined low energy content with low density the volume of biomass required to generate equivalent amount of energy increases enormously[14]. To address this challenge, efforts are being made to increase the efficiency of energy generation. These efforts include the development of processing steps, like pyrolysis, gasification, fermentation, anaerobic digestion and briquetting, by which high value fuels for energy conversion can be produced.

Among these steps one most convenient step is densification. After densification, energy density of the biomass increases without changing its chemical composition. Grover, P.D et. al[15] reported that it is possible densify all kinds of biomass, which increases the energy density to a great extent. In the next section various densification techniques are described in detail.

1. BIOMASS DENSIFICATION:

Low density like 80-100kg/m^3 for Agriculture straws and grasses and 150-200 kg/m^3 for wood residue creates Major barrier for the biomass to be used as feedstock [16]. In addition the problem of storage, transportation and interface with biorefinery system makes the process uneconomical[14]. Above mentioned problem can be rectified by densifying the biomass that increases the density up to 10 fold,[17] providing number of advantages such as easy handling and conveyance efficiencies throughout the supply system of biorefinery system, particle size distribution in controlled manner, improved strength and conformance to pre determined conversion technology and supply system specification.[14,16] No. of densification technologies are available at present like pellet mill, briquette press, screw extruder, tabletizer and agglomerator[17].In this review greater emphasize has been given to densification technology, mechanism and parameters that actually affect the densification behavior of biomass.

2. MECHANISM OF DENSIFICATION

The complete densification occurs in three stages[18]

Firstly the particle rearrangement occurs that causes loss of energy due to inter particle and particle to wall friction followed by second stage of elastic and plastic deformation due to applied forces on the particles, resulting increased particle contact and formation of bonds through Vander-wall and electrostatic forces. In the final stage significant volume decrease occurs approaching true density of component ingredients.

The quality of densification depends on no. of parameters like pressure, die temperature ,die diameter, particle size, moisture content, preheating of biomass mix[18] .It has been reported that the pelletization depends on the ability of the particles to form pellets with suitable mechanical strength and the ability of the process to increase the density[19]. during agglomeration densification occurs due to formation of solid bridges[17],that are developed by chemical reaction and sintering solidification, hardening of the binder, hardening of the melted substances and crystallization of dissolved materials[17].The pressure applied during densification causes reduction in melting point of the particles, increasing the contact area .[17]

Biomass generally consist of cellulose, hemicelluloses, protein, starch, lignin, crude fiber, fat, and ash that influences the densification process.[19,20] During compression at high temperatures, the protein and starch plasticizes which acts as a binder. This binder assists in increasing the strength of the pellet. [19,20] At temperatures above 140°C Lignin in the biomass softens, improving the binding property of the particles.[20] Understanding the solid-type bridges formed during briquetting and Pelletizing is very much essential. Some efforts of microanalysis like Scanning electron microscopy have been done for understanding densification behavior of corn stover and switchgrass.[21] these micro level techniques like SEM and transmission electron microscope (TEM) are very useful in understanding intra-particle cavities, material properties, and process variable interactions on the quality attributes of densified biomass.

3. DENSIFICATION TECHNIQUES

3.1 Pellet mill

Fine ingredients of biomass can be converted into dense, durable pellets by Pelleting process [22-24].A pelletizer consist of a perforated hard steel die with one or two rollers. The feed stock is forced through the perforations by rotating the die and rollers to form densified pellets.[24]

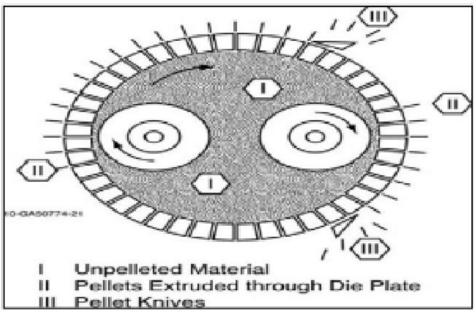

Fig.1 schematic of pellet mill[24]

First the biomass goes through the conditioner for the controlled addition of steam. The steam softens the feed and partially gelatinizes the starch to create more durable pellets. From the conditioner the fed is discharged over a permanent magnet and into a feed spout leading to the Pelleting die. Then friction driven rolls force the feed through the holes of the die as the die revolves. Cut off knives mounted on the swing cover cut the pellets as they are extruded from the die and finally the pellets fall through the discharge opening in the swing door.[24]Power consumption of the pellet mill falls within the range of 15-40 KWh/ton. [24]

3.2 Briquette Press

Briquetting is much more suitable than the pelletizing in order to handle large size particle and higher moisture content. Briquettes offer advantages of better feed handling, higher calorific value, reduced particulate emission, more uniform shape and size and improved combustion characteristics[24].In addition briquettes can be used in furnaces where other solid fuels like wood pellets are used. Briquetting is usually performed using hydraulic press, mechanical or roller presses[27] .

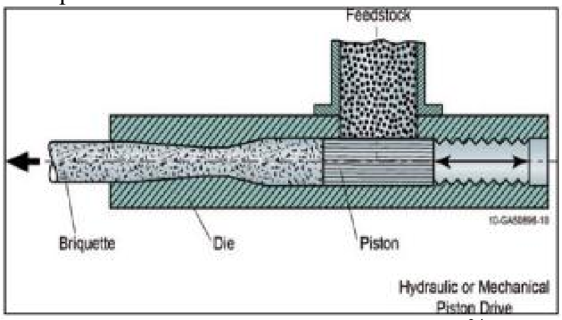

Fig.2 schematic of hydraulic press[24]

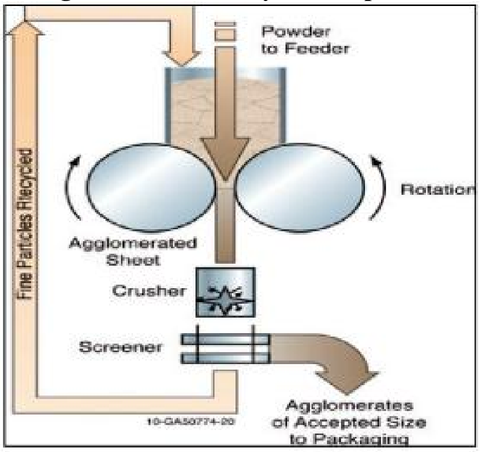

Fig.3 schematic of roller press[24]

Among all, mechanical presses are quite common in India; it provides several advantages like high density and greater output.

Table1.1 shows the comparative analysis of all type of briquetting presses

	Hydraulic press	Mechanical press	Roller press
Density	>1000 kg/m^3	<1000 kg/m^3	450-550 kg/m^3
Operating life	Less	High	Less
Production capacity	50-400 kg/hr	200-2500kg/hr	-
Return on investment	Low	High	Low
Moisture content tolerance	High	Low	-

3.3 Screw extruder

This technology provides advantage of high strength and high density compared to other technologies. During operation biomass is feeded into hopper which moves through the rotating screw and barrel against the die that increases the pressure and frictional resistance of the biomass, resulting in increased temperature[24] .The heated biomass is further extruded through the die to form briquettes.

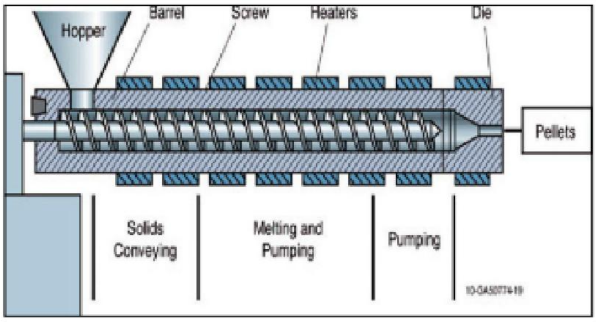

Fig.4 schematic of screw extruder[24]

3.4 Agglomerator

Agglomeration is a method of increasing particle size by gluing particles together .Application of agglomeration in biomass is limited[25].A granulation agglomerator involves the following steps:

- Fine raw material is continually added to the pan and wetted by a liquid binder
- The disc rotates causing the wetted fines to form small, seed-type particles (nucleation)
- The seed particles grow by coalescence into larger particles until they discharge from the pan.[26]

The complete process and process parameters has been shown in the Fig.5

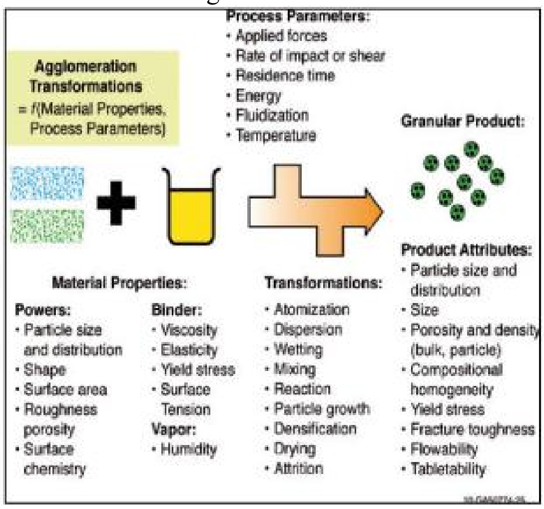

Fig.5 complete process of aglomeration[27]

4. DENSIFICATION SYSTEM VARIABLES

System variables can affect the quality and density of the briquetted biomass. According to a study process variables (pressure, temperature and geometry) and feedstock variables (moisture content, particle size) and feedstock composition play an important role in the quality of densified product.

4.1 Process variables

4.1.1 Temperature

Processing temperature affects the durability and density of briquettes .With increasing temperature pressure required for briquetting goes down[28].Also the maximum permissible moisture content can be increased with temperature rise[29].

4.1.2 Pressure

Pressure plays a very important role in densification. Lower pressure causes reduced density while higher pressure may cause fracture of the briquettes[30].Hence pressure has to be optimized. Butler and McColl[31] observed that increasing applied pressure significantly increases the unit density.

4.1.3 Retention and hold time

Holding time affects the quality of briquetts[32].Holding time affects more at lower pressure compared to the higher one[33]. A 10 s holding time could result in 5% increase in density, whereas at holding time greater than 20 s, the effect diminishes significantly. Final relaxed density of briquetted fuel and the relaxation behavior following removal from the die depend on many factors related to die geometry, the magnitude and mode of compression, the type and properties of the feed material, and storage conditions. Upon removal of material from the die the density decreases with time to final relaxed density[34-35] .For most feed materials, the rate of expansion is highest just after the removal of pressure and decreases with time until the particle attains constant volume[34-35].The relaxation characteristics is mainly measured by percentage elongation.

4.1.4 Die geometry and speed

Die shape and size affects the durability and density of briquettes. Durability depends on the L/D ratio of the die. For larger value of L pressure requirement increases while for lower D value pressure requirement goes down[37].The durability of pellets went up using smaller die with higher L/D ratio. According to a report the process parameter like die geometry, die size L/D ratio, die speed, the particle size of the biomass, steam conditioning has a significant effect on the durability of pellets. [38]Hill and Pulkinen (1988) [35] report that pellet durability of alfalfa increases by about 30–35% when Pelleting temperature increases from 60 to 104^{O}C. They also indicate that the L/D ratio between 8 and 10 is ideal for making high quality pellets. Heffiner and P.fost (1973) [36] evaluated the effect of three die sizes, 4.8 × 44.5, 6.4 × 57.2, and 9.5 × 76.2 mm, on durability, finding that the pellets produced on the smallest die have the best durability values. Tumuluru et al. (2010) [37], in their article on pelleting of distiller's dried grains with solubles (DDGS), reported that larger die diameters of 7.2 mm produce less-durable DDGS pellets as compared to a smaller one (of 6.4 mm), both with and without steam addition.

4.2 Feedstock variables

4.2.1 Moisture content

Moisture content can alter the property of densified product. Moisture content actually controls the starch geletisation, protein unfolding, and fiber solubalisation process during densification. biomass with low moisture content have better densification[38] .Koliyan and Morey[38] suggest that moisture in biomass affects the glass transition temperature ob components present in biomass. Mani et al[39] observed that moisture in the biomass during densification increases the bonding via vander wall's forcing. The overall effect of moisture can be summarized as following[40] :

- Lower the glass transition temperature
- Promotes solid bridge formation
- Increase the contact area of particles by van der wall's forces.

4.2.2 Particle size, shape and distribution

Densification and durability of pellets increases by reducing the particle size due to increased contact area. Medium or fine ground material has large surface area for moisture addition during steam conditioning, resulting better starch gelletisation [41]. Very small particles are not desired due to jamming in mill. [42]Whereas during briquetting larger particle size >6 mm are desirable for good interlocking**.**

5. PRE TREATMENT OF BIOMASS

For quality briquettes one should control the particle size and moisture content .This can be done by pre treatment of biomass. Pretreatment prepares lignocellulosic biomass and reduces the required energy consumption. Some promising pretreatment for biomass are: grinding, pre heating/steam conditioning, steam explosion and torrefaction.

5.1 Grinding

In previous sections we saw that particle size actually controls the durability and density of the product. [42] Grinding partially breaks the lignin, increases the surface area of the material and contributes to better binding. [43]

5.2 Preheating/steam conditioning

Moisture content can affect the durability and density of products and this moisture content can be controlled by preheating and steam conditioning. [45] Preheating could increase the throughput of densification and reduce the energy input. [46] In Steam conditioning steam is added to biomass to make the natural binder, lignin more available during densification**.**

5.3 Steam explosion

In steam explosion high pressure steam is introduced into a reactor for a short period of time and then released, causing the material to expand rapidly[47]. Compression and compaction characteristics can be improved by steam explosion. Steam explosion has also benefit in terms of enzymatic hydrolysis. The activation of lignin during steam explosion help in formation of new bonds, which in turn create more durable pellets.[48]

5.4 Torrefaction

Torrefaction is a phenomenon of slow heating of biomass in the inert atmosphere to a maximum temperature of 300 ^{O}C. Torrefaction removes most of the smoke-producing compounds and other volatiles, resulting in a final product that has approximately 70% of the initial weight and 80–90% of the original energy content.[49,50] The major decomposition reactions affect the hemicelluloses, and, to a lesser degree, the lignin and cellulose.[50,51].torrefaction improves the binding by increasing the number of available lignin sites, breaking down the hemicellulose matrix and forming fatty unsaturated structures increasing density.

6. CONCLUSION

India has a great amount of biomass residue. Densification technology can effectively utilize these abundant resources. Among all the available densification technologies pellets offers an added advantage of high density, easy handling, transportation and durability compared to others. Briquette press is more common in India while agglomeration, roller presses are still in infancy.

On one hand briquette press gives an edge due to larger particle size and high moisture content acceptance, while Screw press being capable of producing dense carbonized biomass, makes appropriate for co-firing and combustion.

Densification is dependent on process variables such as temperature, residence time and application pressure which needs to be optimized according to the application of end product as well as on feedstock variables like moisture and particle size. Retention time of 20s promised an improvement in density with an eye on machine capacity. Higher product density can be achieved by working at high pressure but at a cost of high initial setup cost.

Moisture content affects the glass transition temperature and solid bridge formation which increases the contact area of particles resulting good density. Particle size is an important criterion for selecting proper densification system as per material properties. Smaller particles are supported in pellet mill while briquette press needs larger particle. Proper characterization requires to be done to understand densification mechanism in detail. Studies on pre-treatment effect need to be carryout in detail to explore a relationship between specific energy consumption and densification behavior. High temperature studies on raw and preheated biomass needs to be done to analyze the effect of glass transition temperature on densification.

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