ISSN: 2278-0181
ISNCESR-2015 Conference Proceedings

Biomass Densification Technologies to Obtain Briquettes for Energy Application – A Review

V. M. Victor
Department of Farm Machinery & Power Engineering
SV College of Agricultural Engineering & Technology
Indira Gandhi Krishi Vishwavidyalaya
Raipur, Chhattisgarh

S. V. Jogdand
Department of Farm Machinery & Power Engineering
SV College of Agricultural Engineering & Technology
Indira Gandhi Krishi Vishwavidyalaya
Raipur, Chhattisgarh

A. K. Chandraker
Department of Farm Machinery & Power Engineering
SV College of Agricultural Engineering & Technology
Indira Gandhi Krishi Vishwavidyalaya
Raipur, Chhattisgarh

***Abstract*— Forest area of the country is depleting every year, which is an alarming situation presently. Deforestation is a major contributor to anthropogenic climate change. On the other hand surplus and substantial quantities of agricultural and agro-processing residues are being burnt in the field for quick disposal in different parts of the country, which creates negative impact on the environment. The low density of agricultural residues like straw, grasses, stalks and woody biomass limit their application as a feedstock in energy production. Prior to cost effective use of these materials in energy application, it is necessary to convert them in uniformally formatted, densified feedstock to increase their consistent physical properties like size, shape and bulk densities to reduce technical limitations associated with storage, loading and transportation. A variety of densification systems like pelleting, briquetting or extrusion processing are the commonly used methods to achieve densification of loose biomass. This study gave emphasis on the suitability of these densification systems of biomass, specific energy consumption and end product quality. Study revealed that the piston ram press type briquetting machine is more flexible in terms of feedstock variables where biomass with higher moisture content and large particle sized biomass are acceptable for making good quality briquettes while screw press type machine consumes more energy because it not only compresses but also shears and mixes the materials during process.**

Keywords- briquetting technologies, pellet, biomass densification.

I. INTRODUCTION

Biomass fuels are a potential source of renewable energy. After coal and oil, biomass stands as the third largest energy resources in the world. About 1.5 tonne of crop residue is harvested with each tonne of main product. Crop residue is also produced during primary processing of crops such as sugarcane, rice, groundnut, and coconut. Part of the crop residue produced through agriculture is primarily used as domestic fuel. Off-farm use of crop residue remains limited. Stagnation or even reduction in demand of crop residues and increase in its production is resulting in the burning of large quantity of dry crop residue every year. Apart from destruction of a good source of organic matter and energy, uncontrolled burning of crop residue creates a serious environmental problem which will get aggravated as more crop residue become surplus each year. The chemical composition of crop residues is not much different than wood. However, crop residues are thinly spread over large area, their availability is seasonal and there are problems associated with their storage and handling. Briquetting technologies reduce various problems associated with the management and utilization of biomass in domestic and industrial sectors. Briquetting of some of the crop residues has become cost competitive and the briquettes being used as replacement of firewood for energy application.

The aim of the present paper is a comprehensive review of biomass processing, which includes densification technologies, densification equipments, characteristics of briquettes, unit operations involved in briquette preparation, their cost and specific energy consumption in densification.

A. Briquetting Technology

Briquetting is a technology for densification of biomass / crop residues to increase its bulk density, lower moisture contents, uniform size and shape for easy handling, transport, storage and uniform burning (when used for energy). Briquettes have high specific density, about 1100-1200 kg/ m^3 and bulk density about 600-800 kg/m^3 as compared to loose biomass which have bulk density in the range of 80-100 kg/m^3 for agricultural straws and grasses and 150 - 200 kg/ m^3 for woody biomass (Mitchell et al. 2007). Conventional processes for biomass densification can be classified into baling, pelletization, extrusion, and briquetting, which are carried out using a bailer, pelletizer, screw press, piston or a roller press. Pelletization and briquetting are the most common processes used for biomass densification for solid fuel applications. These high-pressure compaction technologies, also called "binderless" technologies, are usually carried out using either a screw press or a piston press (Sokhansanj et al. 2005).

Briquetting can be done with and without binder. In the commercial briquetting machines no binder is used. It is done under high temperature and/or pressure. At higher temperature (between 100-120^{0} C) the lignin present in the biomass is fluidized and acts as its own binder. When temperature goes down, lignin solidifies and holds the briquettes intact in cylindrical form (Briggs et al., 1999). During densification of starch-rich biomass using an extrusion process like pelleting, the presence of heat and moisture gelatinizes the starch and results in better binding (Wood, 1987 and Thomas et al., 1998).

All agricultural crop residues, woody biomass, saw dust from timber mills, dried leaves from orchards, shrubs and grasses along the road sides can be used for briquetting. During compaction, solid bridges are developed by chemical reactions and sintering, hardening of the binder, solidification of the melted substances, or crystallization of the dissolved materials. The pressure applied during densification also reduces the melting point of the particles and causes them to move towards one another, thereby increasing the contact area and changing the melting point to a new equilibrium level (York and Pilpel, 1972; Pietsch, 1984).

The problem lies in their collection, drying, handling and transport. Crop residues like rice and wheat straw are not presently being briquetted and substantial quantities are being burnt in the field for quick disposal in different parts of the country. They can also be briquetted.

B. Densification Equipments (Briquetting Machines)

a) Piston-ram Press Type

Piston presses are commonly used as briquetting machines for densification of biomass. In this type of machine, the material is fed into a cylinder which is then compressed by a piston into a slightly tapering die. Diameter of briquettes is proportional to output of the machine. Commercial machines with 0.5-1.5 t/h capacity are available. They produce briquettes in the range of 50-90 mm diameter. Piston presses can be driven mechanically or hydraulically. Mechanical presses generally produce hard and dense briquettes, while hydraulic presses which work at low pressure, gives briquettes which are less dense and somewhat soft and friable. The power requirement of such briquetting machines varies from 25 kW to 66 kW.

b) Screw Press Type

In this type of machine the material is fed continuously into a screw which forces the material into a cylindrical die, which is often heated to 250-300°C to raise the temperature to the point where lignin starts flowing. Pressure builds up smoothly. If die is not heated then temperature may not rise sufficiently to cause lignin flow and to bind the material. If the heat generated within the system is not sufficient for the material to reach a pseudo-plastic state for smooth extrusion, heat is provided to the extruders from outside either using band or tape heaters (Grover and Mishra, 1996).Briquettes are often of high quality than piston-press unit but the power requirement per tonne of briquette produced is also high. Briquettes produced by this machine have a hole in the center which makes it burn quickly. The wear and tear of screw is very high and requires frequent reconditioning.

c) Roller Press

Densification of biomass using roller presses works on the principle of pressure and agglomeration, where pressure is applied between two counter-rotating rolls. Ground biomass, when forced through the gap between the two rollers, is pressed into a die, or small pockets, forming the densified product (Yehia, 2007). Design parameters that play a major role on the quality of the densified product are the diameter of the rollers, the gap width, the roller force, and the shape of the die (Yehia, 2007).

Roller-press machines have been in use since 1870. Johanson's (1965) analysis was based on understanding the behavior of granular solids within a roller press, which involves the interaction between the particles of the material itself as well as the interaction between the material and the machine.

d) Pellet Press Type

These machines operate by extruding small diameter (10-30 mm) pellets through a die, which has many holes. The extruding mechanism is often 2 or 3 eccentric rollers, which move inside a large cylinder or conical die. The material to be palletized is dropped in the cylinder and when the rollers ride over this material and rotate, they push the material through holes in the die against resistance from pellets already formed in the die holes. Pellets are less harder than briquettes.

Such machines were originally developed for producing animal feed and have high through puts. The power requirement of this type of machines also varies according to the capacity of the machine. A 500 kg/h capacity machine requires about 16 kW power for its operation.

e) Pellet Mill

The same equipment like pallet press, called a pallet mill, adapted to the specific requirements of wood and other biomasses, is used for mass production of fuel pallets. A pellet mill consists of a perforated hard steel die with one or two rollers. By rotating the die or the rollers, the feedstock is forced through the perforations to form densified pellets. Different dimensions of a commercial pellet die are available as per requirement. Commercial pelletizers are available with production capacities ranging from 200 kg/hr to 8 ton/hr, indicating that the pelletizer capacity is not restricted by the density of the raw material (as in the case of piston or screw presses). Power consumption of the pellet mills ranges from 15–40 kWh/ton (Grover and Mishra, 1996).

C. Characteristics of Briquettes

a) Moisture Content

The final moisture content of the pellets or briquettes from biomass is greatly dependent on process conditions like initial moisture content, temperature, and pressure. Higher moisture content in the final product results when the initial moisture content is greater than 15%. Mani et al. (2006) observe that initial moisture content of >15% and pressure >15 MPa has a negative effect on the final briquette quality where cracks were observed. Pellets with lower moisture content (<5%) can result in revenue loss for the pellet manufacturer as they tend to break up, creating more fines during storage and transportation. Pellets with high moisture content can be subject to spoilage due to bacterial and fungal decomposition resulting in significant dry matter losses during storage and transportation (Tumuluru et al., 2010a).

b) Bulk Density

Bulk density is an important parameter for storage and transportation purposes. Pellets or briquettes with higher density are preferred as fuel because of their high energy content per unit volume and slow burning property (Kumar et al., 2009). Bulk density of pellets or briquettes greatly depends upon processing conditions, like temperature, moisture content, particle size, and pressure. High temperatures and lower moisture content favors high density products. Smaller particle size produces denser products (Shankar and Bandyopadhyay, 2004). It is generally accepted that raw-material particle size influences the density of the pellets; e.g., small particles give a higher density for single pellets. This is true at least at low and medium densification pressures (Mani et al. 2006). Bergström et al. (2008) stated that high pressure in the dies reduces the influence of the raw material particle-size distribution on the bulk density.

c) Calorific Value

In general, the calorific value of pellets and briquettes depends upon process conditions like temperature, particle size, and in feed pretreatment. Generally, pellets with higher density have higher calorific value. The typical calorific values of wood pellets ranges from 17 to 18 MJ/kg (Tumuluru et al., 2010a). Pretreatment processes such as torrefaction and steam explosion can have a significant effect on the calorific value of the final product. The typical calorific values of straw-based pellets range from 17–18 MJ/kg (Satyanarayana et al., 2010). Pretreatment processes such as torrefaction and steam explosion can have a significant effect on the calorific value of the final product and increase them from 20–22 MJ/kg. Tumuluru et al. (2010b) conducted studies on pretreatment of corn stover and miscanthus biomass using the torrefaction method, found that the calorific value increases by about 20% to its original value when torrefied at temperature ranges of 200–300°C.

II. PREPARATION OF FEED STOCK FOR BRIQUETTING

Several unit operations are required for preparation of feedstock for briquetting. The cost of feedstock preparation which ultimately affects the cost of briquetting depends on the number of unit operations used. Unit operations involved and their effect on cost of feedstock preparations of few selected biomass are given in Table 1 and 2.

TABLE 1 : UNIT OPERATIONS INVOLVED IN PREPARATION OF DIFFERENT FEEDSTOCK FOR BRIQUETTING

Feedstock	**Unit Operations**				
	Sieving	**Drying**	**Chopping**	**Shredding**	**Grinding**
Saw dust	√	√	-	-	-
Sugarcane bagasse	-	-	√	-	√
Cotton stalk	-	-	√	√	√
Groundnut shell	-	-	-	-	√
Jatropha shell	-	-	-	-	√
Wheat straw	-	-	-	-	√
Rice straw	-	-	√	-	√
Pearl millet stalk	-	-	√	-	√
Mustard Stalk	-	-	-	-	√
Dry leaves	-	-	-	-	√

Source : Srivastava and Vyas, 2008

TABLE II : COST OF PREPARATION OF DIFFERENT FEEDSTOCK FOR BRIQUETTING

S. N.	***Feed stock***	**Total energy used per tonne in feedstock preparation**	**Total cost of feedstock preparation per tonne (including fixed and operation costs of different machines used), in Rs.**
1	Saw dust	2 Man-h + 1.3 kWh	29.25
2	Sugarcane bagasse	38.86 Man-h + 86.28 kWh	929.07
3	Cotton stalk	64.34 Man-h +102.20 kWh	1368.36
4	Pearl millet stalk	27.96 Man-h + 86.27 kWh	826.42
5	Wheat straw	9.39 Man-h + 43.66 kWh	352.40
6	Rice straw	27.87 Man-h + 51.40 kWh	604.00
7	Groundnut shell	5.32 Man-h + 19.38 kWh	157.45
8	Jatropha shell	6.20 Man-h + 25.12 kWh	196.12
9	Mustard Stalk	24.00 Man-h + 66.00kWh	605.99
10	Dry leaves	24.50 Man-h + 62.50 kWh	589.74

Source : Srivastava and Vyas, 2008

III. COMPARISON OF VARIOUS DENSIFICATION TECHNOLOGIES

A comparison of different densification technologies in terms of feedstock properties, machine capacity and its maintenance, specific energy consumption and its suitability for end use application is shown in Table 1.All densification systems reviewed in this study help in obtaining a uniform feedstock for energy applications. Table 1 revealed that briquettes obtained from screw press equipment is more suitable for co-firing and combustion as the biomass is carbonized during densification, whereas the pellet, roller and piston pressed briquettes are more suitable for thermo-chemical conversion processes. Piston press machine can handle bigger particle size of biomass with higher moisture content, giving it advantage over other briquetting equipments.

The specific energy consumption of different densification systems varies depending on the different unit operations involved like compression, pushing, shearing and mixing. The densification systems that involve more compression and pushing consume more energy because they depend on the dimensions of the pressing channel. About 40 per cent of the energy is required for compressing the material and the remaining energy is required for overcoming the friction during compression. Screw press densification system consumes higher energy among all the densification system because it not only compresses but also shears and mixes the materials, where as pallet press consumes the least energy, may be due to the higher moisture content of the material and loose binding of briquettes (Kaliyan and Morey, 2006).

REFERENCES

[1] J. F. Wood, “The Functional Properties of Feed Raw Materials and the Effect on the Production and Quality of Feed Pellets,” Animal Feed Science and Technology, Vol. 18, pp. 1–17, 1987.

[2] J. L. Briggs, D. E. Maier, B. A.Watkins and K. C. Behnke, “Effects of Ingredients and Processing Parameters on Pellet Quality,” Poultry Science, Vol.78, pp. 1464–1471, 1999.

[3] J. R. Johanson, “A Rolling Theory for Granular Solids,” Transactions of the ASME, Journal of Applied Mechanics, pp. 842–848, December 1965.

[4] J. S. Tumuluru, S. Sokhansanj, C. J. Lim, X. Bi, L. Anthony, M. Staffan, T. Sowlati and O. Ehsan, “Quality of Wood Pellets Produced in British Columbia,” Applied Engineering in Agriculture, Vol. 26(6), pp. 1013–1020, 2010a.

[5] J. S. Tumuluru, S. Sokhansanj, L. Tabil, M. Kashaninejad and S. Bandyopadhyay, “Effect of Extrusion Process Conditions on the Quality Attributes of Multi-Component Biomass Pellets,” Food and Bioprocess Technology, 2010b.

[6] K. A. Yehia, “Estimation of Roll Press Design Parameters Based on the Assessment of a Particular Nip Region,” *Powder Technology*, Vol. 177, pp.148–153, 2007.

[7] M. Thomas, T. van Vliet, and A. F. B. van der Poel, “Physical Quality of Pelleted animal Feed 3. Contribution of Feedstuff Components,” Animal Feed Science Technology, Vol. 70, pp. 59–78, 1998.

[8] N. Kaliyan and R. Morey, “ Densification Characteristics of Corn Stover and Switchgrass,” ASABE Paper No. 066174, Annual International Meeting, Portland, ASAE, St. Joseph, MI, USA, July 9-12, 2006.

[9] N. Satyanarayana, C. Y. Tao, G. Glaser, Hans-J€org and P. Ay, “Increasing the Calorific Value of Rye Straw Pellets with Biogenous and Fossil Fuel Additives,” Energy Fuels, Vol. 24, pp. 5228–5234, 2010.

[10] N. S. L. Srivastava and D. K. Vyas, “ Efficient management of Crop and Agro-processing residues for Animal feed and Energy through Briquetting,” Proc. 42 ISAE Annual Convention and Symposium, CIAE Bhopal, pp 12-24, February 1-3, 2008.

[11] P. Mitchell, J. Kiel, B. Livingston and G. Dupont-Roc, “Torrefied Biomass: A Foresighting Study into the Business Case for Pellets from Torrefied Biomass as a New Solid Fuel,” All Energy, May 24, 2007.

[12] P. D. Grover and S. K. Mishra, “Biomass Briquetting: Technology and Practices,” Regional Wood Energy Development Programme in Asia, GCP/RAS/154/NET, Food and Agricultural Organization of the United Nations, Bangkok, 1996.

[13] P. York and N. Pilpel, “The Effect of Temperature on the Mechanical Properties of Some Pharmaceuticals Powders in Relation to Tableting,” Journal of Pharmacy and Pharmacology, Vol.24, pp. 47–56, 1972.

[14] R. Kumar, N. Chandrashekar and K. K. Pandey, “Fuel Properties and Combustion Characteristicsof Lantana Camara and Eupatorium Spp.,” Current Science, Vol. 97 (6), pp.930–935, 2009.

[15] S. Mani, L. G. Tabil and S. Sokhansanj, “Specific Energy Requirement for Compacting Corn Stover,” Bioresource Technology, Vol. 97, pp. 1420–1426, 2006.

[16] S. Sokhansanj, S. Mani, X. Bi, P. Zaini and L. Tabil “Binderless Pelletization of Biomass,” Presented at the ASAE Annual International Meeting. Tampa, FL, ASAE Paper No. 056061. ASAE, 2950 Niles Road, St. Joseph, MI 49085-9659 USA, July 17–20, 2005.

[17] T. J. Shankar, and S. Bandyopadhyay “Optimization of Extrusion Process Variables using a Genetic Algorithm,” Food and Bioproducts Processing, Vol. 82(C2), pp. 143–150, 2004.

[18] W. B. Pietsch, “ Size Enlargement Methods and Equipments—Part 2: Agglomerate Bonding and Strength,” in M. E. Fayed and L. Otten (Eds.), Handbook of Powder Science and Technology, New York, USA: Van Nostrand Reinhold Co., pp. 231–252, 1984.

TABLE III: COMPARISON OF DIFFERENT DENSIFICATION EQUIPMENTS

S. N.	**Parameters**	**Densification equipments**				
		Piston ram press	**Screw Press**	**Roller Press**	**Pallet Press**	**Pallet Mill**
1.	Optimum moisture content, %	10-15	4-8	10-15	30-35	10-15
2.	Particle size, mm	6-12	2-6	<4	<3	<3
3.	Addition of binder	Not required	Not required	Required	Required	Not required
4.	Shape of briquette/pallet	Cylindrical	Cylindrical	Elliptical	Cylindrical	Cylindrical
5.	Output from machine	In-strokes	Continuous	Continuous	Continuous	Continuous
6.	Specific Energy Consumption, KW/t	37.4-77	36.8-150	29.81-83.1	13.6-65.8	16.4-74.5
7.	Combustion performance of briquettes	Moderate	Very good	Moderate	Very good	Very good
8.	Carbonization of charcoal	Not possible	Makes good charcoal	Not possible	Not possible	Not possible
9.	Suitability in gasifier	Suitable	Suitable	Suitable	Suitable	Suitable
10.	Suitability for confiring	Suitable	Suitable	Suitable	Suitable	Suitable
11.	Homogeneity of biomass	Not homogeneous	Homogeneou s	Not homogeneous	Homogeneou s	Homogeneou s
12.	Maintenance	High	Low	Low	Low	Low