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Economic, environmental and social assessment of briquette fuel from agricultural residues in China – A study on flat die briquetting using corn stalk

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ABSTRACT

Biomass can be relatively easily stored and transported compared with other types of renewable energy sources. Crop straw can be converted into densified solid biofuel via briquette fuel technology to expand its possible applications and enhance its utilisation efficiency. However, the potential economic, environmental and social impacts of crop straw briquette fuel need to be assessed before its large-scale use. This paper provides a comprehensive evaluation of these impacts for a fully-operating 2×10^4 t/a corn stalk briquette fuel plant in China. The results show that with a life time of 15 years, a purchase price of 150 RMB/t for corn stalk and the current sales price of 400 RMB/t for briquette fuel, the plant has a net present value of 9.6 million RMB or 1.5 million USD, an internal rate of return of 36% and a short investment payback period of 4.4 years. The life cycle greenhouse gas emissions are found to be 323 t CO_2,e/year or 1 kg CO_2,e/GJ, much lower than that of coal. Additionally, the process reduces pollution by decreasing the amount of corn stalk that is discarded or burnt directly in the field. In terms of social impacts, the use of corn stalk briquetting fuel plant is expected to play an important role in increasing local residents' income, improving rural ecological environments, alleviating energy shortages, guaranteeing energy security, and promoting socialism new rural reconstruction.

1. Introduction

Increasing environmental and energy dependency concerns have been the motivation for the increased use of bioenergy as a substitute for fossil energy in both space heating and electricity generation [1]. The use of bioenergy is a promising alternative to fossil fuel resources for the production of energy carriers and chemicals, which would consequently mitigate climate change and enhance energy security. In China, bioenergy is the third most important source of renewable energy following hydroelectricity and wind energy [2]. A major application is the combustion of agricultural and forestry residues to generate electricity and heat.

The amount of crop straw produced in China was 820 million tonnes (air dried with ~15% wt. moisture) in 2009, where corn stalk, rice straw and wheat straw were the main types of residues, accounting for 32.3%, 25% and 18.3% of the total, respectively [3]. Agricultural residues are available in large quantities in Henan Province, one of the main agricultural provinces in China and the top province in terms of crop straw production since 2000 [4].

Although China has abundant crop straw, it also suffer from adverse environmental impacts and a significant waste of potential energy resources resulted from crop straw being discarded or burnt directly in the field. Therefore, the use of these residues for energy production is highly beneficial. However, there are several significant barriers to the large-scale deployment of crop straw as an energy source. Compared with fossil fuels, crop straw is a scattered resource with a lower energy density and less efficient to store and transport [5,6]. To enable large-scale crop straw use, it is necessary to first convert crop straw into a high-density, high-value solid fuel, i.e., briquette fuel, as it is easier to handle in both transportation and in feeders for treatment units with a better conversion efficiency more storage options [7,8].

The technology to create biomass briquette fuel (BBF) compresses unshaped raw materials into solid fuel of higher density by

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means of drying, chopping and briquetting [9], thereby saving transportation and storage costs, improving its combustion quality, and expanding the scope of its application [10–13]. BBF can be used not only in power generation through gasification [14], direct combustion [15] and co-combustion [16], but also in industrial boilers, furnaces, heating boilers and other combustion equipment [17–19].

The potential economic, environmental and social impacts of BBF need to be assessed to ensure its sustainable development. Most existing studies have focused on the techno-economic aspect of BBF [14,20–22]. Two recent life cycle assessment (LCA) studies have shown that BBF produced from agricultural residue and woody biomass in Canada and Japan can achieve notable environmental benefits [23,24]. However, life cycle environmental impacts of bioenergy can vary by country due to differences in many factors such as climate and geographical conditions, technologies deployed, process energy mix and transport activities [25]. As there is no LCA study on BBF in China reported, this paper aims to fill this gap by conducting a comprehensive assessment of the economic, environmental and social impacts of a fully-operating 2×10^4 t/a corn stalk briquette fuel plant in Henan province, China. The plant deploys a newly-designed flat die briquetting machine, which will be described in more detail in the next section. In addition, direct emissions from the combustion of the BBF produced by the machine are measured and used in the environmental assessment.

2. Description of the newly-designed flat die briquetting

BBF are processed into various shapes with machines that use different briquetting procedures, such as the screw press, piston press and die press [26–28]. Pellet fuel is primarily produced by a die briquetting machine, which could have a flat die or a ring die. Cubed or blocked-shaped fuel can be processed by all types of briquetting machines. In the screw-press machine, biomass is extruded continuously by a screw through a taper die, which requires a heated-die to reduce friction. With the piston-press machine, biomass is punched into a die by a reciprocating ram via high pressure. In both the piston- and screw-press machines, the application of a heated-die and high pressure increases the temperature of the biomass, which inevitably leads to a high power consumption and fast depreciation of the parts. Furthermore, piston- and screw-press machines cannot produce pellet fuel with diameters less than 10 mm. The advantages of a die press are its low investment, low power consumption, easy operation, and good adaptability for different types of agricultural residues. Its disadvantages usually include invariable size and length of briquettes and high production noise.

We have designed a new flat die BBF machine that has many advantages compared with a normal flat die BBF machine. It can convert a broad range of feedstock into briquettes and easily change the diameter and length of briquettes and discharges briquettes. The briquetting process is easily controlled while producing little noise and using less energy. Fig. 1 shows the structural diagram and a photographic image of the BBF machine. The press roller and flat die are its main components. Press rollers connect with a bearing through a fixed frame, which is set around a principal axis, and the flat die is designed for disassembly and changeable forming holes with diameters that can range from 6 to 30 mm. An adjustment nut is set in the fixed frame of the press rollers and used to adjust the distance between the press rollers and flat die. Three press rollers are uniformly distributed on the flat die, and the central lines of the rollers cross in one point. The bearing chock connects the principal axis to the gearbox, which connects the belt wheel by a transmission shaft, which is a gear drive. A turn table connects with the principal axis at the bottom of briquetting fuel room that is over the bearing chock and below the flat die. There are two holes for the briquette cutting blades in the turn plate with a symmetric distribution, and the height of the cutting blade can be changed to create briquette fuel of different lengths. An observation door is in the press roller room, which is a cylindrical roller cavity chamber over the flat die. An outlet hopper can be fixed in the press roller room for the outlet briquette fuel, where the central line of the outlet hopper is in the same direction with the discharging rate of the briquettes from the turn plate.

The characteristics of this type of BBF machine include: (1) it is easy to observe the briquetting process for different types of biomass such that the distance between the press rollers and the flat die can be varied by the adjustment nut for different types of biomass to be converted into briquettes; (2) the flat die below the press roller can be parted and changed with the diameter of the forming hole such that different diameters of briquette fuels can be produced for the various types of equipment that use biomass briquettes; (3) the gearbox and transmission device are controlled by an automation control system such that the rotational speed and rotational direction of the press roller can be flexibly changed. Energy consumption and noise are reduced during the briquetting process because bevel gears are installed in the transmission device; (4) two cutting blades are installed in the turn plate in a symmetric distribution on the bottom of the briquetting fuel room. The length of briquettes can be changed along with the height of the blades such that the time it takes to fracture the briquette fuel and energy consumption are reduced; (5) the basic direction of the central line of the outlet hopper is in the same direction as the discharging rate of the briquettes from the turn plate such that the briquette yield is high and no briquette is blocked in the briquetting fuel room during the pelletising process.

3. Economic assessment

3.1. Project description

It is crucial that the BBF integration system can achieve large-scale operations and a high production efficiency. In this study, a fully-operating 2×10^4 t/a corn stalk briquette fuel plant located in Henan province, China is used as a case study. The plant consists of four BBF systems as shown in Fig. 2.

The BBF system combines biomass drying, chopping, briquetting, cooling and screening etc., into one unit, and has the following processing procedures: (1) biomass is sent into the drying machine by the feedstock machine. Longer straw such as corn stalk will be chopped into a suitable size before drying. Heating comes from a hot blast furnace, which requires dust settlement and air supply before entering into the drying machine. The non-uniform biomass moisture content is no greater than 3% after drying and can be varied flexibly; (2) to attain a proper particle size for pelletising, the dried biomass is sent into the chopping machine with a good balance and hence small vibrations; (3) the chopped biomass is sent into the briquetting machine after passing through the cyclone; (4) briquetting is sent into the screening machine by the hoisting machine, where briquettes with densities between 0.7 and 1.2 g/cm^3 are obtained after screening and cooling.

In this integrated system, the drying capacity of the dry machine ranges from 0.3 to 1.5 t/h with a heat use efficiency higher than 60%. The chopping capacity of the chopping machine ranges from 0.3 to 0.5 t/h with an electric power consumption of no more than 20 kWh/t. The particle size of the biomass from the chopping machine ranges from 3 to 6 mm and can be varied flexibly. The briquette capacity of the briquetting machine ranges from 0.3 to 1.5 t/h. The electricity consumption for all machines is between 60 and 80 kWh/t.