

Biomass Densification Methods and Mechanism

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ABSTRACT

Densification of agricultural residues may be used as fuel for the generation of energy. Some of the methods available for compaction of the residues are the piston press, screw press, roller press and palletizing machines. Many researchers have tried the densification mechanism of different biomasses. It involves application of attractive forces between solid particles, interfacial forces, capillary pressure, adhesive and cohesive forces, mechanical interlocking behavior and formation of solid bridges. Strength of the compactness depends upon material characteristics and process variables like pressure, temperature and use of binding materials. This article reviews the different biomass densification methods and its mechanism. A comparative study has been made for different methods.

Key words: Agricultural Residues, Densification Mechanism, Material Characteristics, Screw Press, Piston Press.

INTRODUCTION

Many developing countries are interested in utilizing agricultural residues to produce energy and clean the environment. The agricultural residues are considerable in quantity and they can be effectively used as fuel. Some of the major agricultural residues are rice husks,

coffee husks, coir piths, jute sticks, bagasse, groundnut shells, mustard stalks and cotton stalks. Sawdust is another milling residue available in huge quantities. The major problems associated with these residues are transportation, storage, and handling. Further, direct burning of loose biomass in conventional grates has the problem of very low thermal efficiency and leads to heavy air pollution. To overcome these difficulties, briquetting is one of the better options because it solves the transportation, storage and handling problems. The combustion efficiency has also been increased considerably and reduces the pollution problems.

Many researchers explored the area of densification of agricultural residues and employed different methods and mechanisms for various types of residues. This paper presents an overview of the different densification processes and mechanisms.

DENSIFICATION PROCESS

The process of compaction of residues to higher bulk density is called densification. The briquetting process consists of applying pressure with or without a binding material to convert the residue to a compact agro mate. Agricultural residues can be briquetted by overcoming its elastic property through high pressure with or without heating.

Classification of Densification Process

Densification equipments are classified into the following categories based on their working principles: the piston press, the screw press, the roller press and the palletizer. The output of the first three methods is larger in size called briquettes, and the later produces small size products called pallets.

Piston Press

In this equipment (Figure 1), pressure is applied intermittently on the residue material packed inside the cylinder using a piston energized by a flywheel or hydraulic system. The piston of the press reciprocates and compresses the material supplied from the feed hopper. The material is taken into the conical die, compressed by the piston, and the briquetted part is extruded through the die opening. During compression process (because of the friction involved) the material is heated to the range of 1500°C to 3000°C (Bhattacharya, et al. 1989).

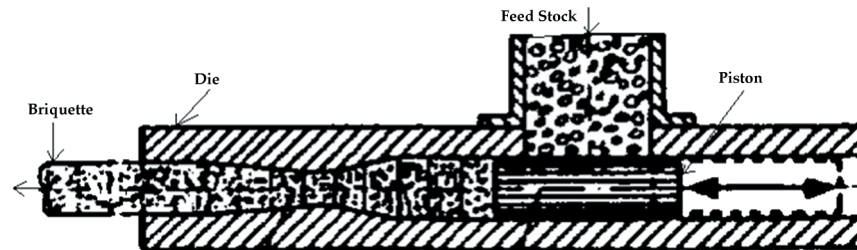


Figure 1. Piston Press

Screw Press

A rotating screw of varying cross section (Figure 2) compresses the residue material feed from the feedstock. The screw is driven by a separate drive mechanism. The screw conveyor pushes the material through the passage of varying cross section, thereby achieving compression. The briquetted material is then expelled from the die. The screw has an end needle so that the extruded part has a hollow central portion (Grover and Mishra 1996). The conical screw press with the coolant arrangement is also shown in the Figure 3.

A screw press with a heater (also used by Bhattacharya) has a specific advantage of improving the melting of lignin contained in the residues, and this acts as a binding material that improves the briquetting process (Figure 4).

The comparison between the piston press and screw press is illustrated in the Table 1.

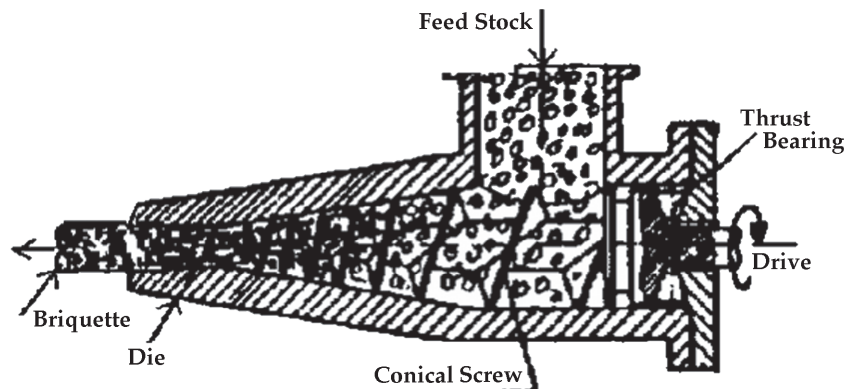


Figure 2. Screw Press

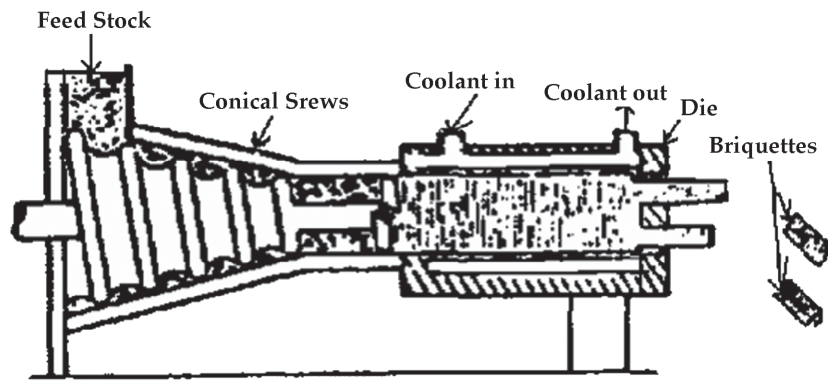


Figure 3. Conical Screw Press

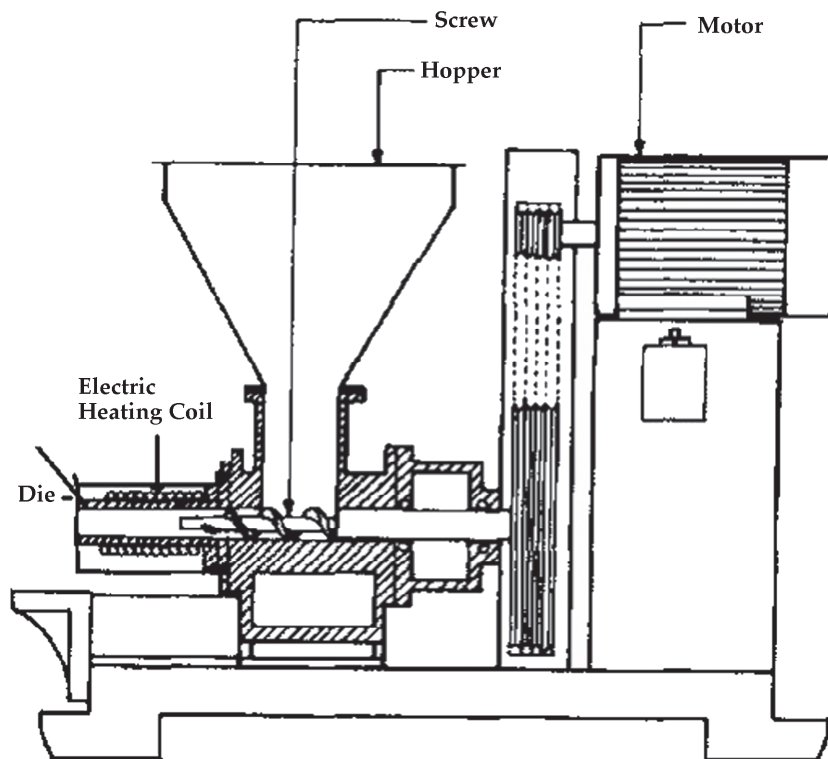


Figure 4. Screw Press with Heater

Table 1. Comparison of piston press and screw extruder

No.	Particulars	Piston Press	Screw Extruder
1.	Optimum moisture content of raw material	10 to 15%	8 to 9%
2.	Wear of contact parts	Low	High
3.	Output from the machine	in strokes	continuous
4.	Power consumption	50 kWh/ton	60 kWh/ton
5.	Density of briquette	1 to 1.2 gm/cm ³	1 to 1.4 gm/cm ³
6.	Maintenance	High	Low
7.	Combustion performance of briquette	not so good	very good
8.	Carbonization of charcoal	not possible	makes good charcoal
9.	Suitability in gasifiers	not suitable	suitable
10.	Homogeneity of briquettes	non-homogeneous	homogeneous

Roller Press

In the roller press (Figure 5), the residue is fed through the hopper and its flow is controlled by a separate control mechanism. A predetermined quantity is supplied to the screw mechanism, and it is pre-compressed. The partially compressed feedstock is fed between the rollers and compressed further to a small size. The sizing of the stock is carried out effectively as it is passes through the screw and roller (Koser, et al. 1982). In comparison to the piston press, the force applied to the stock is less and hence, it is more suitable for the stock with smaller particle size. The product is also less durable.

Pellet Press

The pellet press (Figure 6) consists of an annular matrix and a roller. The residue to be palletized is compressed between the roller and the annular matrix, which contains a number of perforations of pre-determined sizes. The feed is expelled out of these perforations in the form of pellets. A knife cuts the pellets to length and the pellets are collected at the bottom of the equipment.

These devices are more suitable for the mass production of pellets. The pellet press capacity is not restricted by the density of the raw material as is the case the piston or screw presses. Pelletizers are avail-

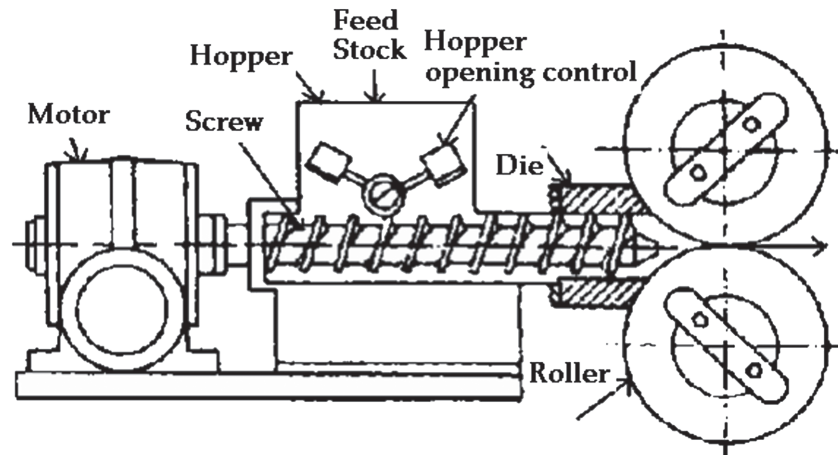


Figure 5. Roller Press

able in varying capacities that range from 200 kg/hr to 8 ton/hr. Power consumption of these pelletizers usually range from 15 to 40 kWh/ton (Grover 1996).

MECHANISM HAVE BONDING BETWEEN PARTICLES

The mechanism of bonding between particles of the materials has been analyzed by Rumpf (1962). According to him, the possible mechanisms can be sub-divided into five major categories:

- 1) Forces of attraction between solid particles
- 2) Interfacial forces and capillary pressure in movable liquid surfaces
- 3) Adhesion and cohesion forces at not freely movable binder bridges
- 4) Solid bridges
- 5) Mechanical interlocking.

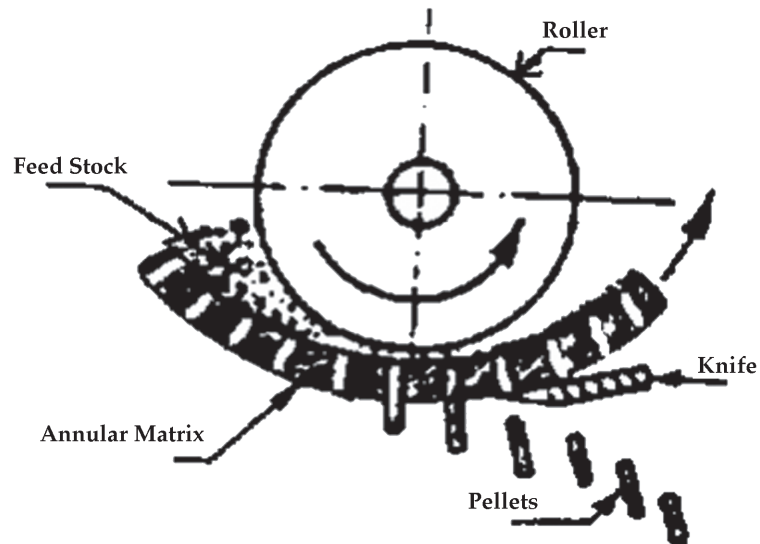


Figure 6. Pellet Press

Forces of Attraction between Solid Particles

The existing forces of attraction between solid particles (like molecular, electrostatic or magnetic) contribute significantly to the adherence of particles. These forces decrease as the size of the particles increases (Grover and Mishra 1996).

Interfacial and Capillary Forces in Movable Liquid Surfaces

The presence of moisture during the densification process develops the cohesive forces between particles. However, there is an air gap between the particles before densification, also called a pendular state (Figure 7a). As the densification process proceeds, the interfacial space between the particles is filled with the liquid, as illustrated in the Figure 7b. At this stage, the particles experience the forces of attraction, surface tension, and capillary forces (negative suction pressure).

The capillary state (Figure 7b) is reached when all the void space within the agglomerate is completely filled with the liquid. Capillary pressure and interfacial forces create strong bonds between particles, which disappear once the liquid evaporates. Between the pendular and capillary states, there exists an intermediate state known as the funicular state (Figure 7c). In the funicular state, the pores are filled with liquid. The cohesive strength of the agglomerate is attributed to the bonding

forces exerted by the pendular bridges and capillary suction pressure (Rumpf 1962).

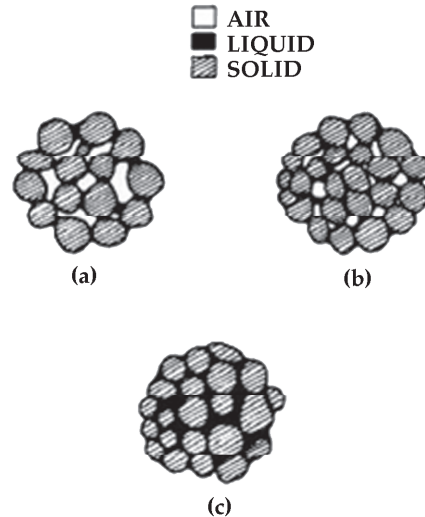


Figure 7. Interfacial and capillary forces in movable liquid surfaces (a) pendular state; (b) capillary state; (c) funicular state (Sastry and Fuerstenau 1973).

Adhesion and Cohesion Forces at Not Freely Movable Binder Bridges

Viscous binders increase the adhesive and cohesive forces, which are very similar to solid bridges during the compaction process (Grover and Mishra 1996). Thin adsorption layers are also immobile and can form strong bonds between adjacent particles by either smoothing out surface roughness, increasing the inter-particle contact area or by decreasing the effective inter-particle distance and allowing the intermolecular attractive forces to participate in the bonding mechanism. The area of adsorption contact increases appreciably when the solid particles are subjected to high pressure and produce high bonding forces (Rumpf, 1962).

Solid Bridges

The solid bridges largely determine the strength of the final products. Solid bridges are formed by different mechanisms such as

crystallization of dissolved substances, hardening binders, melting and sintering and chemical reaction. Basically, solid bridges are formed at high pressures and temperatures. These bridges may consist of solutes left behind after the evaporation of the liquid. The most common solid bonding mechanisms that are usually encountered during palletizing and briquetting are hardening of binders, melting and subsequent cooling of pellet components that may occur during compaction and extrusion (York 1972 and 1973).

Mechanical Interlocking

Mechanical interlocking of particles may occur during the agitation and compression of fibrous, flat-shaped and bulky particles. It is probably a minor contributor to pellet strength, although it can provide sufficient mechanical strength to resist the disruptive forces caused by elastic recovery following compression (Gray 1968).

Mechanism of Compaction

The compaction mechanism of different particulate materials will be different from each other. During the first stage of compression, particles are heated as a result of friction and rearrange themselves to form a closely packed mass. At this stage, the particles retain most of their original properties. At high pressures, the particles are forced against each other and undergo elastic and plastic deformation. Therefore, the inter-particle contact is increased. As a result, short range bonding forces like Vander Waal's forces and electrostatic forces become effective. Under stress, brittle particles may fracture leading to mechanical interlocking. Mechanical interlocking is the only bonding mechanism that does not involve atomic forces and is expected to contribute very little to the overall strength of the pellet (Gray 1968). At still higher pressures, reduction in volume continues until the density of the pellet approaches the true densities of the component ingredients. If the melting point of the ingredients is reached, it forms a eutectic mixture and the heat generated at a point of contact can lead to a local melting of materials. Once cooled, the molten material forms very strong solid bridges (Ghebre-Sellassie 1989).

There is a close correlation between the increases in density to the increase in applied pressure in the early stages of compression, but the rate of increase in density falls rapidly as the density of the pressed material approaches the density of water (Otis and Poroy 1957 and

Aboaba, et al. 1973).

Bruhn (1989) explained the compaction mechanism of alfalfa. In the first stage, large reductions in pore volume occur, followed by material deformation. In this stage, stems are flattened and cracked and curled particles are flattened. The plant material is distorted to fill voids and hollow stems. Later, empty dry cells are crushed and the juice-filled cells (protoplasm) subjected to pressure or shear forces begin to rupture (Koegel, et al. 1973). Finally in the liquid extraction stage, any juice or oil present begins to extrude through the vent holes or clearance between the members of the compression chamber (Bruhn, et al. 1971). Moisture present in the material cannot escape but limit the maximum density attainable and may interfere with the performance of natural bonding agents and decrease the stability of the press cake form (Gu, et al. 1982).

Grover and Mishra (1996) explained the mechanism of compaction in a screw extruder for the production of fuel briquettes. A simple extruder features three distinct zones: feed, compaction and extrusion zones. The important forces that influence the compaction of biomass play their role mostly in the compaction zone. When the biomass is fed into a screw extruder, the force is developed as a result of the restriction in the die, and compaction occurs as follows:

- a) Release of air from void spaces facilitates the increase in inter-particle contacts.
- b) Compacted mass becomes relatively soft as a result of heat generated at inter-particle contacts. High pressure causes the formation of local bridges and interlocking of particles.
- c) Compression in tapered die forms the briquettes with uniform density.

Strength of Compacts

Drzymala (1993) described the process of compaction of fine powders when forming briquettes and the durability of bonds formed. The stress at the points of contact between freely heaped particles is equivalent to the pressure resulting from the weight of the particles positioned above. If an external load is applied, some of the weaker points of contact will be broken and some of the particles will come

to more stable positions. When the load is increased, loosely heaped material are settled, which entails a reduction in volume of pores and an increase in the number of points of contact. At the initial stage of settling, the compaction takes place as a result of overcoming the forces of friction between the particles, and not as a result of plastic deformation or cracking of the particles. In this respect, the particle surfaces do not become smoother, and their mechanical strength increases, as the overlapping and wedging forces increase with increasing loading. Then, the total frictional force increases, because the increase in the number of points of contact results in an increase of the total surface area of contact. Therefore, in the initial stage of compaction, the durability of bonds between particles increases with increasing density. This increase in the durability of the bonds persists until the contact between the particles changes under the influence of the increased external load. As the external load increases, the particles undergo plastic deformation and lose their surface irregularities. This phenomenon may cause a reduction in the overall durability of contacts between particles (Drzymala 1993 and Pietsch 1983). Binding materials decrease the friction between the particles and facilitates their more dense packing. They also increase the durability of bonds. Some surface-active agents make it easier for particles to shift and aid in their compaction.

CONCLUSION

Piston press and screw press are the commonly used equipments for making biomass fuel briquettes. Energy consumption of piston press is less than screw press, but the combustion performance of briquettes made from screw press is better than that from piston press. Roller press is suitable for finely powdered biomass materials, and briquettes made from it are less durable. Regarding the pellet press, the capacity is not restricted by the density of the raw material, as in the case of piston or screw presses. The densification mechanism, durability of the briquettes, and specific energy requirements depend upon the biomass physical properties, like its moisture content, particle size, and nature of binding materials used. The densification mechanism also depends on the process variables like pressure and temperature. More research is required to study the compression characteristics of different biomass materials, and a cost and energy effective compaction process needs to be developed.

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