Research and Development of Production Line for Annual Output of 300 Thousand Tons Woody Coal and Its Key Manufacturing Technology

Le-Ying Zhang¹, yan Liu¹, Yue Zhang¹, Dian-Xiang Zhu¹, ², b, *
¹ School of Intelligent Manufacturing, Taizhou Institute of SCI.& TECH., NUST., Taizhou, 225300, Jiangsu Province, China
² Department of Wood Science and Technology, Nanjing Forestry University, Nanjing, 210037, Jiangsu Province, China
*join9054@qq.com, b dianxiang@163.com

Abstract. Woody coal is a clean and environmentally friendly renewable resource and can be used as a substitute for coal. In this paper, the combustion characteristics of woody coal, energy saving and emission reduction effect, manufacturing technology and key production equipment were studied and developed. On this basis, a production line for an annual output of 300 thousand tons woody coal was established, which realized the scale of woody coal and low cost production.

1. Introduction
Woody coal is a kind of biomass solid forming fuel. Through a series of specialized equipment, the dispersed biomass materials are dried and smashed to a certain particle size, and at regular temperature, humidity and pressure, biomass solid fuel with regular shape is formed [1]. There are two kinds of biomass solid fuel: biomass pellet fuel and biomass briquette fuel. Biomass pellet fuel (woody coal) is the most used, because it is smaller than the briquette fuel, and the fuel performance is closer to the coal.

The production of woody coal is developing towards low cost and large scale. At present, woody coal has been commercialized in Japan, Europe, the United States and other places. Some Southeast Asian countries such as Burma have no large woody coal production line, the market is in a blank state and there is a huge market prospect. In 2008, China established a production line with an annual output of 10 thousand tons biomass solid forming fuel, mainly with corn straw and wood chips as raw materials. It can also process wheat straw, cotton stalk and peanut shell to produce pellet fuel and briquette fuel[2]. In 2013, the first domestic biomass solid fuel production line with an annual output of 200 thousand tons was also developed and built to achieve scale production and effectively reduce the unit energy consumption of biomass pellet fuel production[3].
2. Production technology and key manufacturing equipment of woody coal

The forming of woody coal pellets mainly depends on the lignin of plant materials. Lignin is a thermoplastic polymer material, which softens with viscosity at 70°C-110°C. It can make hemicellulose and cellulose from plant raw materials bonded to pellet fuel under pressure. Therefore, compression molding is usually used to produce woody coal pellet fuel.

2.1. Study on the production process of woody coal

The production process of woody coal pellet fuel mainly consists of cutting raw materials, dedusting and deferring, screening, crushing, drying, stirring, compressing and granulating at high temperature, cooling, screening and packing, storage and transportation. The specific technological process is shown in figure 1.

2.1.1. Preparation Process. The main material is branch material, auxiliary crop straw and sawdust. According to the different requirements of different users to the calorific value of woody coal, different kinds of raw materials can be mixed accurately to produce different product.

2.1.2. Crushing Process. The cutting wood chips are sent into a hammer machine for a pulverization, which is separated into materials less than 12mm in diameter, and then it is sent into the dryer to dry. After drying, the material is screened, and the material larger than 6mm in diameter is sent into the hammer machine for recrushing, and the qualified material is sent to the next process. The material is much easier to crush after drying, and the shape of the material is easier to control. The energy consumption of the recrushing is reduced by about 30% compared to that of the crushing.

2.1.3. Drying Process. Two parallel three channel dryers are used in parallel. According to the change of moisture content and output requirement of raw materials in different seasons, sometimes only one or two drying machines need to be driven, leaving room for future expansion of production. When the productivity is the same, the three channel drier is shorter, the floor area is smaller, and the outlet temperature is lower than the single channel drier. Its thermal efficiency is higher, and it is less likely to catch fire.

2.1.4. Raw Material Cleaning Process. Because of the mixture of raw materials in China, the content of impurities is higher than that of single raw materials. If no measures are taken, the production of wood ash will exceed the standard and the effect will be poor. For this purpose, the raw material cleaning technology from Italy was introduced and learned, and the impurities such as sand and gravel in the raw materials were effectively removed. The removal rate reached 95%. The quality of woody coal is further improved, and the service life of the ring mold and the press roller of the granulator are prolonged.

2.1.5. Granulating Process. In the pelletizing section, a multi machine combination mode is adopted, and the pelleting is developed independently. The diameter of the ring mold is 800mm and the capacity of the single machine is 5 tons/hour. The production capacity of woody coal production line ultimately depends on pelleting, and granulation molding process adopts multi-unit parallel connection mode. To save labor and improve work efficiency, the German robot palletizing system is adopted.
2.1.6. Control System. The PLC automatic control interface is used to control the whole line in the central control room.

2.2. Development of key equipment for woody coal production

2.2.1. Chipper for woody coal. The chipper for woody coal needs to cut the branches as small as possible. Therefore, the chipper for the chipboard needs to be reformed, and the number of cutting blades should be increased properly. The amount of the blade and the mesh size of the screen mesh are improved. The overall energy consumption of the improved chipper for woody coal has been reduced by about 35% compared to the same type of that for the chipboard.

2.2.2. Diamond roller screen. In general woody coal production line, raw materials are screened by vibrating screen or grading screen. But the vibrating screen has a fatal weakness. When using vibrating screen to screen wet material, it is easy to plug the mesh hole and reduce the subsequent production. There is also a weakness in grading screen, which can only screen materials in thickness direction. In order to make up for the shortage of vibrating screen and grading screen, a diamond roller screen is designed and researched, which consists of three sieve zoning and four sieve values.

The primary sieve is used to remove ash and dust from raw materials. The roller shaft adopts a diamond shaped roller, that is, the surface of the roller shaft has a convex diamond pattern, the specifications are fine, and the clearance of the roller surface is also fine. The second stage sieve is used to screen sawdust. In the main part of the roller shaft, the depth and width of the staircase grooves are determined by the specifications of the required sieving materials. The annular grooves of
a shaft are butted with the ring peaks of the adjacent axes to form a moment shaped discharge port. The third stage sieve is for sieving wood slices. The roller shaft is a rectangular spline shaft with a standard sprocket on the shaft and a sprocket with a thread hole. The sprocket is fixed in the groove of the spline shaft with the internal six angle bolts. The space is separated by the sprockets on the adjacent axis into rectangular discharge ports. The wood chips fall at the rectangular discharge port, and the wood chips that exceed the size of the discharge port will fall at the edge of the last axis.

2.2.3. Raw material chopper for woody coal. Urban waste wood materials are increasing and various materials are of different shapes. They are not suitable for chippers directly. How to cut these different raw materials into the size needed for woody coal production is a problem that must be solved. Therefore, a new cutting tool roll is designed in this equipment, and the combination tool structure is used. After the cutting edge of the cutter is worn, the fastening bolt can be adjusted to the other side of the blade. It is convenient to install, can be repeatedly used, the cutter body is spiral symmetry, the cutting vibration is small, the cutting force is big, and the energy consumption is low.

2.2.4. Three rotor hammer planer. Hammer planer, as important equipment in woody coal production, directly affects the output, quality, cost, and energy consumption of woody coal production. Compared with the two rotor hammer planer, the high performance three rotor hammer planer has a cut off effect in the production of material with bark, and it is not easy to plug the mesh, and the output is stable. On the premise of the same production capacity, it can save energy consumption by 40% compared to single rotor hammer planer.

2.2.5. Woody coal granulator. A woody coal granulator with an 800mm diameter ring mold and capacity of 5 tons per hour has been developed. The granulating machine is equipped with a quenching and tempering water spraying device and an auxiliaries adding device, which can appropriately improve the granulation process of biomass pellets. Compared with the existing "inflow" way of adding water, the water spray device adds water to a certain pressure and atomized into the conditioner and increases the contact area between water and material, so that the moisture content of the material is even more uniform. Additives are added to the feed screw to help the forming additives, which can effectively reduce the molding pressure and improve the quality of molding granules. At the same time, the automatic adjustment device of the die gap is designed in the machine, which improves the operation conditions and improves the overall working accuracy of the machine tool.

3. Design of 300 thousand tons of woody coal production line
As shown in figure 2, the workshop floor plan of 300 thousand tons biomass fuel pellets production line per year is created by the woody coal project group. It mainly includes wood chipping and hammer crushing system, crushing and drying system, granulating system and finished product processing and packing system. The main equipment includes: drum chipper, hammer mill, three channel dryer, ring molding roller granulator, counter current cooler, particle screen machine, bag packing machine, film winding machine, and all kinds of conveyors and bins with them.

Fig.2. The workshop floor plan of 300 thousand tons biomass fuel pellets production line per year
The production line uses a large number of independent research and development technical equipment, such as granulator (800mm diameter ring mold, capacity of 5 tons per hour), three rotor hammer planer (capacity 20 tons / hour), fine-grained diamond roll screen, specific gravity sand separation equipment and other equipment.

4. Study on the combustion characteristics of woody coal and the effect of energy saving and emission reduction

4.1. Study on combustion characteristics of woody coal
The calorific value of wood and straw pellet fuels is lower than that of bituminous coal, and the calorific value of wheat straw is second to the sawdust. As a result, wood is used as a raw material for biomass pellets in Europe, Canada and the United States. For example, in Nordic Baltic Sea, the main raw materials are wood materials such as round wood, wood chips and saw dust. While in China, considering the problem of excess straw with low calorific value, we use a mixture of wood materials and straw as raw materials. Its calorific value can reach about 4195 kilocalorie per kilogram. The use of this renewable biomass energy can save coal energy which is finite resource. The combustion characteristics of woody coal based on straw and poplar wood are as follows:

(1) The combustion process of rice straw and poplar wood can be divided into three stages: water analysis stage, volatilization analysis and combustion stage, fixed carbon combustion and burnout stage. Among them, the weight loss of volatilization analysis and combustion stage is the largest.

(2) The performance of poplar wood and straw woody coal in the actual combustion process is shown as follows: 1) easy to fire and combustion; 2) need to provide sufficient furnace chamber space and appropriate excess air coefficient, to promote the complete combustion of volatile components and reduce the chemical incomplete combustion heat loss; 3) compared with coal, fixed carbon combustion and burnout time will be shortened; 4) the ash and fly ash produced are very few and environmental pollution is very small.

(3) The ash fusibility of poplar woody coal is very close to that of bituminous coal, and all of them belong to fusible ash. The ash softening temperature of rice straw woody coal is low and it belongs to easily fusible ash. Therefore, the temperature of the boiler grate with straw woody coal should not be too high, otherwise it will cause serious slagging.

(4) The number of SO2 produced by 1kg poplar wood burning is only 3% of that of bituminous coal.

4.2. Study on energy saving and emission reduction effect of woody coal
The production of woody coal can effectively reduce the burning of straw. In every harvest season, a large amount of straw is burned. This is not only a waste of energy, but also pollution of the environment. It can even affect traffic. So it has become a serious public hazard. Woody coal can be made of straw as raw material that can be pressed and molded. The pellet size of biomass fuel is uniform, its density and strength are much higher than that of raw material, which is convenient for transportation and storage. Through the implementation of the project, we can promote the increase of farmers' income, solve the employment of local labor force, and provide clean energy and reduce haze.

Industrial boiler heating is the main source of heating for industrial enterprises and centralized heating in northern China. At present, the main fuel used by industrial boilers is coal. Bituminous coal is used in most areas, and the average calorific value is about 5100kCal/kg. The average thermal efficiency of the coal-fired industrial boilers is 65%. After the use of woody coal, the efficiency of the boiler increased by 15%. It can be raised to about 80%. The calorific value of woody coal is related to the type of material used to produce woody coal. Using wood processing residues and wheat straw as woody coal raw materials, the calorific value of woody coal produced is 4000–4300 kCal/kg. And each ton of woody coal can replace 1.04 to 0.96 tons (average 1 tons) of bituminous coal, that is, 1 tons of woody coal instead of 1 tons of bituminous coal. 

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After combustion of fuel in the boiler, a large amount of sulfur dioxide, carbon dioxide, fly ash and slag will be discharged. SO$_2$ is the main air pollutant, while CO$_2$ is the main greenhouse gas. The ash and sulfur content of woody coal are much less than that of bituminous coal. Woody coal is a clean and efficient renewable energy. It has obvious effect of energy saving and emission reduction. 300 thousand tons of woody coal can replace 300 thousand tons of bituminous coal.

The pollutant emission from woody coal burning can be detected by elemental analysis and industrial analysis. Dynamic combustion method was used to determine the content of elements such as C and S. Test equipment is the German VarioIII Automatic Element Analyzer. Under the high temperature of 1150°C, the sample was oxidized in a combustion tube which was introduced into a high concentration of oxygen and helium gas, and the decomposition products were detected by thermal conductivity detector in a certain order. The main content of the fuel technical analysis includes the analysis of the content of water, ash, volatile matter and fixed carbon. Instruments and facilities were used as follows: sartoriusBS224S electronic balance, DHG-C automatic computer dryer, temperature controllable muffle furnace, and micro plant shredder.

Compared with the burning of 300 thousand tons of bituminous coal, the emission reduction effect of using woody coal made of wood or wheat straw is:

1. It can reduce sulfur dioxide emissions by 9072 tons and 8448 tons, with a reduction rate of 97.4% and 90.7%.
2. It can reduce 442752 tons carbon dioxide emissions, emission reduction rate was 86.5%.
3. Dust emission can be reduced by 1914 tons and 1794 tons, with a reduction rate of 98.3% and 92% respectively.
4. 88926 and 64446 tons of slag can be reduced and the emission reduction rate is 93.1% and 67.5% respectively.
5. The fly ash and slag produced by biomass pellet combustion are rich in potassium, magnesium and other nutrients. After collection, they can be used as good agricultural fertilizer, and can be used for the growth of economic crops such as flowers [8].

5. Conclusions
Woody coal is a safe, clean and environmentally friendly energy. It can replace bituminous coal by 1:1. In the course of storage, transportation and use, there will be no accidents, such as poisoning, explosion, leakage, etc. caused by other energy sources. Few sulfur dioxide is produced by the combustion process. And ash after combustion is high quality organic fertilizer, after processing it can be sold as commercial fertilizer. So the use of woody coal instead of fossil energy can achieve the goal of energy saving and emission reduction.

The research team has carried out systematic research and development on the large-scale production process and equipment of woody coal. We have researched and developed an annual output of 300 thousand tons of woody coal production line with a large number of independent researches and development of technical equipment. The scale of woody-coal and low-cost production has been realized. The establishment of the production line and research and development of production technology and equipment will help promote the healthy development of biomass fuel industry.

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