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Theoretical Aspects of Biomass Briquetting: A Review Study

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Abstract
The existing burden on biomass resources, the negative impacts on the environment and the problems of energy supply could be alleviated by undertaking comprehensive alternative energy technologies for decentralized application. One of such viable and promising technologies is briquetting, which is used to extract biomass energy and convert it into a more useful form through densification in order to facilitate handling, storage and transportation. Briquette, which is final product of biomass briquetting, has a wide variety of use from household to industrial. Therefore, this paper reviews biomass briquetting, its technology and fundamental principles. The advantages as well as its drawbacks are also examined along with the factors that can influence biomass briquetting. The review study concluded that briquetting is one of viable means of converting biomass residues into renewable energy and that the quality of briquettes depends on the type of the biomass feedstock used and operating conditions such as moisture content, temperature and addition of substrates as well as particle size.
Keywords: agricultural wastes, briquetting, briquette, briquette charcoal, densification, deforestation.

1. Introduction
Life is a continuous process of energy conversion and transformation. The accomplishment of civilization has largely been achieved through the increasingly efficient and extensive harnessing of various forms of energy to extend human capabilities and ingenuity (Pallavi, et al. 2013). Thus, access to energy is necessary to sustain human life and to achieve overall economic, social and environmental aspects of human development. It is generally acknowledged that burning of fossil fuels and deforestation are major contributors to anthropogenic climate change. Biomass from plants can serve as an alternative renewable and carbon-neutral raw material for the production of energy (Tumuluru, et al. 2010). There is scarcity of energy and there is the need to source for alternative form of energy, which is different from convectional types. The worldwide inevitability of oil depletion, instability in world petroleum market (apparently due to the instability in the Middle-East and the unrest in the Niger-Delta area of Nigeria) and the hazardous emissions from petroleum-based fuels are serious problems besetting continued utilization of fossil fuels. For example, Nigeria imports about 80% of her domestically consumed refined fuel resulting in incessant increase in fuel prices and its attendant civil unrest. However, most countries of the world, Nigeria inclusive has abundant supplies of biomass resources particularly agro-forestry residues and municipal solid wastes, whose potentials can be fully tapped for energy generation (Jekayinfa and Scholz, 2009). Also, the problem of agricultural residues disposal is posing challenge to the farmers and to the general public as these residues constitute a nuisance to the environment as well as an eyesore to the public. Therefore, if these wastes could be used to generate energy, it would be a welcomed solution to the problem of waste pollution, disposal and control (Oladeji, 2012.). One of viable and promising technologies by which these wastes can be converted to biomass energy is through the process of briquetting (Wilaipon, 2008). Therefore, the aim of this paper was to make comprehensive review of biomass briquetting, its technology and fundamental principles. The advantages as well as its drawbacks were also examined along with the factors that can influence biomass briquetting.

2. Methodology
The method adopted for the study involved extensive literature review on the subject matter. Sources used included internet, previous reports and publications of notable researchers (the present author inclusive) on biomass, particularly on biomass briquetting.

3. Briquetting
Briquetting is the process of compaction of residues into a product of higher density than the original raw materials. It is also known as densification (Kaliyan and Morey, 2008). The handling characteristics of material for packaging, transportation and storage are also improved (Stout and Best, 2001). If produced at low cost and made conveniently accessible to consumers, briquettes could serve as compliments to firewood and charcoal for domestic cooking and agro-industrial operations, thereby reducing the high demand for both (Wilaipon, 2008). Besides, briquettes have advantages over fuel wood in terms of greater heat intensity, cleaningness, convenience in use and relatively smaller space requirement for storage (Kaliyan and Morey, 2009). The briquettes are normally cylindrical or rectangular in shape (Garriot, 2004).

3.1 Need for Briquetting

A huge quantity of agricultural residues and a major part of it is consumed world-wide in traditional uses (such as fodder for cattle, domestic fuel for cooking, construction material for rural housing, industrial fuel for boilers, etc.). The direct burning of agricultural residues in domestic as well as industrial applications is very inefficient. Moreover, transportation, storage and handling problems are also associated with their use Pallavi, et al. 2013). One of the approaches that are being actively pursued worldwide towards improved and efficient utilization of agricultural and other biomass residues is their densification in order to produce pellets or briquettes (Li and Liu, 2000). Briquetting is the process of conversion of agricultural waste into uniformly shaped briquettes that are easy to use, transport and store. The briquetting of biomass improves its handling characteristics, increases the volumetric calorific value, reduces transportation costs and makes it available for a variety of application. The biomass briquette is a fuel consisting of biomass, such as agricultural waste or waste paper, bound together and compressed into small pieces approximately 5 to 15cm. Briquette-making can serve as cottage industry in areas where these bio-wastes are in abundance (Ilavsky and Oravec, 2000)

3.2 Types of Briquetting

On the basis of compaction, the briquetting technologies can be divided into:
High pressure compaction, medium pressure compaction with a heating device and low pressure compaction with a binder (Grover and Mishra, 1996; Wilaipon, 2009). At present, there are two high-pressure technologies: Piston press and screw extrusion machines used for briquetting. The briquetting produced by a piston press are completely solid, while screw press briquettes have a concentric hole, which gives better combustion characteristics due to a larger specific area. The screw press briquettes are also homogenous and do not disintegrate easily. Having a high combustion rate, these can substitute for coal in most applications and in boilers. 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 a higher heat value (KJ/Kg), and makes the briquettes burn more slowly as compared to the raw materials from which the briquettes are made (Kaliyan and Morey, 2009).

4. History of Briquetting

The compaction of loose combustible material for fuel-making purposes was a technique used by most civilizations in the past (Wilaipon, 2008). Biomass densification, otherwise known as briquetting of agro-residues has been practiced for many years in several countries. Briquettes were discovered to be an important source of energy during the First and Second World Wars for heat and electricity production, using simple technologies (Yadong and Henry, 2000). During this period, briquetting of sawdust and other waste materials became widespread in many countries in Europe and America under the impact of fuel shortages. Screw extrusion briquetting technology was invented and developed in Japan in 1945. As of April 1969, there were 638 plants in Japan (Grover and Mishra, 1996)). The methods used were no more than simple baling or drying. Industrial methods of briquetting dated back to the second part of the 19th century.

5. Briquettes

Fuel briquettes are essentially a compressed block of organic waste materials used for domestic cooking and heating. The final end product of briquetting process is known as a briquette. Briquettes are made from raw materials that are compacted into a mould. Briquette could be made of different shapes and sizes depending on the mould (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; Kaliyan and Morey, 2006). But in general, briquettes have better physical properties and combustion rate than the initial waste. Production of briquette charcoal helps to ease the pressure on the forest reserve, there by solving the deforestation problem.

6. Applications of Briquettes

Briquettes have many numerous uses which include both domestic and small industrial cottage applications (Ahmed, et al. 2008). They are often used as a development intervention to replace firewood, charcoal, or other solid fuels. This is because with the current fuel shortage and ever rising prices, consumers are looking for affordable alternative fuels and briquettes fill this gap for:

- Cooking and water heating in households;
- Heating productive processes such as tobacco curing, fruits, 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.

7. Advantages of Briquetting Process

Briquetting process offers a lot of advantages. Some of these are:

Briquetting process improves the efficiency of agricultural residues. Study has revealed that there is increment in caloric value (El-Saeidy, 2004; Wilaipon, 2008). Briquettes are easy and cheap in handling, storage and transportation compared to raw agricultural residues and wastes i.e. the densified product is easy to transport and store (Kaliyan and Morey, 2009). Briquetting process helps to solve the disposal and pollution problems often created by biomass residues (Ndiema, et al., 2002). Other notable advantages are: raw materials for briquetting are readily available world-wide, especially in the less developed countries and low cost machinery can be used. Burning of briquettes could be clean and smokeless and does not cause widespread eye and respiratory diseases in women and children, who are mainly involved with domestic activities (Shakya, 2002). Fuel briquetting protects environment. This is because open-air burning of residues is avoided as most of these residues are gathered for briquetting. The process also helps to reduce deforestation by providing a substitute to fuel-wood. **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.

8. Limitations of Briquetting Process

As good as briquetting process appears to be, it has the following drawbacks: -

Briquettes can only be used as solid fuels. They have no application as liquid fuel such as the one being used in internal combustion engines (Grover and Mishra, 1996). The second major problem identified with the briquetting process is the life of the screw, where dies screw is used. Usually the screw wears out within 3-4 hours and becomes unusable. Repairing of the screw causes interruption in the work and also one screw cannot be repaired more than 10 times (Mishra, 1996). Therefore, the cost of screw and its repair are one of the major barriers to further dissemination of briquetting technology (Moral and Nawasher, 2004; Mishra, 1996). Briquettes cannot withstand direct contact with water, so a covered storage facility is required. The maximum attainable temperature is $1000^{O}C$ due to their low carbon content. However, this temperature is more than adequate for cooking purpose, but may not be sufficient for industrial applications (Oladeji, 2011). The burning capacity per unit volume is low compared to coal, so a larger storage area is required.

9. Materials for Briquetting Process

A wide variety of materials have been tested and used by researchers. For examples, wheat straw (Demibras, 1999); woods (Fapetu, 2000a); cotton (El-Saeidy, 2004; Singh, 2006); rice straw and husk (Pathak and Singh, 2000); banana peel (Wilaipon, 2008) and so on. The results clearly showed that many agro-residues could be successfully briquetted for energy generation. Other materials that can be used for briquetting process include a lot of different materials such as ground nut shells, straw, tree leaves, grass, rice and maize husks and banana leaves. It is also possible to use already processed materials such as paper, sawdust and charcoal fines (Fapetu, 2000b; Enweremadu et al., 2004a and b; Wilaipon, 2007; Oladeji et al., 2009). The selection of raw material is usually most dependent on what is easily available in the surrounding areas where the briquettes are made (Rahman, 2001). Another important criterion for the selection of the raw material is its ability to bond together when compressed.

10. Attributes of Biomass Residues for Briquetting

There are many factors to be considered before a biomass qualifies for use as feedstock for briquetting. Apart from its availability in large quantities, it should have the following characteristics.

10.1 Low Moisture Content

Moisture content should be as low as possible, generally in the range of 10-15% (Grover and Mishra, 1996). High moisture content will pose problems in grinding and excessive energy is required for drying (Kaliyan and Morey, 2009; Ollet, et al. 1993).

10.2 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). The ash content of different types of biomass with lower ash content will not show any slagging behaviour of the biomass. Generally, the greater the ash content the greater the slagging behaviour. But this does not mean that biomass with lower ash content will not show any slagging. The mineral composition of ash and their percentage combined determine the slagging behaviour.

11. Briquetting Technology

Biomass densification represents a set of technologies for the conversion of biomass into a fuel.

The technology is also known as briquetting and it improves the handling characteristics of the materials for transport, storing etc. (Toan, et at. 2000).

This technology can help in expanding the use of biomass in energy production, since densification improves the volumetric calorific value of a fuel, reduces the cost of transport and can help in improving the fuel situation in rural areas (Ahmed, et al. 2008). Briquetting is one of several agglomeration techniques which are broadly characterized as densification technologies. Agglomeration of residues is done with the purpose of making them denser for their use in energy production (Tumuluru, et al. 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).

12. Binding Mechanisms of Briquetting Technology

Biomass briquetting is known as high compaction technology or binder less technology in which biomass residues are compressed under high temperature and pressure (Chaney, 2010). These residues contain lignin that is a non-crystallized aromatic polymer with no fixed melting point, but at 200–300°C, lignin starts to become soft, melted and liquefied. At high pressure lignin will glue cellulose together and solidified and formed briquette (Bhattacharya, et al., 2002; Ilavsky and Oravec, 2000; Moral and Rahman, 2001). Densification of biomass under high pressure brings about mechanical interlocking and increased adhesion between the particles, forming intermolecular bonds in the contact area (Moral and Khan, 2004; Moral and Rahman, 2001; Grover and Mishra, 1996). In the case of biomass the binding mechanisms under high pressure can be divided into adhesion and cohesion forces, attractive forces between solid particles, and interlocking bonds (Rahman, et al., 2003). Lignin of biomass/wood can also be assumed to help in binding in this way. The application of external force such as pressure may increase the contact area causing the molecular forces to transmit high enough which increases the strength of the bond between the adhering partners. Another important binding mechanism is van der Waals' forces (Grover and Mishra, 1996). They are prominent at extremely short distances between the adhesion partners. This type of adhesion possibility is much higher for powders. Fibres or bulky particles can interlock or fold about each other as a result forming interlocking or form-closed bonds.

13. Step-by-step Production of Briquettes

The briquetting process usually starts with the collection of the residues followed by size reduction, drying and compaction by extruder or press. Briquetting can be carried out with or without a binder. The one without a binder is more convenient, but it requires sophisticated and costly presses and drying equipment (Tabil, 1997). Enumerated in sections 13.1-13.6 are procedural steps for briquette production

13.1 Sorting

This is also known as sieving. Usually, all unwanted materials or large biomass wastes are removed to ensure that all the feedstock is of the required size. All the unwanted larger pieces within the feedstock can be sieved out with a wire mesh.

13.2 Shredding of Biomass Materials into small Pieces

Under this process, the biomass materials are chopped into small pieces so as to enhance their workability and compactness. This process is not however general but depends on the type of biomass feedstock. For example, while biomass feed stocks such as groundnut, waste, bagasse, wheat straws, barley and maize straws and cobs would need to be chopped into small sizes, biomass feed stocks such as coffee husks and saw dust would not require shredding.

13.3 Mixing

This is normally required in situations where different range of biomass feed stocks is to be used primarily to optimize the burning characteristics of the final fuel. A typical example is when biomass materials with high ash content are to be mixed with biomass material of low ash content. Biomass with low energy content such as papers can be appropriately mixed with those of high energy content. This helps to attain the right quality such as long burning period, non-smoking and odour free. This will enable the briquettes to compete well in the market.

13.4 Binder

The application of binder depends on the technique of briquetting employed. In addition to biomass mixing, an appropriate binder is added and mixed with the biomass thoroughly, especially if a low pressure technique is to be employed. This enhances the compactness of the biomass materials and prevents them from disintegrating apart. According to Tabil (1997), typical examples of such binders include film binders (tar, petroleum asphalt and portland cement), matrix binders (coal, and sodium silicate) and chemical binders (pitch water, sodium silicate and lingosulfonates).

13.5 Addition of Water

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).

13.6 Compaction & Drying

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 Ph.D). Thereafter, the briquettes will need to be left to dry for up to a week (Wilaipon, 2008).

14. Briquetting Machines

There are several types of briquetting machines available for densification and compaction of biomass. Their mode of operation varies from one principle to another (Singh, et al., 2007). Some of these machines are discussed in sections 14.1- 14.5.

14.1 Screw Presses

Screw extrusion briquetting technology was invented and developed in Japan in 1945 (Grover and Mishra, 1996). These briquetting machines are popular densification equipment suitable for small-scale application in developing countries. The screw press is another type of mechanical press machine. In screw presses, material is fed continuously into a screw, which forces the material into a cylindrical die. This die is often heated to raise the temperature to the point where lignin flow occurs. If the die is not heated, then the temperature may not rise sufficiently to cause lignin flow and binding materials may have to be added (Tabil, 1997)). These can be molasses, starch, or some cheap organic materials. The briquettes from screw machines are often of higher quality than from piston units. The screw press is usually sized in the range 75-250 kg/h, though, larger machines are available. The screw press can produce denser and stronger briquettes than those produced by piston presses (Singh, et al., 2007). There are basically three types of screw press. These are: Conical screw press, screw press with heated dies, and screw press without heated dies (Grover and Mishra, 1996).

14.2 Piston Presses

The piston press is one of the main high press technologies used for briquetting. The piston press acts in a discontinuous mode with material being fed into a cylinder, which is compressed by a piston into a slightly tapering die (Mishra, 1996). The compressed material is heated by frictional forces as it is pushed through the die. The lignin contained in all woody cellulose materials begins to flow and acts as a natural glue to bind the compressed material. When the material emerges from the die, the lignin solidifies and holds it together, forming cylindrical briquettes which readily break into pieces about 10-30 cm long. The briquettes produced by a piston press are completely solid. 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. Basically, there are two types of piston press. These are the mechanical and hydraulic piston presses (Grover and Mishra, 1996).

14.3 Mechanical Piston Press

The development of the modern type of mechanical piston press started in Switzerland during World War II (Grover and Mishra, 1996). It was based upon work done in German in the 30's. The development was centered on Fred Housman and the Glomera presses. The mechanical machines are usually larger ranging from 0.3 to 0.45 t/h. Mechanical presses generally produce hard and dense briquettes from most materials. The most common drive is an electric motor geared down through a belt coupling. A direct-drive system using an internal combustion or steam engine is possible and would not change the basic design of the briquetting machine.

The capacity of this machine is defined by the volume of material that can be fed in front of the piston before each stroke and number of strokes per unit of time. Capacity by weight is then dependent on the density of the material before compression.

14.4 Hydraulic Piston Presses

The principle of operation is basically the same as with mechanical piston press. The main difference is that energy to the piston is transmitted from an electric motor via a high-pressure hydraulic system (Grover and Mishra, 1996). In this way, the machines are made compact and light, since the forces are balanced out in the press-cylinder and not through the frame as obtained in the mechanical piston presses. The material is fed in front of the press cylinder by a feeding cylinder (a so-called press-dog), which often pre-compacts the material with several strokes before the main cylinder is pressurized. The speed of piston cylinder is much slower with hydraulic press action than with mechanical that results in markedly lower outputs. Hydraulic press can possibly be considered when looking for a small briquetting machine, which makes briquettes, which are less dense and are sometimes soft and friable. Table 1 shows differences between piston press and screw press.

14.5 Pellet Presses

Pellets are the results of a process, which is closely related to the briquetting processes described above. The main difference is that the dies have smaller diameters (usually up to approximate 30 mm) and each machine has a number of dies arranged as holes bored in a thick steel disc ring (Klass, 1998). The material is forced into the dies by means of rollers (normally two or three) moving over the surface on which the raw material is distributed. The pressure is built up by the compression of this layer of material as the roller moves perpendicular to the centre line of the dies (Tumuluru, et al. 2010). Thus, the main force applied results in shear stresses in the material, which often is favourable. The speed of the compression is also markedly slower when compared to piston presses, which means that air locked into the material is given ample time to escape and that the length of the die (i.e. the thickness of the disc or ring) can be made shorter, while still allowing for sufficient retention time under pressure. The pellets will still be hot when leaving the dies, where they are cut to lengths normally about one or two times the diameter. Successful operation demands that a rather elaborate cooling system is arranged after the densification process. The main application of pellet machines is to produce animal feed from various types of agricultural wastes. Only a very limited number of plants have been set up to produce fuel pellets (Gilbert et al., 2009). The most standard pellets machines are roller presses with a circular die and cog-wheel pellet principle. Such machines were originally developed for the production of animal feedstuffs. These operate by extruding small pellets of diameter 10-30 mm through a die that has many holes. The extruding mechanism is often an eccentric roller that moves inside the large cylindrical or conical die. Its throughput performance depends on various parameters. The most important of these is the fineness of the pressed materials. The size of the die and its holes also play a major role. With the cog-wheel pellet principle, the pressed materials are pre-compressed, and then pressed and formed in the press canals in the roller coat. The press canals have different cross sections, for instance cylindrical, plate-type or wavy (Clauß, 2002). The technical properties of briquetting and pellet machines are presented in Table 2

15. Factors Affecting Biomass Briquetting

In order to produce good quality briquettes, feed preparation is very important. Feed parameters are discussed in this section, as these play a practicable role in briquetting technology. For densification of biomass, it is important to know the feed parameters that influence the extrusion process (Obernberger and Thek, 2004). For different briquetting machines, the required parameters of raw materials like their particle size, moisture content, and temperature are different (Grover and Mishra, 1996). These are discussed in sections 15.1 -15.5

15.1 Effects of Particle Size

Particle size and shape are of great importance for densification. It is generally agreed that biomass material of 6-8 mm size with 10-20% powdery component gives the best results (Kaliyan and Morey, 2009). Although, the screw extruder, which employs high pressure, is capable of briquetting material of oversized particles, the briquetting will not be smooth and clogging might take place at the entrance of the die resulting in jamming of the machine. The larger particles, which are not conveyed through the screw start accumulating at the entry point and the steam produced due to high temperature (due to rotation of screw, heat conducted from the die and also if the material is preheated) inside the barrel of the machine starts condensing on fresh cold feed resulting in the formation of lumps and leads to jamming (Gilbert et al., 2009). Therefore, it is desirable to crush larger particles to get a random distribution of particle size, so that an adequate amount of sufficiently small particles is present for embedding into the larger particles. The presence of different size particles improves the packing dynamics and also contributes to high static strength. Only fine and powdered particles of size less than 1 mm are not suitable for a screw extruder because they are less dense, more cohesive, non-free flowing entities (Mani, et al. 2006)

15.2 Effects of Moisture

The percentage of moisture in the feed biomass to extruder machine is a very critical factor. In general, it has been found that when the feed moisture content is 10-12%, the briquettes will have 8-10% moisture (Grover and Mishra, 1996). At this moisture content, the briquettes are strong and free of cracks and the briquetting process is smooth. However, when the moisture content is more than 15%, the briquettes are poor and weak and the briquetting operation is erratic (Kaliyan and Morey, 2009). Excess steam is produced at higher moisture content leading to the blockage of incoming feed from the hopper, and sometimes it shoots out the briquettes from the die. Therefore, it is necessary to maintain optimum moisture content. The right amount of moisture develops self-bonding properties in lignocellulosic substances at elevated temperatures and pressures prevalent in briquetting machines. It is important to establish the initial moisture content of the biomass feed so that the briquettes produced have moisture content greater than the equilibrium value, otherwise the briquettes may swell during storage and transportation and disintegrate, when exposed to humid atmospheric conditions (Grover and Mishra, 1996; Mani, et al, 20006).

15.3 Effects of Temperature of Biomass
By varying the temperature of biomass, the briquette density, briquette crushing strength and moisture stability can be varied (Joseph and Histop, 1999). In a screw extruder, the temperature does not remain constant in the axial direction of the press, but gradually increases. Internal and external friction cause local heating and the material develops self-bonding properties at elevated temperature. It can also be assumed that 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 derivates. The addition of heat also relaxes the inherent fibres in biomass and apparently softens its structure, thereby reducing their resistance to briquetting which in turn results in decreased specific power consumption and a corresponding increase in production rate and reduction in wear of the contact parts (Grover and Mishra, 1996). However, the temperature should not be increased beyond the decomposition temperature of biomass, which is around 300^{O}C.

15.4 Effects of Temperature of the Die
The distinctive feature of a screw type briquetting machine is that heat is applied to the die 'bush' section of the cylinder. This brings about two important operational advantages (Joseph and Histop, 1999). The machine can be operated with less power and the life of the die is prolonged. It has been shown that by heating the material for a determined temperature interval, a more stable product with a lower recovery of original dimensions could be obtained than was possible with unheated materials **(**El-Saeidy, 2004**)**. It has been also concluded that bio-residue having relatively high moisture content could be stably compacted at an elevated temperature, whereas this was not possible at ambient conditions. The temperature of the die should be kept at about 280-290^{O}C. If the die temperature is more than the required one, the friction between the raw material and the die wall decreases such that compaction occurs at lower pressure, which results in poor densification and inferior strength. Conversely, low temperature will result in higher pressure and power consumption and lower production rate (Grover and Mishra, 1996).

15.5 Effects of External Additives
The briquetting process does not add to the calorific value of the base biomass. In order to upgrade the specific heating value and combustibility of the briquette, certain additives like charcoal and coal in very fine form can be added. About 10-20% char fines can be employed in briquetting without impairing their quality (Tabil, 1997). Furthermore, only screw pressed briquettes can be carbonized. When carbonized with additives in the briquette to make dense char coal, the yield is remarkably increased. However, depending upon the quality of charcoal and coal powder, various formulations can be evolved for optional results.

Conclusion
From the review study, the following conclusions among others can be drawn:-

- Briquetting is a process in which organic materials and biomass residues are converted to biomass energy through compaction and densification of loose materials to denser products.
- The products of briquetting are predominantly charcoal and can be in different shapes.
  Briquettes produced from biomass materials of 2-8 mm size give the best results, while those less powdered particles of size less than 1 mm are not suitable for a screw extruder, therefore, it is desirable to crush larger particles to get a random distribution of particle size, so that an adequate amount of sufficiently small particles is present for embedding into the larger particles. The presence of different size particles improves the packing dynamics and also contributes to high static strength.
- The optimum feed moisture content is between 10 and 15% and the briquettes produced will be strong and free of cracks and the briquetting process will be smooth.
- Certain additives like charcoal and coal in very fine form can be added to biomass feed stocks in order to upgrade the specific heating value and combustibility of the produced briquette
- At the elevated temperature, machine can be operated with less power and the life of the die is prolonged.
- By pre-heating the feed stocks, a more stable and quality briquettes could be produced.

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Table 1. Comparison of a Screw Extruder and a Piston Press

Parameters	Piston press	Screw extruder
Optimum moisture content of raw material	10-15 %	8-9 %
Wear of contact parts	Low in case of ram and die	high in case of screw
Output from the machine	in strokes	Continuous
Power consumption	50 kWh/ton	60kWh/ton
Density of briquette	1-1.2 gm/cm^3	1-1.4 gm/cm^3
Maintenance	High	Low
Combustion performance of briquettes	not so good	very good
Carbonization to charcoal	not possible	makes good charcoal
Suitability in gasifiers	not suitable	Suitable
Homogeneity of briquettes	non-homogeneous	Homogeneous

Source: Grover and Mishra, (1996)

Table 1. The Technical Features of Briquetting and Pellet Machines

Machine Type	Common throughput Range (t/h)	Specific energy demand (kW/t)	Bulk density (kg/m^3)
Piston press	0.1-1.8	50-70	300-600
Roller press with circular die	3-8	20-60	400-700
Cog-wheel pellet principle	3-7	20-60	400-600
High pressure piston press	0.04-0.2	508-646	650-750

Source- El-Saeidy, 2004