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Optimization of a biomass briquette fuel system based on grey relational analysis and analytic hierarchy process: A study using cornstalks in China

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HIGHLIGHTS

- Evaluation model of biomass briquette fuel system is established base on GRA and AHP.
- 5 hierarchies along with 20 other indices are included in the model.
- An optimal scheme is selected for a 2×10^4 t/a corn stalk briquette fuel plant.
- An analysis of the selecting biomass briquette fuel system scheme is improved.
- The result is of benefit to scheme selection of biomass briquette fuel system.

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ABSTRACT

Biomass, such as agricultural straw, can be converted into briquette fuel using technology to expand the possible applications of biomass and improve biomass utilization efficiency. The major machines required in a briquette fuel system, such as those used for drying, chopping, briquetting, and cooling, have become more efficient. However, a biomass briquetting fuel system requires special machines to reach a high character index, and all units in the system must match and be combined to produce an optimum system that satisfies multiple objectives, such as economy, environmental protection, stability, and large-scale operation. In this paper, a mathematical model for a synthesized evaluation was established according to theories of grey relational analysis (GRA) and the analytic hierarchy process (AHP). This model was used to select a biomass briquette fuel (BBF) system scheme considering hierarchies of economy, cleanliness and environmental protection, production capacity, product quality, and production stability, along with 20 other indices, including capital investment, dust content, drying capability, briquette rate, and the machine repair cycle. The most significant factors influencing each hierarchy were analyzed using a sensitivity analysis. Based on the GRA and AHP theories, an optimal scheme was selected for a fully operational 2×10^4 t/a cornstalk briquette fuel plant in China. The optimum scheme included six sets of briquetting machines with a capacity of 2 t/h + three sets of chopping machines with a capacity of 5 t/h + six sets of drying machines with a capability of 2 t/h + 1 set of cooling machines with a capacity of 12 t/h. The evaluated indices and weight coefficients were chosen objectively, and the comprehensive and technical performances of the selected BBF system scheme improved. These results provide a reference for the scheme selection and operation of large-scale BBF systems.

1. Introduction

Biomass can convert solar energy into chemical energy, which is stored in a biological form, through photosynthesis. Biomass resources are widely available worldwide and provide a major

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share of the renewable energy sources in most countries [1]. Bioenergy provides nearly 15% of the world's total energy consumption and is the fourth-largest energy source after oil, coal, and natural gas. Bioenergy is the only form of renewable energy that can be collected, stored, and transported, and is the form of renewable energy most similar to "conventional" fossil fuel energy sources [2]. In recent years, biomass has become increasingly important for district heating, power generation, and the transportation sector due to various support schemes [3]. Biomass is not only a "green" clean energy source but is also the only type of renewable carbon resource. Biomass is the only carbon–neutral energy resource that can be converted into any form of fuel, including solid, liquid, or gas [4], all of which play important roles in renewable energy.

Compared with coal, oil, and natural gas, agricultural straw is a scattered resource with a lower energy density and is less efficient for storage and transportation [5]. Generally, briquette fuel has better energy parameters, higher density, and lower moisture content than its raw materials [6]. For large-scale use, crop straw must be converted into a high-density, high-value solid fuel (i.e., briquette fuel) that is easier to handle in terms of transportation and when used in feeders for treatment units. Briquette fuel also allows for better conversion efficiency and more storage options [7]. The process of creating biomass briquette fuel (BBF) involves compressing unshaped raw material into higher-density briquette fuel by drying, chopping, and forming into briquettes [8], thereby reducing transportation and storage costs, improving the combustion quality, and generally expanding the scope of its application [9–11].

During the past decade, research on and the applications of BBF have increased, and the ratios of energy consumption during the densification process have been investigated [12]. Some research on biomass briquettes regarding falling stability and compressibility strength was performed to determine the mechanical strength of the briquettes and to determine their water resistance [13]. The results of research on the transformation of biomass (vegetable market waste) into an energy briquette showed that biomass can be converted into high-quality briquette fuel. Such transformation of biomass may prove to be a viable option for "restoring" the waste to a useful energy source rather than being left to decompose, creating environmental problems of its own [14].

Several studies have focused on biomass torrefaction and chopping (pulverization). A study on process optimization of combined biomass torrefaction and pelletization for fuel pellet production indicated that the parameters of particle size and degree of torrefaction had significant influences on the compression and friction work, as well as the pellet dimensions and strength [15]. Torrefaction is a promising bioenergy pretreatment technology, with the potential to make a major contribution to the commoditization of biomass. Analyses of mass and energy balances were used to identify torrefaction process performance characteristics, such as thermal efficiency and mass yield, and to discuss their determining factors [16].

Understanding the effects of mill operating factors on biomass size reduction would be useful for predicting or adjusting the particle-size distributions that affect the supply chain efficiency and biomass-to-fuel conversion processes. To study such effects, biomass (wheat straw) particle-size distributions generated by a knife mill were determined for the integral classification of screen sizes; the results indicated the relative effects of knife mill operating factors on the production of particular particle sizes of wheat straw [17]. A novel biomass crushing system was presented, including a description of the production process and an investigation of the physical characteristics of the biomass powder produced; the bulk density was found to be significantly increased after pulverization [18].

With various energy crises and forms of environmental pollution becoming subjects of increasing concern, technological innovations in energy-related equipment have begun to focus on improving efficiency, reducing consumption, and protecting the environment. Regarding BBF systems, many kinds have different components and productivities. For example, systems with drying and briquetting as major components are usually suitable for sawdust briquette fuel systems, while those with chopping and briquetting components are appropriate for small-scale straw briquette fuel systems. Drying, chopping, briquetting, and cooling machines are major components in large-scale operations (usually having productivity >5000 t/a) of BBF systems. By integrating the machines involved in these processes, biomass materials can be converted into high-efficiency briquettes.

The present study focuses on a biomass briquetting fuel system for which the drying, chopping, briquetting, and cooling sections are combined to produce an optimum system that satisfies multiple objectives, such as economy, environmental protection, stability, and large-scale operation. Thus, the final decisions regarding the economy, environmental protection, stability, and scale of BBF system operation are complex. Fig. 1 shows a schematic presentation of different indices affecting the production of briquette fuel. The factors of product quality, production capacity, and cleanliness and environmental protection, as well as production stability, are all affected by the economy; i.e., these factors will be improved when all the indices of the economy are increased, whereas the economy can be better or worse if these factors remain changed. One or several indices of cleanliness and environmental protection will be affected by product quality, production capacity, and production stability. Product quality, production capacity, and cleanliness and environmental protection will be affected by production stability because the product quality will be better, production capacity will increase, and both cleanliness and environmental protection will improve when production stability is improved. Economy, cleanliness and environmental protection, production capacity, product quality, and production stability determine the optimum scheme, whereas the optimum scheme affects the indices.

This study developed a mathematical model for selecting the components of a BBF scheme system, considering hierarchies of economy, cleanliness and environmental protection, production capacity, product quality, and production stability, along with 20 other indices, quantifying factors such as capital investment, dust content, drying capability, briquette rate, and machine repair cycle. Based on theories of grey relational analysis (GRA) and the analytic hierarchy process (AHP), an optimal BBF system was then selected. The evaluation indices and weight coefficients were chosen objectively to improve the comprehensive and technical performance of the selected BBF system schemes.

2. Main indices of a biomass briquette fuel system

Many factors influence the large-scale operation of a BBF system incorporating different machine components with different operation sequences. To develop an optimal scheme, many indices should be considered to maximize the multiple objectives. However, such multiple objectives are typically inconsistent and even contradictory, so quantifying and combining the different indices are important to obtain a comprehensive and optimal solution. The BBF system consists of five major factors: economy, cleanliness and environmental protection, production capacity, product quality, and production stability.