ISSN: 0976-3031

Available Online at http://www.recentscientific.com

CODEN: IJRSFP (USA)

International Journal of Recent Scientific Research
Vol. 8, Issue, 10, pp. 20561-20568, October, 2017

International Journal of Recent Scientific Research

DOI: 10.24327/IJRSR

Review Article

DENSIFICATION OF BIOMASS BY BRIQUETTING: A REVIEW

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DOI: http://dx.doi.org/10.24327/ijrsr.2017.0810.0916

ARTICLE INFO

Article History:

Received 06th July, 2017
Received in revised form 14th August, 2017
Accepted 23rd September, 2017
Published online 28th October, 2017

Key Words:

Biomass, Briquetting, Energy, Optimization, Technologies,

ABSTRACT

Great stress on energy demands has been imposed due to continuously increasing population, focusing all attention to alternate sources of energy. In this context, briquetting presents efficient utilization of biomass as a source of energy and fuel. The process of briquetting is based on the densification of loose biomass available as agricultural residues, municipal as well as paper waste etc. This leads to increased calorific value by the elimination of volatile matter and gives a solid fuel which is easy to transport and store and helps to curb environmental pollution also. This review has reported various technologies being used to make briquettes like screw extrusion, hydraulic press, piston presses etc. To popularize this technology, new machines and new challahs designs, optimization of different parameters like compression temperature, pressure, feedstock availability etc. has been discussed. Awareness can be imparted among people for maximum utilization of biomass briquettes to save fuel for future and for sustainable energy production.

INTRODUCTION

With the continuously growing population around the world, the demand for energy is becoming critical challenge for the world's energy leaders. In the last three decades, global energy consumption has almost doubled due to global economic growth, continued urbanization, as well as the increased demand on mobility and other energy dependent services (ChristophFrei *et al*., 2013). On the other hand, reliance on fossil fuel is hampered by continuous escalation of prices, depleting oil reserves and greenhouse effects. This anticipated crisis of increasing energy demand and environmental issues has prompted the exploitation of renewable energy resources that can be used to produce energy again and again, e.g. solar energy, wind energy, biomass energy, geothermal energy, agricultural residues etc. (Islam *et al.*,2008; Himraj 2003). These energy sources are available indigenously and are known as alternative sources of energy. This form of energy is clean or inexhaustible and can decrease the environmental pollution but this is still under-utilized due to the handling, transportation, storage and combustion issues (Matiru, 2007).

Biomass

Among different renewable sources, biomass energy is versatile as it can be produced in gaseous form (gas and biogas), liquid form (alcohol) and solid form (charcoal and briquettes) by adding value to commercialization. Biomass can be defined as all renewable organic matter including plant materials, animal products and manure, food processing and forestry by products, and urban wastes etc. with highly different properties to be used as fuels.

Energy obtained from biomass is not site specific, thus can be established at any place where plant and animal waste is available. Biomass energy is in the right path for adopting a holistic approach in the promotion of energy recovery in renewable energy. Lower percentage of carbon and a higher percentage of oxygen in biomass result in a lower heating value per unit mass of biomass compared with fossil fuels. This means that more biomass fuel must be handled and processed to obtain an equivalent unit of usable energy. Biomass has miscellaneous advantages such as easily finding, low price, carbon dioxide neutral feature, and very high worldwide potential. Agricultural and forest residues, industrial wastes, municipal solid wastes (MSW), and refuse derive fuels (RDF) are the well-known types of the biomass energy resources which are numerous in number (Paist *et al.,* 2005). However, direct combustion of biomass has negative aspects due to the intrinsic properties such as low density, low calorific value in a unit volume, and high moisture, etc. So, it is important to develop strategies to convert biomassto secondary fuels having better characteristics in comparison to the parent material. Moreover, to reduce the environmental pollution risks of such fuels, some precautions must be taken.Biomass-derived

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cooking fuels are used by more than three billion people worldwide but has drawbacks including health hazards, negative environmental effects, and perpetuation of poverty (IEA,2011).

In this context, production of smokeless fuel briquettes from biomass having quite high calorific value to take advantage of the energy potential of biomass in environmental friendly way.

Briquetting

Briquetting is densification or compaction of residues into a product of higher density than the raw materials. It can be used either for heat generation in households and small scale home industries, or even for power generation in large industries (Kaliyan and Morey, 2008). The fuel briquettes produced depends on the locally available materials which may be sugarcane bagasse, charcoal dust, coffee husks, gum Arabica, tree leaves, water hyacinth, rice husks, sawdust and other wood residues or agricultural by-products (Rousseta *et al*., 2011). In China agricultural by-products like rice straw and rice bran are used in briquette production (Chou *et al*., 2009), maize cobs in Thailand (Wilaipon, 2007) and coffee husks in Brazil (Felfli *et al*., 2010). Briquettes could serve as compliments to firewood and charcoal for domestic cooking and agro-industrial operations, if produced at low cost and made conveniently accessible (Wilaipon, 2008).

Briquettes are held together by a binding agent or "binder". This binding material can be any partially decomposed fibrous organic material, to release the fibers necessary to physically hold the briquette together. Various advantages and disadvantages have been experienced throughout the world. The main difficulty has been the fact that, in many places, briquettes are too high in cost to compete with existing wood fuel (GaniyuTajudeen, 2007). Briquette could be made of different shapes and sizes depending on the mouldand are normally cylindrical or rectangular in shape (Garriot, 2004). The appearance, burning characteristics of briquettes depend on the type of feedstock and the level of compactness and the mould used (El-Saeidy, 2004; Wilaipon, 2009).

Need For Briquetting

Direct burning of agricultural residues is very inefficient due to the transportation, storage and handling problems associated (Pallavi *et al*., 2013).Whereas, briquettes provides a sustainable approach for improved and efficient utilization of agricultural and other biomass residues (Li and Liu, 2000).

Moreover, briquettes have many advantages as fuel over raw biomass in terms of the convenience of storage and transport (Kaliyan and Morey, 2009), the ease of charging the furnace, increase in CV (Wilaipon, 2008), improvement of gasification characteristics, reduction of entrained particulate emissions, uniformity in size and shape, good substitution for natural fuels (Ndiema *et al*., 2002) and world-wide availability, especially in the less developed countries and use of low cost machinery. It lowers overall fuel costs for users as they are made from biomass waste. Finally, briquetting process provides job opportunities (El-Saeidy, 2004). According to Pallavi *et al.* (2013), other notable advantages of using briquettes are saving time and decreasing local deforestation rates.

History of Briquetting

Most civilization used the technique of compaction of loose combustible material for fuel-making purposes (Wilaipon, 2008). Potential of briquettes was discovered during the First and Second World Wars for heat and electricity production, using simple technologies i.e. lever operated preses (Yadong and Henry, 2000). In Europe and America sawdust and other waste materials were densified under the impact of fuel shortages. Screw extrusion briquetting technology was invented and developed in Japan in 1945 and by April 1969, there were 638 plants in Japan (Grover and Mishra, 1996). Simple methods like baling or drying were used. Industrial methods of briquetting started in second part of the 19th century. Today's much larger and more complex industrial briquetting machines, although, operate on the same principle (Lardinois and Klundert, 1993).

Initially briquetting was a failure due to; inappropriate briquetting machinery, non-availability and high cost of the briquetting machines' spare parts, poor projects' planning and implementation where free supply of raw materials was assumed, low local prices of firewood and charcoal which inhibited the marketing of briquettes and unacceptability of briquettes in the household sector due to their ignition difficulties and smoke generation which caused indoor pollution, little involvement of the private sector and early withdrawal of donor as well as lack of government financial support.

Principle and Technology

Briquetting is the mechanical treatment to upgrade the loose biomass into a higher density and uniform solid fuel via compaction with resulting product of higher density, energy content and less moisture compared to its raw material. It represents a set of technologies for the conversion of biomass into a fuel (Toan *et al*., 2000). The high pressure and temperature simultaneously act upon the mass, the cellular structures within the material release lignin, which binds individual particles into a compact unit-briquette (Chaney, 2010). The idea of briquetting is to use materials that are not otherwise usable due to a lack of density, compressing them into a solid fuel of a convenient shape that can be burnt like wood or charcoal (Adekoya, 1989). Different type of wastes like milled paper, plastic and other combustible wastes can be used (Yaman *et al*., 2000).

Depending on the type of material, the pressure applied and the binder used, different binding methods are used. The binding mechanism of biomass under high pressure can be divided into adhesion and cohesion forces, attractive forces between solid particles, and interlocking bonds (Rahman *et al*., 2003). Application of high pressure on biomass, results in mechanical interlocking and increased adhesion/cohesion (molecular forces like van der Waal's forces) of the solid particles, which form intermolecular bonds in the contact area (Moral and Khan, 2004; Moral and Rahman, 2001). This is executed by briquetting presses. According to FAO (1990), briquetting could be categorized into five main types depending on the types of these presses used; piston presses, screw presses, roller press, pelletizing, manual presses and low pressure briquetting (Singh *et al.,* 2007). On the basis of pressure used, briquetting technologies can be divided into: high pressure compaction, medium pressure compaction assisted by a heating device and low pressure compaction with a binding agent (Wilaipon, 2009).

High and medium pressure compaction

It does not use any additional binder and the energy usage is also low. In this, for the Screw Press Compress, the Biomass is extruded nonstop by the screw through a hot and taper block. For Piston Press Compress, the hardness at the touch part and block part is less in comparison to the screw and block for Screw Press type. From quality aspect, the briquetting and production procedure for Screw Press is better than Piston Press type. The center of pore that is associated with briquetting process from Screw Pressure help in achieving the perfect and flat burning. So, this briquette can be carbonized.

Screw press

Screw extrusion briquetting machines are suitable for small-scale applications. The central hole incorporated into the briquettes produced by a screw extruder helps in better combustion characteristics due to a larger specific area. The briquettes produced are homogenous and do not disintegrate easily showing a higher quality (Tabil, 1997). Having a high combustion rate, these can substitute for coal in most applications and in boilers. These briquettes can be produced with a density of 1200Kg/m^3 from loose biomass of bulk density 100 to 200 Kg/m^3. A higher density gives the briquette of higher heat value (KJ/Kg), and makes the briquettes burn more slowly as compared to the raw materials (Kaliyan and Morey, 2009; Singh *et al*., 2007). Here, the speed of densification, the energy consumption of the press and the quality of the briquettes produced depend on: flow ability and cohesion of the feed material, particle size and distribution, surface forces and adhesiveness. Screw presses are basically of three types: Conical screw press, screw press with heated dies, and screw press without heated dies (Grover and Mishra, 1996). The merits and demerits of this technology are:

- Continuous output and uniform sized briquettes.
- Partially carbonized outer surface of the briquette, facilitating easy ignition, combustion and protection from ambient moisture.
- Smooth run without any shock load.
- Light weight due to absence of reciprocating parts and flywheel.
- No contamination of machine parts and the oil used.
- The power requirement of the machine is high compared to that of piston press.
- Wear and tear is high.

Piston press

This type of press acts in a discontinuous mode. In this material is fed into a cylinder, compressed by a piston into a slightly tapering die. Then the compressed material is heated by frictional forces as it is pushed through the die either mechanically by a reciprocating ram powered by a massive flywheel, or by a hydraulically driven piston. The production rate of these machines is between 25-1800 kg/h, depending on the press canal diameter, the kind of materials pressed, and their properties. Piston presses are basically of two types: mechanical and hydraulic piston presses. Hydraulically operated machines apply pressure not only in longitudinal but also in radial direction where the energy to the piston is transmitted from an electric motor via a high pressure hydraulic oil system unlike the mechanical piston press. It is compact and light and results in lower outputs due to the slower press cylinder compared to that of the mechanical machine. This machine can tolerate higher moisture content than the usually accepted 15% moisture content for mechanical piston presses (Grover and Mishra, 2006). The merits and demerits of this technology are:

- Wear of the ram is considerably reduced due to less relative motion between the ram and the biomass.
- Most cost-effective technology.
- Briquettes are somewhat brittle as the carbonization of the outer layer is not possible

Below is the list of the differences between Piston Press and Screw Press.

Low pressure compaction

A binding agent is needed in low pressure briquetting to assist the formation of bonds between the biomass particles. Binders can be film binders (tar, petroleum asphalt and Portland cement), matrix binders (coal, and sodium silicate) and chemical binders (pitch water, sodium silicate and lingosulfonates). Otherwise these binding agents can be divided into two main groups: organic and inorganic binders, which are:

- ***Organic binders:*** Molasses, Coal tar, Bitumen, Starch, Resin
- ***Inorganic binders:*** Clay, Cement, Lime, Sulphite liquor

Here subsequent curing (drying, burning, chemical reaction, etc.) is required after compaction to provide the “green” briquettes with required strength and stability.

Hand moulded briquettes

Small quantities of briquettes can also be made by hand moulds. Here sun drying or a gentle heat treatment in a curing furnace is required to form strong briquettes due to the property of binders in building up hydrogen bonds among themselves and the biomass (Vest, 2003). In China, ground coal is mixed with water and approximately 20% of clay binder to form honeycomb briquettes by a mechanized briquetting press and then sun drying. In Kenya and Benin, biomass offine particle size (saw dust, rice husks, wood shavings, charcoal dust, etc.) is mixed with approximately 20% of (waste) paper pulp to form briquettes in a manually operated piston press.

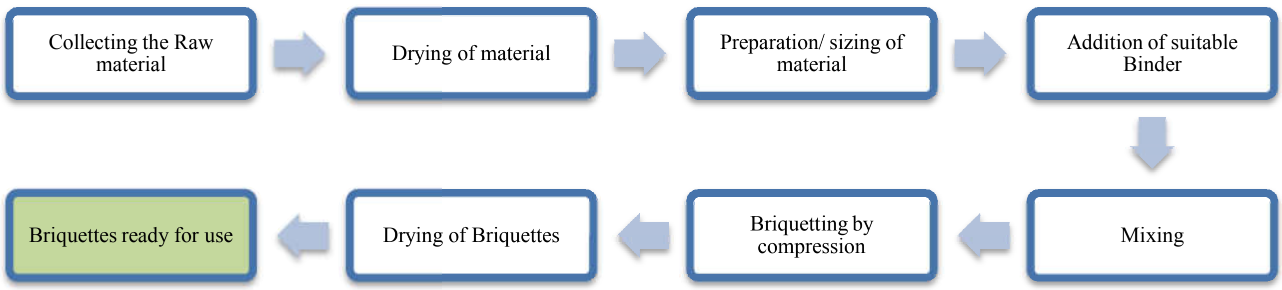
However, plastic and municipal waste cannot be converted into the briquette in the same way as it does not contain a great amount of biological materials such as lignin to act as a natural binder. Thus a higher pressing temperature and compacting pressure should be applied (Ndiema *et al*., 2002; Husain *et al*., 2002).

Production Process

The briquetting starts with the collection of the residues followed by size reduction, drying and compaction by extruder or press. It can be binder or binderless. Binderless briquetting requires sophisticated and costly presses and drying equipment

(Tabil, 1997). Firstly sorting or sieving is done to remove all unwanted materials with a wire mesh to ensure that all the feedstock is of the required size. Bulky feedstock like groundnut waste, bagasse, wheat straws, barley, maize straws and cobs, biomass material is chopped into small pieces to enhance the workability and compactness. In multi-feedstock, mixing is done to optimize the burning characteristics of the final fuel. E.g. Biomass materials with variable ash contents, variable energy content etc. This helps to attain the right quality such as long burning period, non-smoking and odor free. Water is usually added to the feedstock to make them loose and easy to work on. Some biomass materials require to be soaked in water for a number of days to ensure that they are soft enough to work on (Musa, 2007). Finally, the feedstock is ready for compaction, either by machine or by hand. This will be followed by ejection from the mould after some dwell time has been observed (Oladeji, 2011). Thereafter, the briquettes are left to dry for up to a week (Wilaipon, 2008).

- ***Bagasse/bagasse pith:*** high moisture content of 50% after milling, hence drying is energy intensive, low ash content and a correspondingly high heating value of the order of 4400 kcal/kg.
- ***Pith:*** does not require milling, available from sugar mills at much lower costs.
- ***Coffee husk:*** low ash and 10 % moisture content.
- ***Mustard stalks:*** Like cotton sticks, it is also an appropriate material for briquetting.
- ***Others:*** lentil stalks, sawdust, and *Lantana camara* in hilly areas, tea wastes, and coir pith, wheat straw; *Jatrophacurcas* (Singh *et al.,* 2008); woods (Fapetu, 2000a); cotton (El-Saeidy, 2004; Singh, 2006); banana peel and so on.
- Already processed materials such as paper, sawdust and charcoal fines (Fapetu, 2000b; Wilaipon, 2007; Oladeji*et al.*, 2009).



Process Flow Diagram for Briquetting

Characteristics of Bio-Briquettes

Briquetting of biomass depends on the feed parameters influencing the extrusion process. For different briquetting machines, these feed parameters like their particle size, moisture content, density, compressive strength and temperature are different (Obernberger and Thek, 2004). Briquette hardness and thereby briquette quality can be checked by water test, where a quality briquette should fall to the bottom in a moment due to its higher specific density than water (Križan, 2007).

Feedstock quality

Availability of feedstock in large quantities, ability to bond together when compressed,low moisture content (10-15 percent), granular and uniform size so as to flow easily in bunkers and storage silosetc. are important factors for selection of biomass (Rahman, 2001). Some of the appropriate agro-residues with their properties are:

- ***Rice husk (Pathak and Singh, 2000):*** good flow ability, normally 10 % moisture, ash with fewer alkaline minerals; thereby high ash sintering temperature, however its calorific value is less than wood and other agro-residues.
- ***Groundnut shell:*** Low ash (2-3%) and moisture content less than 10%
- ***Cotton sticks:*** higher content of alkaline minerals and needs to be used with caution.

Pretreatment and size reduction of the raw material

It prepares the raw biomass for briquetting. Size reduction of raw biomass enables to obtain better properties of the product by drying, mixing and briquetting (Mani *et al*., 2006; Gilbert *et al*., 2009). Biomass material of 6- 8 mm size with 10-20% powdery component gives the best results (Kaliyan and Morey, 2009). However, coarse particles need a higher compacting power and cause low homogeneity and stability. Size reduction is achieved by two-shaft and four-shaft shredders and their combination with single shaft shredders and their productivity depends on the dimensions of the machine, rotation velocity, size and shape of the input fraction. Finally mixing the pretreated biomass with suitable binders leads to better briquette pressing as well as to greater calorific value.

Moisture content

The percentage of moisture in the feed biomass to extruder machine is a very critical factor. Feed moisture of 10-12% produces briquettes of 8-10% moisture and such briquettes are strong and free of cracks (Grover and Mishra, 1996). Moisture content more than 15%, produces poor and weak briquettes (Kaliyan and Morey, 2009). It is necessary to establish the initial moisture content of the biomass feed to maintain equilibriumand thus to avoid swelling of briquette during storage, transportation and disintegration, when exposed to humid atmospheric conditions (Mani *et al*., 2006).

External additives

To upgrade the specific heating value and combustibility of the briquette, certain additives like starch, gum arabica, soil, animal dung or waste, charcoal, wood, paper waste and coal are added in very fine form. About 10-20% char fines can be employed in briquetting without impairing their quality (Rousseta *et al.,* 2011). The density also increases with binder ratios and is influenced by type and amount of binder. They can improve the mechanical strength and the energy content like calcium carbonate, beach sawdust, ash chipping, nut shell, rice shell, husks of grape-vine and cuttings of grape-vine etc.. Lignin of such additives acts as stabilizer of cellulose molecules in the cell wall. The more lignin the material contains the more of it can be released to produce briquettes with higher quality. The briquettes with additives are compact, no crumbling, no cracking in drying phase, and it is possible to cut and engrave them. Briquettes bonded with molasses show higher density than with cow dung and clay binder as molasses give a better gluing effect of adjacent particles resulting in stronger bonds hence minimal expansion of briquettes after extrusion.

Calorific Value

Binder types and amount have effects on the calorific value of briquettes. Rotich (1996) obtained calorific value of 17.6- 18.1 MJ/kg for rice husk briquettes while (Wilainpon, 2007; Ivanov *et al.,* 2003) found 14.1 MJ/kg and 24-27 MJ/kg for maize cobs and lignite briquettes (with bio-binder), respectively. Molasses bonded briquettes had higher calorific values than cow dung and clay and fulfilled the requirement for making commercial briquettes which the calorific value should be more than 17.5 MJ/kg.

Ash content and composition

Biomass residues normally have much lower ash content (except for rice husk with 20% ash) but their ashes have a higher percentage of alkaline minerals, especially potash (Grover and Mishra, 1996). Slagging can take place with biomass fuels containing more than 4% ash and non-slagging fuels with ash content less than 4%. According to the melting compositions, they can be termed as fuels with a severe or moderate degree of slagging.

Pressing temperature

Temperature of biomass affects the briquette density, briquette crushing strength and moisture stability. In a screw extruder, the temperature changes due to local heating caused by friction in the axial direction of the press. The moisture present in the material forms steam under high-pressure conditions, which then hydrolyses the hemicelluloses and lignin portions of biomass into lower molecular carbohydrates, lignin products, sugar polymers and other derivatives. Heating of the material for a determined temperature also yields a more stable product with a lower recovery of original dimensions (El-Saeidy, 2004). However, the temperature should not be increased beyond the decomposition temperature of biomass (300°C).

Compacting pressure

Strength of briquettes increases with the increase of the pressure to the strength limit (Approx. 150-250 MPa) of the compacting material. Increased strength causes low absorption of atmospheric humidity and thus increases the briquette durability. The briquettes manufactured at lower pressures (30-60 MPa) fall to pieces. Different parameters affect the compacting pressure e.g., Feedstock, temperature of pressing chamber, temperature, dimensions (length, diameter) and shape of the pressing chamber and the compacting procedure.

Density

Density is an important parameter to characterize the briquetting process. Higher density leads to higher energy/volume ratio which is desirable in terms of transportation, storage and handling. Briquettes with higher density have a longer burning time. The standards define the interval of briquette density values from 1 to 1.4 kg/dm^3 (g/cm^3) (Lehtikangas, 2001). The density of bio waste briquettes depends on the density of the original bio waste, the briquetting pressure and, to a certain extent, on the briquetting temperature and time.

Quality Parameters in Briquetting

Ignition Time

The average time taken to achieve a steady glowing flame due to volatility is known as ignition time. It increases with the amount of binders which is attributed to increase in density due to better bonding. This increased bonding results in lowporosity thus, reducing the infiltration of oxidant and outflow of combustion products during combustion. The ash produced slows down the flame propagation and combustion rate due to its low thermal conductivity and density (Oladeji, 2010). Low porosity of briquettes also hinders drying, devolatization and char burning processes due to fewer free spaces for mass diffusion.

Burning Time

Burning duration of briquettes increases with amount of binder due to the increase in density resulting in reduced porosity. Similar to ignition time, reduced air gap between the adjacent particles inhibits the flame propagation due to low thermal conductivity. This variation can be attributed to the incombustible matter and low volatile matter. According to Chaney (2010), combustion rate of briquettes is also influenced by density due to reduced porosity which tends to hamper the rate of infiltration of oxidant and outflow of thecombustion products during combustion.

Combustion properties and chemical analysis of briquettes

The combustion properties include ash content, calorific value and volatile matter. Briquette and biomass as a control can be analyzed using Infrared (IR) Spectroscopy (Shepherd and Walsh, 2007). Multiple elements can be analyzed using micro analyzers and total x-ray fluorescence (TXRF) spectrometers to establish presence and possible sources of heavy metal contamination in briquettes (Stosnach, 2005).The concentration of carbon monoxide (CO), fine particulate matter (PM 2.5) and carbon dioxide (CO_2) are measured from burning an amount of fuel that fills the small-sized energy saving cook stove as practiced by households.

Applications

Briquettes have both domestic as well as small industrial cottage applications for heating, combined heat and power

(CHP) and electricity generation in many countries (Ahmed *et al*., 2008). These are often used as a development intervention to replace firewood, charcoal, or other solid fuels. Briquettes fill the gap of current fuel shortage and ever rising prices as affordable alternative fuels for:

- Cooking and water heating in households
- Heating productive processes such as tobacco curing, tea drying, poultry rearing etc.
- Firing ceramics and clay wares such as improved cook stoves, pottery, bricks etc.
- Fuel for gasifiers to generate electricity
- Powering boilers to generate steam Social inclusion of unemployed youth and women
- Public participation in urban cleanliness and the conservation of tree and forest cover.

In countries like United States of America, Australia, Japan, Korea, Taiwan and countries of European Union, biomass briquettes are also used for other fueling purposes (Rousseta *et al*., 2011; Gominho *et al*., 2012).

Limitations

There are some limitations to the briquetting technology. Firstly, briquettes can only be used as solid fuels and have no application as liquid fuel such as the being used in internal combustion engines (Grover and Mishra, 1996). Cost of screw of die screw press and its repair are also one of the major barriers to further dissemination of briquetting technology (Moral and Nawasher, 2004). Covered storage facility to avoid any water contact is required for briquettes, which adds to the cost. Low carbon content of briquettes limit the maximum attainable temperature to 1000°C which is not sufficient for industrial applications (Oladeji, 2011). The burning efficiency per unit volume of briquettes is low in comparison to coal, so a larger storage area is required. The bonding properties of the briquettes do not significantly improve above a typical pressure plateau (Ndiema *et al*., 2002). Chin *et al*. (2000) found a distinct pressure plateau at approximately 4,000 kP a above which the improvement in briquette properties became minimal for sawdust, rice husk, peanut shell, coconut fiber, and palm fiber as briquetting materials. Not every bio waste is suitable for briquetting, even under high pressures, e.g. olive refuse (Yaman *et al*., 2000). The high capital investment and maintenance expertise associated with industrial briquetting is also a big limitation for the popularization of this technology (Grover and Mishra, 1996).

Future Prospective

Fewer studies have focused on low pressure briquetting achievable during hand pressing. More precise and reliable data on appropriate feedstock for briquetting is needed to evaluate the implications on agro-ecosystems and the environment. Production and utilization methods are inefficient and there is need for more data on their cost-effectiveness and sustainability. Optimization of types of feedstock and mixing ratios between raw material and binders and emission characteristics of fuel briquettes is needed. Improved physical characteristics of fuel briquettes are important in handling and transportation. Central and local government authorities need to provide assistance to community types of small Enterprises, enabling them to better access resources and market opportunities. Government involvement through development of supportive policies and regulations such as provision of tax incentives to private companies for establishment of briquetting plants based on utilization of biomass waste is an important for sustainable briquette production. Further action research on appropriate production and utilizations processes is required. These include technologies with high biomass conversion rates and low gas emissions, such as improved kilns and cooking stoves.

CONCLUSION

Briquettes also called "smokeless fuel" is high calorific value product which can be easily transported and stored due to densification of biomass. Being a non-polluting solid fuel, it is competitive with coal with respect to calorific value. Briquetting technology using various waste materials should be popularized as an alternative to address the modern world energy issues as it is an efficient, cost effective and easy to duplicate technology. Appropriate briquetting machine suitable to the local communities, for biomass to make a significant impact as fuel for rural communities needs to be developed.

References

Adekoya L.O., (1989) "Investigations into Briquetting of Sawdust" The Nigerian Engineer. 24(3):.1-10

Ahmed S., Rahman M.M., Islam M.M., Mashud M., Nawsher M. and Ali M., (2008) "Moral Role of Biomass Briquetting in the Renewable Energy Sector and Poverty Diminution for Bangladesh" Proceedings of the 4th BSME-ASME International Conference on Thermal Engineering 27-29 December, 2008, Dhaka, Bangladesh

Chaney J., (2010) Combustion Characteristics of Biomass Briquettes. Ph.D. Thesis Submitted to University Nottingham.

Chin O.C. and Siddiqui K.M., (2000) Characteristics of some biomass briquettes prepared under modest die pressures. Biomass and Bioenergy 18(3): 223-28.

Chou C.S., Lin S.H., Lu W.C., (2009) Preparation and characterization of solid biomass fuel made from rice straw and rice bran. *Fuel Process Tech* 90: 980-87.

ChristophFrei *et al*. (2013) World Energy Council, World Energy Issues Monitor Report: 2.

El-Saeidy E.A., (2004) "Technological Fundamentals of Briquetting Cotton Stalks as a Bio-fuel" An Unpublished Ph.D. Thesis, Faculty Agriculture and Horticulture, Humboldt University, Germany

FAO., (1990) The briquetting of agricultural wastes for fuel. Food and Agriculture Organization of the United Nations, ViadelleTreme di Caracalla, 00100 Rome, Italy: 2-33.

Fapetu O.P., (2000a) "Management of Energy from Biomass" Nigerian Journal of Engineering Management 1: 14-19

Fapetu O.P., (2000b) "Production of charcoal from Tropical Biomass for Industrial and Metallurgical Process" *Nigerian Journal of Engineering Management* 1(2): 34-37.

Felfli F., Juan M., Mesa P., Rocha J., Filippetto D., Luengo C., Pippo W., (2010) Biomass briquetting and its perspectives in Brazil. *Biomass and Bioenergy*: 1-7

GaniyuTajudeen (2007). Design and Construction of Briquetting Machine with Slicer 1: 1-2

Garriot G., (2004) Agricultural Report-Briquetting Available at http://www.Vitiorgy/

Gilbert P., Ryu C., Sharif V. and Switchenbank J., (2009) "Effect of processing parameters on pelletisation of herbaceous crops" *Fuel* 88:1491-97

Gominho J., Lourenco A., Miranda I., Pereira H., (2012) Chemical and fuel properties of stumps biomass from Eucalyptus globulus plantations. *Ind Crop and Prod* 39: 12-16

Grover P. and Mishra K., (2006) Development of an Appropriate Biomass Briquetting Technology Suitable for Production and Use in Developing Countries. *Biomass Conversion Technology Journal*1:45-48.

Grover P.D. and Mishra S.K., (1996) Biomass Briquetting: Technology and Practices. Food and Agriculture Organization of the United Nations: Bangkok.

Himraj D., (2003) Fuel Substitution in Sub Sahara Africa. Journal on Environmental Management 17:283-88

Husain Z., Zainac K. and Abdullah Z., (2002) Briquetting of Palm Fibre and Shell from the Processing of Palm Nuts to Palm Oil. *Journal on Biomass and Bio Energy* 22: 505-09.

International Energy Agency (2011).World Energy Outlook.Technical report, International Energy Agency.

Islam R.F., Islam R.M. and Beg R.A., (2008) Renewable energy resources and technologies practice in Bangladesh. *Renewable and Sustainable Energy Reviews*12:299-343.

Ivanov J., Sudakova G. and Kuznetov B., (2003) Manufacture of Briquetted and Granulated Fuels from Lignite with Bio binders and Heated Die. *Journal on Chemistry for Sustainable Development* 11:847-52.

Kaliyan N. and Morey R.V., (2009) "Factors affecting strength and durability of densified biomass products" Biomass and Bio-energy 33:337-59

Križan P., (2007) Research of factors influence on quality of wood briquettes, *Journal Acta Montanistica Slovaca* 12(3): 223-30.

Lardinois I., Klundert A., (1993) Organic Waste: Options for Small-Scale Resource Recovery Urban Solid Waste Series1. Amsterdam, The Netherlands: TOOL: 50-61.

Lehtikangas P., (2001) Quality properties of pelletized sawdust, logging residues and bark. *Biomass and Bioenergy* 19:351-60.

Li Y. and Liu H., (2000) "High-pressure Densification of Wood Residues to Form an Upgraded Fuel" *Biomass and Bio-energy* 19: 177-86

Mani S., Tabil L.G. and Sokhansanj S., (2006) "Effects of Compressive Force, Particle Size and Moisture Content on Mechanical Properties of Biomass Pellets from Grasses" *Biomass and Bio-energy* 97: 1420-26

Matiru V., (2007) Forest Cover and Forest Reserve Cover in Kenya Policy and Practises. Oxford Press, Nairobi, Kenya.

Moral M. and Nawasher A., (2004) "Briquetting of Biomass in Bangladesh", Proceedings of World Renewable Energy Congress VI (WRE C 2000) pp. 2402-05 held at Briton, U.K. on 1-7 July 2004

Moral M.N.A. and Khan K., (2004) Biomass Briquetting Machine (Electrical and Diesel System) Design, Construction and Operational Manual, Bangladesh Institute of Technology (BIT) Khulna, Khulna, Bangladesh

Moral MNA and Rahman MM (2001) "Biomass for Briquetting"-In Training workshop on Reverse Engineering, Dhaka, Bangladesh 98-118

Musa N.A., (2007) "Comparative Fuel Characterization of Rice Husk and Groundnut Shell Briquettes" NJRED 6(2): 23-26.

Ndiema C., Manga P. and Ruttoh R., (2002) Densification and Characteristics of Rice Straw Briquettes. *Journal of the Institute of Energy* 75:11-13.

Ndiema C.K.W., Manga P.N. and Ruttoh C.R., (2002) Influence of die pressure on relaxation characteristics of briquetted biomass. *Energy Conversion and Management* 43(16): 2157-61.

Obernberger I. and Thek G., (2004) "Physical Characterization and Chemical Composition of Densified Biomass Fuels with regard to their Combustion Behavior" *Biomass and Bio-energy* 27:653-69

Oladeji J.T., (2011) "The Effects of Some Processing Parameters on Physical and Combustion Characteristics of Corncob Briquettes" Ph.D. Thesis of the Department of Mechanical Engineering, LadokeAkintola University of Technology, Ogbomoso, *Nigeria Journal of Energy Technologies and Policy* www.iiste.org ISSN 2224-3232 (Paper) ISSN 2225-0573 (Online) 5(3): 2015

Oladeji J.T., Enweremadu C.C. and Olafimihan E.O., (2009) "Conversion of Agricultural Wastes into Biomass Briquettes" *IJAAAR* 5(2): 116-23

Oladeji M., (2010) Fuel Characterization of Briquettes Produced from Corncobs and Rice Husk Residues. *The Pacific Journal of Science and Technology* 11: 101-06.

Paist A., Kask Ü., Kask L., Vrager A., Muiste P., Padari A. and Pärn L., (2005) Potential of biomass fuels to substitute for oil shale in energy balance in Estonian energy sector. *Oil Shale* 22: 369-80.

Pallavi H.V., Srikantaswamy S., Kiran B.M., Vyshnavi D.R. and Ashwin C.A. (2013) "Briquetting Agricultural Waste as an Energy Source" *Journal of Environmental Science, Computer Science and Engineering & Technology* 2(1): 160-72.

Pathak B.S. and Singh A., (2000) "Husk utilized as fuels" AMA, Japan 19(3): 65 - 70.

Rahman M.A., (2001) "Economic and Social Commission for Asia and the Pacific"- In Regional Seminar on Commercialization of Biomass Technology, Guangzhou, China

Rahman M.M., Khan K., Moral M.N.A. and Rahman A.N.M., (2003) "Biomass Briquetting Technology and Environmental Pollution"- In The role of Renewable and Alternative Energy Sources for National Development, Khulna University of Engineering and Technology (KUET) and Asian Institute of Technology (AIT), Khulna, Bangladesh. 24-30

Rotich (1996) Carbonization and Briquetting of Sawdust for use in Domestic Cookers. M.Sc. Thesis, Department of Agricultural Engineering, University of Nairobi, Kenya.

Rousseta P., Caldeira-Piresb A., Sablowskic A., ThiagoRodriguesd T., (2011) LCA of eucalyptus wood charcoal briquettes. *J Cleaner Production* 19(14): 1647-53

Shepherd K., Walsh M., (2007) Infrared spectroscopy-enabling an evidence-based diagnostic surveillance approach to agricultural and environmental management in developing countries. *J Near Infrared Spec*15: 1-19.

Singh M., (2006) "Economics of Bio-fuels for the Transport Sector in South Africa" *Energy for Sustainable Development* 10(2): 40-47

Singh R.N., Bhoi P.R. and Patel S.R., (2007) Modification of commercial briquetting machine to produce 35 mm diameter briquettes suitable for gasification and combustion. *Renewable Energy* 32: 474-79.

Stosnach H., (2005) Environmental trace-element analysis using a benchtop total reflection X-rayfluorescence spectrometer. *Anal Sci* 21: 873-76.

Toan P.K., Cuong N.D., Quy N.T. and Singh P.K., (2000) "Application of Briquetting Technology to Produce Briquetties from Agricultural Residues and Bye-products"- In World Renewable Energy Congress (WREC), UK

Vest D.I.H., (2003) Small Scale Briquetting and Carbonisation of Organic Residues for Fuel: 1-8.

Wilainpon P., (2007) The Effect of Moderate Die Pressure on Maize Cob Briquettes. *Journal on Energy Conversion and Management* 43: 167-74.

Wilaipon P., (2007) Physical characteristics of maize cob briquette under moderate die pressure. *American Journal of Applied Science* 4: 995-98.

Wilaipon P., (2008) "The Effect of Briquetting Pressure on Banana-Peel Briquette and the Banana Waste in Northern Thailand". *American Journal of Applied Sciences* 6(1): 167-71.

Wilaipon P., (2009) "Density Equation of Bio-Coal Briquettes and Quantity of Maize cob in Phitsanulok, Thailand" *American Journal of Applied Sciences* 5(12):1808-11.

Yadong L. and Henry L., (2000) "High- pressure densification of wood residues to form an upgraded fuel" *Biomass and Bio-energy* 19: 177-87

Yaman S., Sahan M., Haykiri-acma H., Seven K. and Kücükbayrek S., (2000) Production of fuel briquettes from olive refuse and paper mill waste. *Fuel Process Technology* 68:23-31.

How to cite this article:

Ajit Kaur *et al.*2017, Densification of Biomass By Briquetting: A Review. *Int J Recent Sci Res.* 8(10), pp. 20561-20568.
DOI: http://dx.doi.org/10.24327/ijrsr.2017.0810.0916

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