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A Comprehensive Review on Biomass Pelleting Technology and Electricity Generation from Biomass

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ABSTRACT

Biomass resources are considered renewable as they are naturally occurring and when properly managed, may be harvested without significant depletion of their sources. Biomass around the world is in abundance and is suitable for energy utilisation. However, one of the major problems associated with biomass is low bulk density. The approach to checkmate these setbacks is to efficiently compact biomass to produce pellets. A pellet is a solid of compressed combustible material suitable for heating. This paper review showed that several research studies have been carried out on pelleting/briquetting of biomass materials such as sawdust, wood chips, rice husk, coconut shell, palm residues etc. in order to increase their energy value, bulk density and mechanical strength. It also showed that pellets and briquettes can be manually produced or by using hydraulic and screw press technologies. It revealed that pellets produced from the screw press technology are better than the pellets or briquettes from the manual or hydraulic press technology due to the fact that the screw press pellets/briquettes have better mechanical strength, calorific value, combustion performance efficiency, etc. The paper review also pointed out that pellets produced from screw press technology has the potential to increase power generation capacity from a biomass power plant.

1. Introduction

Biomass refers to non-fossil biodegradable organic material from plant, animal and microbial origin. According to [1] as reported in [2], biomass is the fourth global primary energy resource after coal, oil and gas, and is set to become an important contributor to the world energy mix. Biomass materials include products, by-products, residues and wastes from agricultural and forestry activities; non-fossil and biodegradable fractions from municipal and industrial wastes. Classical examples are trees, grasses, agricultural crops, agricultural wastes, wood waste and their derivatives, bagasse, municipal solid waste, waste paper, waste from food processing as well as aquatic plants and algae, and animal wastes [3]. Biomass resources are considered renewable as they are naturally occurring and when properly managed, may be harvested without significant depletion of their sources. As an energy resource, biomass may be used directly as solid fuel for cooking, or converted via a variety of technologies such as pyrolysis, gasification and direct combustion for electricity generation, process heating, steam generation, and mechanical or shaft power applications as well as for biofuel production. Direct combustion of raw agricultural waste as fuel feedstock has some obvious disadvantages including difficulty in controlling the burning rate of the biomass, difficulty in mechanized feeding supply, low heat density, difficulty in stock handling and transportation as well as large storage requirements. [4] reported that most of these problems are associated with the low bulk density of the agricultural waste. The approach to checkmate these setbacks is to efficiently utilize agricultural wastes as fuel is by their compaction to produce pellets.

2. Biomass Pelleting and Technology

2.1 Biomass Pelleting

A pellet is a solid of compressed combustible material suitable for heating. According to [5], pelleting is a mechanical way or treatment technique by which loose biomass material is upgraded into a uniform solid fuel through pressure compaction, thus increasing its density. By this technique, the physical properties and combustion efficiency improve. [6] reported that it involves the conversion of biomass material (that exits in loose form) into a solid fuel that can be used for various heating purposes. Pellets are made from oil palm residue, rice husk, coconut shell, wood etc. It is also an economic alternative when compared to the conventional fuel. They are used as fuel in households for heating purposes. Pellets can provide for sustainable renewable energy due to enormous supply of biomass resources. Fuel pellets can be made manually or by pellet making machines. Globally, pellets are utilised for thermal applications and combustion purposes. It can be used in boilers for steam generation and domestic heating purpose. The global wood pellet shown in Figure 1 was as reported in [7]. Several biomass samples have been used to obtain pellets. However, the existing information about one type of biomass sample cannot be applicable to another one. The kind and amount of the biomass show important differences for different geographical areas, depending on the characteristics of its climate and agriculture.

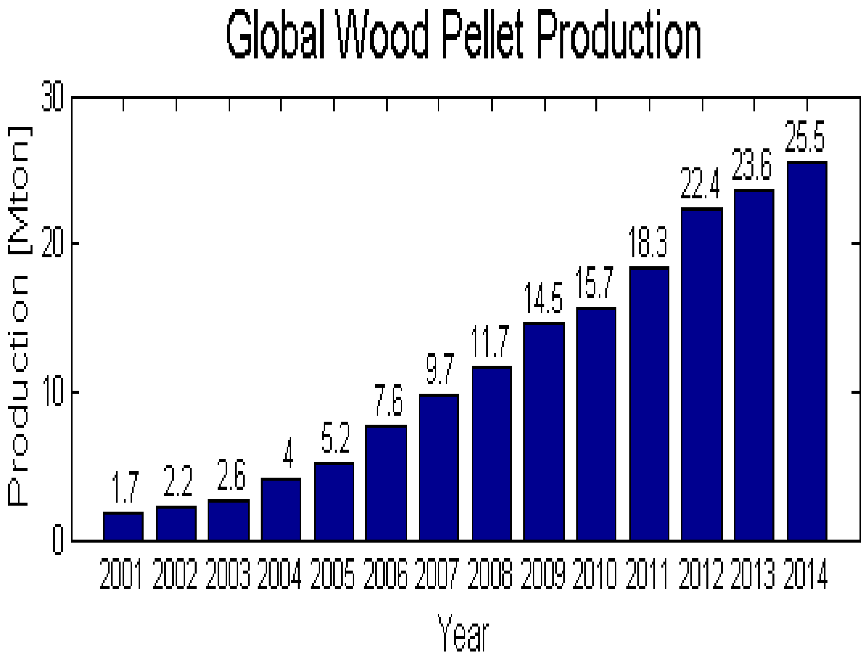

Figure 1: Global wood pellets production
Source [7]

Agricultural biomass residues have the potential for the sustainable production of bio-fuels and to offset greenhouse gas emissions [8, 9]. Straw from crop production and agricultural residues existing in the waste streams from commercial crop processing plants have little inherent value and have traditionally constituted a disposal problem. In fact, these residues represent an abundant, inexpensive and readily available source of renewable lignocellulosic biomass [10].

New methodologies need to be developed to process the biomass, making it a suitable feedstock for bio-fuel production. In addition, some of the barriers to the economic use of agricultural crop residue are the variable quality of the residue, the cost of collection, and problems in transportation and storage.

In order to reduce industry's operational cost as well as to meet the requirement of raw material for biofuel production, biomass must be processed and handled in an efficient manner. Due to its high moisture content, irregular shape and size, and low bulk density, biomass is very difficult to handle, transport, store, and utilize in its original form [6]. Densification of biomass into durable compacts is an effective solution to these problems and it can reduce material waste. Densification can increase the bulk density of biomass from an initial value of 40-200 kg/m^3 to a final compact density of 600-1200 kg/m^3 [11, 12, 13, 14] Because of their uniform shape and size, densified products may be easily handled using standard handling and storage equipment, and they can be easily adopted in direct-combustion or cofiring with coal, gasification, pyrolysis, and utilized in other biomass-based conversions [15, 16] such as biochemical processes.

According to [2], the quality of fuel pellet is usually assessed based on its density and durability. High density of pellet represents higher energy per unit volume of material, while durability is the resistance of pellets to withstand various shears and impact forces applied during handling and transportation. High bulk density increases storage and transport capacity of pellets. Since feeding of boilers and gasifiers generally is volume dependent, variations in bulk density should be avoided [17]. A bulk density of 650 kg/m^3 is stated as design value for wood pellet producers [18]. Low durability of pellets results in problems like disturbance within pellet feeding systems, dust emissions, and an increased risk of fire and explosions during pellet handling and storage [19]. [20] considered four physical properties that are of greatest value when developing or evaluating fuel pellet formulations or processes. They are resistances to crushing, impact, abrasion and water penetration. [21] carried out a study on environmentally acceptable smokeless fuel pellets that have been prepared with a low-rank coal and olive stone as biomass. [22] carried out a study on the densification of agricultural residues and wood waste into fuel pellets that can provide a relatively high-quality alternative source of fuel, especially where solid wood fuel resources are scarce. [23] stated that after the processing operation of pelleting, the moisture of pellets should be about 15% to 15.5%. [24] also stated that the most favourable moisture content for the mixture before pelleting is between 13% and 17%, and with this percent, it is expected that the dense materials (pellets) would have a high quality and durability.

According to [25], biomass fuel pellets have significant advantages over the conventional fuels such as diesel, kerosene, furnace oil, lignite, coal, and fire wood. These advantages include that biomass fuel pellets are more economical than coal, it is renewable unlike other fossil fuels; it contains lower sulphur content, and hence does not pollute the environment, pellet combustion is quite uniform compared to coal due to higher quantity of volatile matter which are necessary for sustainable and complete combustion, pellets give better boiler efficiency due to its low moisture content and higher density compared to fire wood or loose biomass, its storage and handling are convenient and hygienic etc. Several publications such as [26, 27] have also enumerated the potentials of biomass pelleting from oil palm residues for energy generation in developed countries.

2.2 Pelleting Technology

The significance of pelleting cannot be overemphasized. It is one of the alternative means of saving the consumption and dependency on fuel wood and a convenient way of handling, transporting and storing biomass fuels. The process helps to solve residual disposal problems as well as the reduction of fuel wood deforestation. It provides additional income for farmers and creates job. In addition, pellets have a consistent quality and high burning efficiency [28].

Pelleting technology is yet to get a strong foot hold in many developing countries like Nigeria because of technical constraints and lack of technology to suit local conditions. Overcoming the many operational problems associated with this technology and ensuring the quality of the raw material used are crucial factors in determining its commercial success. In addition to this commercial aspect, the importance of this technology lies in conserving wood, a commodity extensively used in the developing countries and leading to wide spread of deforestation [29]. The common types of biomass pelleting machines are; mechanical, hydraulic and screw presses. Several research studies had been carried out on biomass pellets, taking into cognisance the design and fabrication of a machine to produce these pellets. For instance, a comparative study between piston press and screw press pellets was carried out by [30]. They reported that the screw press pellet fuel has advantage over the piston press pellets. In other words, the screw press technology produces better pellets than the piston press technology. The quality of pellets produced from screw technology give better combustion efficiency due to its higher specific area and does not disintegrate easily which makes them superior to the piston press technology. [31, 32] further gave a number of characteristics comparing these two technologies. These are shown in Table 1.

Table 1: Comparison between a screw extruder and a piston press Source: [32]

NOS	CHARACTERISTICS	SCREW EXTRUDER	PISTON PRESS
1.	Optimum moisture content of raw material	8-9%	10-15%
2.	Wear of contact parts	high in case of screw	low in case of ram and die
3.	Output from the machine	Continuous	in strokes
4.	Power consumption	60 kWh/ton	50 kWh/ton
5.	Density of pellets	0.001-0.014 kg/m^3	0.001-0.012 kg/m^3
6.	Maintenance	Low	High
7.	Combustion performance of Pellets	very good	not so good
8.	Carbonisation to charcoal	makes good charcoal	not possible
9.	Suitability in gasifier	Suitable	not suitable
10.	Homogeneity of pellets	Homogeneous	non-homogeneous

A number of pellets have been produced using these technologies as reported by [33]. For instance, [34] carried out a study on production of fuel pellets from olive refuse and paper mill waste using the piston press technology. [35, 36] presented an experimental production of solid waste pellets from municipal solid waste by screw extrusion technology and piston press technology. [37] prepared composite fuel pellets from a mixture of biomass and coal in a roller press pelleting machine. [38] carried out studies on fibrous agricultural and wood waste materials that were compressed with suitable adhesive into solid fuel pellets in a manually compressing machine. [39] produced composite sawdust pellet fuel utilized for cooking. These pellets were produced manually. [40] also produced pellets from agricultural wastes using a manually operated machine. [4] carried out a study on high pressure densification of wood residues to form an upgraded fuel and produced pellets from wood residues using the piston technology. [41] investigated the characteristics of some biomass pellets prepared under modest die pressure and produced pellets from sawdust, rice husks, and peanut shell etc. using piston technology. [42] designed and fabricated a screw press pellet making machine. In evaluating the performance of the machine, pellets from sawdust with cassava starch was used as binder. The performance evaluation results indicated that the machine can produce pellets of 200 mm in length, 46 mm in diameter and internal hole of 10 mm in diameter, with production capacity of 60 pellets per hour. [42] also carried out design, construction and testing of poultry feed pellet machine. The machine operation capacity was found to be 5kg/h*r*. [43] carried out a study of biomass fuel pellets produced from oil palm mill residues. In their study, they presented a systematic approach in utilizing the large amount of oil palm mill residues (PKS, PF and EFB) that are loosely-bound and have low energy density. They developed pellets using the hydraulic press technology. However, their focus was on determining fuel pellets with optimum ratio of waste materials mixtures that have considerably high heating value, mechanical properties. Their proximate analysis and ultimate analysis were also determined. The end result was an optimised solid fuel with relatively high energy content made from a suitable mixing ratio of the different palm oil mill residues and an appropriate binder to ensure acceptable mechanical strength. [44] carried out a study on combustion analysis of various combinations of fuel pellets and fabricated a manually operated pelleting machine. The manual pelleting machine was made of wood material and has the capacity to produce two pellets in one cycle (a minute). However, a lot of energy is required from the operator of the machine which of course, causes fatigue and the time required to produce quite a good number of pellets was enormous. Pellets from sawdust and Fenugreek, dry leaves and paper were produced. They concluded from the result obtained that it is better to utilize methi as a binder and sawdust as its main constituent will have better performance parameters.

Some other researchers have studied the densification of woody and lignocellulosic biomass using screw press technology. [45,46] worked on understanding the compression characteristics of alfalfa pellets; [47] examined the influence of die pressure on relaxation characteristics of pelleted biomass; [48] studied pelleting fractionated alfalfa products; [49] investigated high-pressure densification of wood residues for fuel; [50] studied the compaction characteristics of lignocellulosic biomass using an Instron; and [51] studied the effect of pelleting process variables on the quality attributes of wheat distiller's dried grains with solubles. [52] carried out a study on design and fabrication of a manually operated pellet making machine. The fabricated manual machine had a low compressing pressure and production rate. He recommended the need to develop locally made (i.e. local available materials for fabrication) pelleting machines that would be powered by electric motors which are capable of exerting higher pressure and produce better quality pellets. [53] carried out a study on the development of biomass fuel for household utilisation using perennial grass as alternative to fuel wood. He designed and fabricated a screw press machine. However, the machine performance efficiency was low due to ineffective fabrication thereby resulting to poor pelletizing. [54] designed and fabricated a low pressure pelleting machine. They produced pellets without a binder. In other words, the lignin in the biomass material was used naturally to bind the material under pressure. [55] used a wooden mould to develop fuel pellets from biodegradable waste materials using maida (wheat flour) as a binder. [56] carried out a study on the development of small scale screw extrusion machine for production of sawdust pellets in rural areas in Indonesia. The extrusion machine was powered by a 5.5hp gasoline internal combustion engine. In their work, the pelleting machine was used to produce sawdust pellets with two different ratios of starch-sawdust. The result shows that the extrusion machine is able to produce compact sawdust pellets with different ratios of starch to sawdust. [57] evaluated the performance of a pelleting machine. The pellets were developed using screw press technology for different combinations of major biomass materials such as cashew shell, rice husk and grass. The developed pellets were sun dried and subjected to various tests such as the determination of moisture content, calorific value and water boiling test for assessing the quality of the fuel. [58] carried out a study on the effect of moisture content and particle size on energy consumption for dairy cattle manure pellets. Pellets were developed using hydraulic press machine. [59] studied and produced pellets from animal manure using screw press technology in order to investigate the effect of moisture content and dust levels on pellet strength. The results obtained showed that the strength of pellets reduced with increasing moisture content and the percentage of the soil in manure. The report proposed moisture content level of 45% for forming the pellets and below 20% for storage of manure pellets. In order words, the mixture for pelleting requires 45% moisture content and below 20% for already formed pellet. [60] carried out a study on pelleting of palm kernel shell, PKS using cassava starch as binder. The pellets were developed using the mould system technology. This was achieved by carbonising the shell to get the charcoal followed by the pulverization of the charcoal. The pellets were analysed for their combustion characteristics. The results obtained showed that the palm kernel shell pellets had higher calorific value than the pellets from charcoal and sawdust. [61] produced pellets from sugar cane waste using car-jack press. He also considered the use of clay and cassava starch as binder. [62] developed fuel pellets from empty fruit bunch (EFB) and waste papers as binder using the hydraulic press technology. They focused on the percentage ash content of the pellets after combustion. Pellets from six different mixing ratios (i.e. 90:10, 80:20, 70:30, 60:40, 50:50, and 40:60) were produced. From the combustion analysis results, the pellet with 50:50 mixing ratio was found to have the least percentage ash content of 1.11% compared to others. However, it was also noted that its calorific value was lower than 90:10, 80:20, 70:30, and 60:40 mixing ratios which is a key factor for combustion. [63] carried out a study on the production of fuel pellets from waste paper and coconut husk. The pellets were produced using a manually operated closed end die piston press at an average pressure of 1.2×10^3 N/m^2 using four coconut husk: waste paper mixing ratios (by weight), i.e., 0:100; 5: 95; 15: 85; and 25: 75. Results obtained showed that pellets produced from 100% waste paper and 5:95 waste paper-coconut husk ratios respectively exhibited the largest (though minimal) linear expansion on drying. While the equilibrium moisture content of the pellets ranged between 5.4 % and 13.3%. [64] investigated the mechanical properties of pellets produced from sawdust and charcoal as a potential domestic energy source. The pellets were produced using manual mould technology while cassava starch gel and orange waste were used as binder. Mixing ratios of 50:50, 60:40, 70:30, 80:20 and 90:10 of biomass materials (sawdust and charcoal) were used with 16.6% binder. The ignition time, water boiling test, and shattered index of the pellets were analysed. [65] carried out a study on the performance of composite sawdust pellet fuel in a biomass stove under simulated condition (using a fan to aid combustion). The pellets were produced using a manually operated hydraulic pellet making machine in percentage mixing ratios of 50:50, 60:40, 70:30, 80:20 and 90:10 (sawdust to charred palm kernel). Charred palm kernel shell of size 1.18mm was utilized. Starch gel was used as a binder. The calorific value of the pellets was determined and thereafter sundried. The water boiling test, WBT, was used to simulate cooking conditions using these pellets. [7] carried out an experimental investigation on the handling and storage properties of biomass fuel pellets made from oil palm mill residues. The pellets were developed specifically from palm kernel shell and palm fibre in the ratio of 60:40 using waste paper as binder. The hydraulic press technology was used for pelletizing. From their result, it was reported that the mechanical strength of the pellets were okay without sacrificing the combustion properties of the pellets. [2] carried out a comparative assessment of energy values of pellets from some agricultural by-products with two different binders. Wastes from rice husk, maize cob, groundnut shell and sugarcane bagasse were turned to pellets using banana peel and cassava peel gel as binder. The technology for pelleting was the hydraulic press system. From the results obtained, the pellets from the by-products in terms of energy values are ranked as follows: groundnut shell > sugar cane bagasse > maize cob > rice husk. [63] carried out a comparative assessment of energy value of pellets from rice husk with fuel wood. They developed pellets from biomass material such as rice husk using cassava starch as a binder. The pelleting was carried out manually using a dead weight. Good and strong pellets were produced from rice husk. Water boiling tests were carried out for combustion performance analysis which showed that 1kg of rice husk pellets took 15 minutes to boil 2 litres of water where as it took 1.2kg of firewood 21 minutes to boil the same quantity of water. [8] investigated the production and characterization of pellet charcoal by carbonization of agro-waste using locally sourced tapioca starch as binder at concentrations of 6.0, 10.0, 14.0 and 19.0 % w/w. Characterization test such as fixed carbon, ash content, moisture content, bulk density and calorific value (CV) were carried out on the charcoal pellets. The results showed that the pellet charcoal have higher CV compared to both sugarcane bagasse and wood charcoal. This was confirmed in its higher values of fixed carbon and bulk density. The corn cobs pellets have lower moisture content compared to sugarcane bagasse; however it has higher moisture content than wood charcoal. In addition, the sugarcane bagasse and wood charcoal were found to have lower ash content (4.33 % and 9.80% respectively) compared to all the five charcoal grades produced. The briquette charcoal has a mean calorific value of 32.4 MJ/kg which is significantly higher than that of both bagasses at 23.4 MJ/kg and wood charcoal at 8.27MJ/kg. Several researchers have used various binding agents for pelletizing biomass materials. In addition to the ones stated earlier, for instance, [60] explored the effects of powdered raw materials (PKS and PF) with water and starch as binders in developing pellets. Other binding options in other studies include used paper. [11] suggested that kraft paper, newspaper and used paper waste could be used to bind coal dust and other particulate combustible waste to make strong pellets. [3] had also found that the presence of paper mill waste increases the shatter index of the pellets produced. Besides, sawdust and paper mill waste increase compressive strength of the pellets as discovered by [5]. [2] also carried out fabrication and performance evaluation of pellet making machine for oil palm residues such as palm kernel shell, palm fiber and empty fruit bunch and other biomass materials. They reported that the pellet machine operates with the screw extrusion technology and has the capacity to produce 250 pellets in one hour. They also reported that the size of the pellets produced is 70mm x 50mm with 10mm internal diameter.

2.3 Electricity Generation from Biomass Wastes

It is a widely acknowledged fact that the palm oil mills in Nigeria generate large quantities of waste from their processing activities. These wastes include the PKS, PF and EFB and are generated from various stages of the processing activities. Some palm oil industries such as Nigeria Institute for Oil Palm Research (NIFOR) and PRESCO Plc in Nigeria, burn these raw residues as solid fuels in their boilers to provide steam for their mill processing operations. As a case study, [2] examined the utilization of empty fruit bunch (EFB) as an alternative fuel for firing a steam turbine plant for the production of electricity. They reported that PRESCO Plc uses about 840kg/hr. of raw empty fruit bunch, EFB, as fuel for firing their boiler and subsequently generate steam for their oil palm processes as well as 1.5MW of electricity to power their equipment. [2] carried out a study on the potentials of oil palm residues for energy utilisation. From his findings; he reported that NIFOR could generate 2.95MW of electricity for their mill using these raw residues (PKS, PF and EFB). However, in his concluding remark, he recommended that further studies be carried out on the raw residues in order to make them more suitable, durable and sustainable for power generation. In another study, [58] stated that the calorific values (CV) of oil palm residues (PKS, PF and EFB) are quite low due to their high moisture content and loose form which of course affects the overall combustion performance, thereby reducing efficiency. [2] also stated that oil palm residues burn with a lot of smoke during cooking due to their high moisture content. The side effect of such environmental hazard to health cannot be over emphasized. [44] also reported that in India, biomass from agro residues generated 773.30MW of electricity in 2009. The technology used includes direct combustion, cogeneration and gasification. In addition, [44] further reported that India had 175.78 MW of off-grid biomass power capacity. [34] carried out a study on oil palm biomass as a sustainable energy source using Malaysia as a case study. They presented a scenario of biomass in Malaysia covering the availability of feedstock as well as current and possible utilization of oil palm biomass and discussed some projects in Malaysia related to the utilization of oil palm biomass as a source of renewable energy. From the findings presented, it was clear that Malaysia has positioned herself in the right path to utilize biomass as a source of renewable energy and this can act as an example to other countries in the world that has huge biomass feedstock.

Essentially, as a way of improving on the work of [2], [12] investigated power generation potential from fuel pellets developed from oil palm residues. They reported that with 62.5million pellets produced from 10000tons of oil palm waste resource such as palm kernel shell, palm fibre and empty fruit bunch, 3.265MW of electricity could be generated from the Nigeria Institute for Oil Palm Research (NIFOR). This indicates an increase of approximately 11% in power generation capacity compared to the work of [2].

3. Conclusion

The reviewed literature suggests that biomass around the world are in abundance and are suitable for energy utilisation. A lot of research studies have shown that biomass materials such as sawdust, wood chips, rice husk, coconut shell, palm residues etc. can be pelletized or briquetted to increase their energy value and mechanical strength. It is also widely acknowledged that pellets and briquettes produced from the screw press technology are better than the pellets or briquettes from the hydraulic press technology due to the fact that the screw press pellets/briquettes have better mechanical strength, calorific value, combustion performance efficiency, etc. The reviewed literature also pointed out that pellets produced from screw press technology has the potential to increase power generation capacity from a biomass power plant.

4. Conflict of Interest

There is no conflict of interest associated with this work.

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