Development and Performance of Wood Waste Briquettes in Pyrolysis Reactor

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Abstract In the present scenario, fossil fuel-based energy comprising oil, coal and natural gas is the main source of global energy. It is leading to many environmental issues like global warming, acid rain and urban smog. Moreover, this fossil fuel is non-renewable and anticipated to be depleting in the next 4–5 decades. Wood-based energy generation is one of the oldest energy sources, and consist of many advantageous characteristics. In this review, the briquette manufacturing technology from waste wood through different processes is discussed. Huge amount of wood-based biomass produced every year throughout the world, in the form of used furniture, temporary houses and industrial waste is a liability to municipal departments of the cities and generally used as a landfill. Such wood waste can be potentially utilized for briquette manufacturing. The wood waste type, amount and availability are varying in different countries depending on domestic and industrial practices. Since the briquette is a product of wood, the product quality is dependent on the raw material characteristics like density, moisture and calorific properties of wood. Other factors like impurities in waste wood and the addition of binding material in briquette manufacturing determine the economics and market value of the briquette. The quality of the briquette is assessed on the basis of product density and calorific value. Different manufacturing technology is being practised based on the size, the moisture content in raw material and the adhesive used. The briquettes are generally burnet in a pyrolysis reactor that requires lower heating temperature, and equipment

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S. N. Sarmin et al. (eds.), *Wood Waste Management and Products*, Sustainable Materials and Technology, https://doi.org/10.1007/978-981-99-1905-5_4

investment, however, produce high energy and different by-products like bio-oil, biochar and pyrolysis gas which is used in further heating. Therefore, wood waste briquetting is not only a good substitution for energy sources but a genuine disposal of waste material.

Keywords Briquets · Biomass · Biochar · Industrial waste · Municipal waste residue · Renewable energy · Pyrolysis

1 Introduction

Energy is a basic need of modern civilization, used for generating heat for domestic as well as industrial purposes. Wood is one of the primitive sources of energy used in various forms such as firewood, charcoal, pellets and briquettes [1]. Wood-based energy is widely used for cooking, especially in developing countries like India where a large population lives in rural areas [2]. However, utilizing wood as fuel stock is not easy due to its bulky nature and low densities, which makes it difficult to use efficiently for various purposes and usually make it difficult to transport economically [3]. Furthermore, the energy generation by direct combustion of wood or its products is a wasteful practice and produces greenhouse gases. With the industrial revolution, wood utilization is replaced to a great extent by various non-renewable energy sources like fossil fuels and more recently, nuclear power on a large scale. However, such sources of energy are non-renewable and hazardous to the environment.

With the growing concerns of climate change and limited availability of fossil fuels, wood is regaining its significance in many responsible countries. This trend is increasing every year from 2010 to 2020 [4]. This pattern of biomass utilization varies in rural population as compared to urban population. The rural population collects twigs and branches of trees for their livelihood whereas the urban population consumes the whole trees which lead to deforestation [1]. In India, a huge amount of biomass is produced every year comprising the residues from the crop, used furniture, industrial waste and temporary houses at construction sites [4]. Most of these wastes are the liability of municipal departments of the cities and are generally used as landfill. These can be alternatively used for briquettes manufacturing for generating energy worldwide. Furthermore, briquettes utilization will reduce forest degradation and illegal exploitation of natural forests around the world. The steps involved in briquette manufacturing process are summarized in Fig. 1.

2 Historical Developments in Briquette Manufacturing

Briquette production is an age-old practice being used throughout the world for centuries. The fuel shortages during World War I and World War II intensified the briquette utilization, produced from various raw materials. However, after World War

Fig. 1 Flowchart of briquettes manufacturing

II, the market for briquettes decreased due to large and cheap availability of fossil fuel [5]. However, at the beginning of the 1980s with increasing concern over the environment, briquettes utilization had regained expansion in the whole European countries. It is being used as substitute for firewood in bakeries, and restaurants, as well as factories with fuelwood-burning furnaces, like red brick factories. Some of the key developments in briquette manufacturing in the last century are summarized Table 1. This development is primarily depending on three factors: availability of raw materials, the feasibility of technologies and a growing market for briquettes [6].

Since the raw material for briquettes is cellulosic biomass, energy generation through this method is considered a renewable source of energy. It comprises around 6% of total global energy consumption [4]. A survey conducted in Europe suggested that the production of briquettes was negative during the year 1995–2000 due to a lack of political will and an unorganized briquette market [8]. However, this trend changed dramatically and started increasing during the last ten years [9]. To minimize the stress on natural resource, recycling waste wood for manufacturing valuable products could be an intelligent solution. Considerable attention has been given to recycling materials like glass, iron, aluminium, plastics, etc., however, a little attention is given to recycling wood materials. The post-consumer wood materials are either burned down as a heat source or left to decompose. Over the decades, the waste wood from the wood industries and sawmills were burned directly in the furnace for heating. However this trend is changing in many responsible countries and wood wastes are entirely consumed by the composite industries like particle board and fibre board industries [10]. The other source of wood waste generating millions of tonnes every year from demolished projects, temporary settlements, new construction or land clearing, etc., still has no use and viewed as a burdensome disposal problem. Although these wood wastes are widely available in huge quantities, the main problem is the lack of technical information on methods for efficient and optimum utilization

Table 1 Development in Briquettes manufacturing [7]

Sr No	Developments	Year	Invented by
1	Equipment used for densified wood products	1864	Halsted and Halsted
2	Fully mechanized method for the production of briquettes from sawdust and shavings	1920s	Heidenstamm
3	Production of binderless briquettes	1982	Natividad

Table 2 List of patents applied and published in the development of briquettes manufacturing

Sr No	Patent No	Year of publication	Title	Inventor
1	US2824790A	1958	Briquetting of coal	Haig and Anthony
2	US3091012A	1963	Method and apparatus for making briquettes	Gustav et al.
3	JP4130826B2	2008	Method for producing moulded charcoal for fuel	Mitsuyoshi et al.
4	US1893417A	1933	Smoke less briquettes	Gustav et al.
5	US1893555A	1933	Method of manufacturing briquettes	Gustav et al.
6	US2164933A	1939	Process of baking fuel briquettes	Maurel
7	EP1502667A1	2005	Municipal waste briquetting system and method of filling land	Grillenzoni
8	WO2004067686A1	2004	Aromatic wooden briquettes for domestic cooking	Simic
9	EP2785816A1	2014	Briquette with binder and sodium and/or potassium silicates	Stormanns

without any adverse effect on the environment. Table 2 includes the list of patents applied and awarded in briquettes manufacturing.

3 Source of Wood Waste

The products manufactured from wood require multiple processes, from tree felling to finished goods. It is estimated that approximately only 50% of a whole tree is turned into valuable products, and the rest becomes waste [11]. The waste could be in the form of bark, sawdust, chips, coarse residues, shavings, planer peel and end trimmings generated during the industrial processes. This unused part of wood can potentially pollute the environment in the form of either land, air or water pollution. The average biomass generated from agriculture and forest as waste in European countries was found to be 242 million tonnes (Mt) for 2010–11, and it is expected to increase to 280 Mt by 2030 [9] (Fig. 2). It is assumed roughly half of the biomass of felled trees is wasted as residuals at site, followed by abandoned logs (3.75%), butt trimmings (2.5%), tops and branches (33.75%) and stumps (10%) [12].

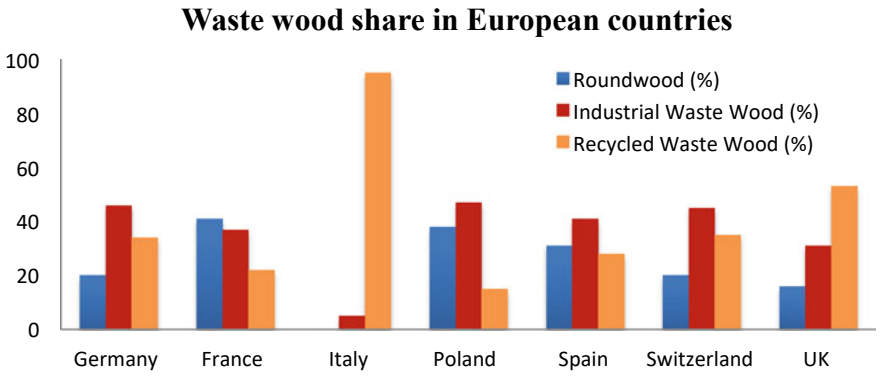


Fig. 2 Waste wood generated in European countries in the year 2015

The direct burning of this waste wood as a source of energy is considered to be a wasteful practice exhibiting poor burning efficiency and causing indoor air pollution [13]. Converting this wood-based biomass into briquettes can help to meet the energy demands for household cooking and mitigate many issues associated with firewood [14]. The additional advantage of briquettes utilization is, the waste wood obtained from industries or wood waste generated due to rapid industrialization and urbanization can be effectively utilized [15].

3.1 Industrial Wood Wastages

A significant amount of wood waste is produced from the wood processing industries in the form of sawdust, shavings, wood chips and wood cuttings. An estimate from Wood Recyclers Association 2021 reveals that Germany alone produced 11.9 million tonnes of wood waste from wood packaging, demolition and construction, wood processing industry in 2015 [16]. The packaging industries of Finland produce around 207,000 tonne of wood waste every year of which only 15% is used in product recycling and the rest are burnt energy generation.

The wood waste left at the felling site is generally burned in brick kilns to produce heat for cooking. Similarly, the fine or small particles produce in sawmills, while burning in large furnaces heaped up and do not mix well with the oxygen supply, hence resulting in incomplete combustion of biomass. This incomplete combustion generates substantial emissions of greenhouse gas like carbon dioxide and carbon monoxide, which are the primary gases contributing to global warming. However, the briquettes made from such wood particles may have better exposure to air and help in complete combustion and utilization. Ahmed et al. [17] suggested that saw dust including wood powders, wood shavings, wood chips and planer shavings are the ideal materials for briquette production. It has a suitable size, good adhesive force the least abrasion to the briquetting mills. A denser wood species with low moisture

Table 3 Fuelwood characteristic of commercially important timber species giving huge amount of industrial waste

Timber species	Density (g/cc)	Ash content (%)	Calorific value (kJ/g)	References
Acacia pinnata	0.27	1.40	18.20	[18]
Albizia procera	0.63	2.30	18.20	[18]
Rhus parviflora	0.68	1.40	18.00	[18]
Toona serrata	0.78	3.00	19.10	[18]
Acacia nilotica	0.9	0.84	19.50	[19]
Albizzia lebbeck	0.86	1.21	19.50	[20]
Salix tetrasperma	0.93	1.74	19.32	[18]
Tectona grandis	0.68	1.36	20.30	[21]

content is always preferred for briquetting due to its high energy content per unit volume and slow burning rates (Table 3).

3.2 Municipal Wood Waste

The traditional raw material for briquettes manufacturing is a non-commercial wood industrial wood waste. However, this range has been increased to municipal waste and agricultural residue waste which are available in huge quantities throughout the world. Apart from this, large quantities of waste wood are generated in residential, commercial and industrial sources as a container or packaging material. Escamilla-García et al. [22] studied the municipal waste generated every day in Mexico city and observed that it is 65% organic biomass waste including organic matter and cellulosic biomass (Fig. 3). Based on the different sources of the waste wood, it can be classified as (1) Wood packaging and pallets waste; (2) Construction and demolition wood waste and (3) Wood waste and paper waste from industries.

The other raw material for briquette manufacturing could be the used and discarded papers, block board, MDF and HPL generated in huge quantities from residences, offices, classrooms and stores are the products of wood or sawdust. It takes large space and huge effort to manage the dump site. However, they are easy to catch fire and making pellets can increase their density and unify their size, solve pollution and save fuel cost.

Recycle products	Density (g/cc)	Ash content (%)	Calorific value (kJ/g)	References
Block board	0.81	1.12	18.4	[23]
Medium density fibreboard (MDF)	0.80	1.10	18.6	[23]
High-pressure laminate (HPL)	1.38	0.81	20.4	[2]

(continued)

(continued)

Recycle products	Density (g/cc)	Ash content (%)	Calorific value (kJ/g)	References
Paper and paper board	1.12	1.5	20.08	[24]

4 Briquette Manufacturing Methods

Briquette manufacturing process is simply a densification process that produces a uniform fuel with high energy density and reduces the transport and handling costs of the bulky biomass. The densification of biomass is generally obtained by the mechanical or hydraulic press of a piston on a die. Further, in order to obtain quality briquettes a binder and heat treatment is also applied depending on the properties of the feedstock [25]. The quality of the final product is evaluated based on the resistance to compression, energy density, compaction rate and equilibrium moisture, etc. However, to produce quality briquettes selection and processing of raw material is a very important factor [26]. Such as dry materials are hard to mould, while damp materials make the wood pellets too loose. To keep the raw materials with suitable moisture, it is necessary to dry them in the range of 12–15%. Further, the size of raw materials should be less than the hole size of the pellet mill die [27]. As the hole size is usually 6, 8 and/or 10 mm, the raw materials should be under 5 mm. The adhesive generally, needed to add as a binder for making pellets. The lignin in wood biomass can also be utilized as in-situ binding material at high temperatures. The quality of the final product is evaluated based on the resistance to compression, energy density, compaction rate and equilibrium moisture, etc.

5 Briquettes Manufacturing Technology

In the process of briquette manufacturing a high pressure is applied to the biomass generally mixed with a binder in order to enhance the adhesion between the particles. There are several techniques being used worldwide which can be classified as follows: piston press, screw press, hydraulic press and roller press.

5.1 Piston Press

Piston press is one of the simplest and most common briquetting tools made up of a die and a piston (Fig. 4a). The biomass feedstock mixed with adhesive is supplied into the chamber. The pressing piston is utilized to compress the biomass against the

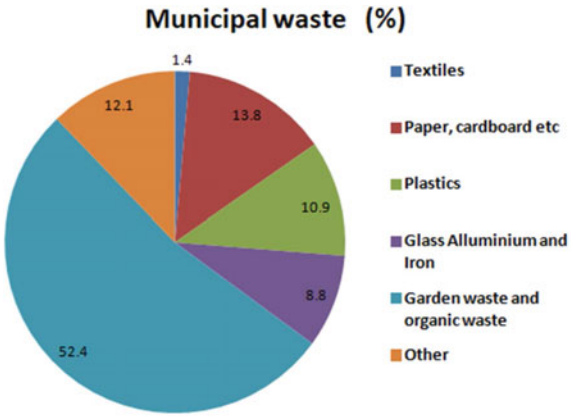
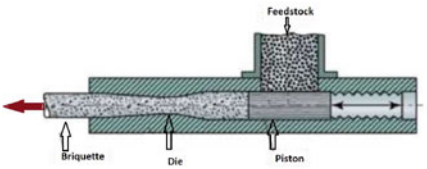
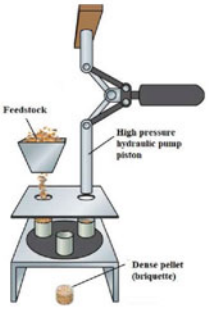


Fig. 3 A study on municipal waste generated every day (tonne/day) in Mexico City [22]

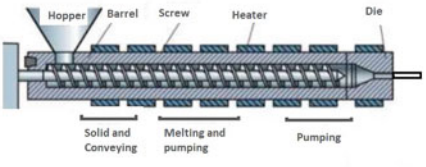
die at high pressure and give the shape to briquettes as passes through the die. By using this technique, round or square briquettes are often generated. The machine can be used for biomass having a moisture content of up to 22% [28].



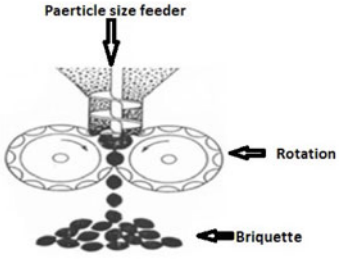
(a) Piston Press



(b) Hydaulic Press



(c) Screw Press



(d) Roller Press

Fig. 4 Techniques of briquettes manufacturing [28]

5.2 Hydraulic Press

In a hydraulic press briquetting a high-pressure hydraulic fluid system is used to transform the motor's electric energy into mechanical energy (Fig. 4b). The fundamental benefit of this approach is that it may function effectively even in environments with high moisture content. However, it has the disadvantage of a slower manufacturing rate as compared to other techniques and oil leaks.

5.3 Screw Press

A screw press is made up of a die and a screw extruder (Fig. 4c). It has generally a low diameter in the die region and is conical in shape. In this method of briquette manufacturing, the raw material must be devoid of impurities like metallic fragments, stones, etc. As the material enters the conical die it compresses to the biomass with high pressure. The advantage of this method is that it does not require any binding materials and produces high-quality briquettes. However, it can't give good results in biomass having a particle size of more than 4 mm and moisture content of more than 12%.

5.4 Roller Press

A roller press is a set of tiny dies with a diameter of around 30 mm to create pellet-sized briquettes (Fig. 4d). In this method of a thick disc with several holes drilled around it is utilized. The biomass material enters the die through a set of rollers, where it takes on the shape of the die. Die types that are used are ring and flat types.

6 Pyrolysis Reactor

In contrast to combustion, pyrolysis is the chemical decomposition of organic materials in the absence of oxygen. Therefore, pyrolysis is considered the safest way of getting green energy from waste materials. The major benefit of the pyrolysis process includes lower heating temperature requirements, lower equipment investment, and the production of by-products like liquid phase bio-oil. The criteria for choosing the most favourable pyrolysis reactors are various according to the type and properties of biomass, the energy conversion costs etc. [17]. Due to this fact, the conversion of biomass through these processes provides different types and forms of bioenergy. The bio-oil obtained from the boiler can be used directly as fuel in boilers and after modification into combustion engines. The other products like biochar and pyrolysis

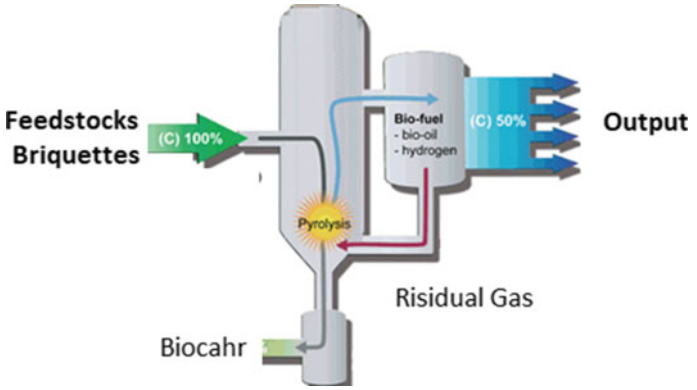


Fig. 5 Briquette pyrolysis and biochar production sketch. Adopted from Lehmann [29]

gas, can also be used as biofuels to generate heat or power in other processes (Fig. 5). Although the pyrolysis reactor has many advantages, it still has many challenges like the type of reactor, operating parameters and biomass type.

6.1 Types of Pyrolysis Reactors

There are hundreds of types of pyrolysis reactors based on the designs and therefore impossible to include all in this review. In this review classification of pyroysis reactor is classified based on the particle size i.e. fast, Intermediate (small particles >2 mm), and Slow pyrolysis reactor (logs or chips). The "fast pyrolysis reactors" is designed to use powdery biomass (particle diameter <2 mm) as feedstock and generate maximum yields of bio-oil. In the intermediate pyrolysis reactors, small particles (particle diameter >2 mm) are used to operate. The slow pyrolysis reactors are designed to use feedstock in the form of logs or chips. The slow pyrolysis reactors are further classified as kilns, retorts and converters based on the feedstocks used in the form of log, pile-wood, and chips respectively. The converters using small particles operate at conditions comparable to the intermediate pyrolysis reactors.

7 Conclusions

Although the forest is one of the renewable resources on planet earth, it is depleting very fast due to unsustainable utilization. Thousands of metric tonnes of wood waste are generated as a result in the form of used furniture, municipal waste and industrial waste. Utilizing this wood waste and transforming it into valuable products is not only conserving our natural resources but a genuine disposal of waste material. The review

covered the major developments in briquettes utilization and patents applied and awarded in United State relevant to briquette manufacturing. The factor determining the quality and character of briquettes is addressed in detail. A comparison is made to study the calorific value of wood and found that a densified biomass has always better physical and thermal properties as compared to simple wood. Briquetting parameters were examined and it is observed that temperature, die pressure and moisture content play a major role during briquette preparation. The piston press method is found to be the most widely used technique due to its easiness in construction and functioning. The briquette pyrolysis parameters such as calorific value, moisture content burning rate, and ash content are discussed. It was observed that the calorific value are higher density are the two major factors determining the briquette quality. When the density is higher it burns slowly with high compaction pressure. Further, higher ash content decreases the calorific value of briquettes and increases the risk of metal corrosion.

Promoting a briquette-based energy generation and uses in small, middle, and large-scale combustion plants will save from dangerous gas emission. Utilizing waste wood for briquetting is not only a solution to disposal management but directly reduce the pressure on natural forest. Furthermore, it has numerous economic, social and environmental advantages such as recycling wood, economic gain from waste, and mitigating greenhouse gas emissions.

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