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Full Length Article

Briquetting and carbonization of naturally grown algae biomass for low-cost fuel and activated carbon production

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ABSTRACT

This study reports the briquetting and carbonization processes of naturally grown algae biomass collected from regional lakes. After drying them in air and chopping them into small pieces (~2.5 × 2.5 cm), three different briquetting pressures (e.g., 2, 3, and 5 tons/cm^2) were applied to form algae briquettes with 3–5% moisture content. Three major investigations were performed on the prepared samples. The first test was to investigate the briquettes' handleability, in which the algae briquettes were dropped 100 times from a height of 1.524 m to resemble a handling mechanism. The second test was conducted on the samples to resolve the residual strength of the briquettes before and after the carbonization process at 800 °C. Ignition points of the algae briquettes were reviewed in the third analysis. Test results showed that briquettes under 2, 3, and 5 tons/cm^2 of pressure had density values of 1303, 1423, and 1553 kg/m^3, respectively. Drop tests demonstrated that the weight contractions of the briquettes were reduced from 10.2% to 2.1%, when the pressure was intensified from 2 to 5 tons. Ignition temperatures for the non-carbonized briquettes under 2, 3, and 5 tons/cm^2 were 492, 510, and 520 °C, respectively; however, after carbonization, these temperatures were reduced to 474, 487, and 492 °C, respectively. Compression strength tests for the non-carbonized briquettes under 2, 3, and 5 tons/cm^2 resulted in 22.1, 29.2, and 33.5 MPa, respectively. These test outcomes can be suitable for future guidance of an algae-based biomass and fuel system for reducing environmental impacts.

1. Introduction

The phenomenon of global warming is a prediction concept based on the greenhouse gas effect, which has been evaluated using testable/observable information gathered from historical and current data relative to varying surface temperatures. The global sea level rise and melting of arctic ice show that the science behind these predictions has merit [1]. Whatever the reason or motivation behind renewable forms of energy for solving the most economical, social, environmental, and health issues, these concerns could be mitigated by utilizing environmentally friendly renewable energy sources. Substantial interest is being focused on solar, wind, geothermal, and biofuel energy. Among the biofuel categories, algae-based fuels have been receiving a great deal of interest because algae is seen as a super cell [2,3]. Algae's vast biodiversity with fast growth potential in its adapted condition, and also the large assortment of useful, naturally occurring, or stress-induced chemical compounds that algae can generate have been reasons for the underlying interest in algae-based renewable fuels. Much of the algae research is geared towards producing liquid biofuels. Only a limited amount of research has been conducted on using the algae biomass as a direct fuel, which could have the potential of replacing wood and charcoal in its utility as a fuel.

Among all the algae types, microalgae are seriously considered because of their various benefits. Microalgae can be cloned to double their biomass within 24 h because they are single-celled organisms [1]. Microalgae can be harvested in a marginal, semiarid countryside depending on the species that is preferred for cultivation. In addition, they can multiply on natural water, gray water, or even saltwater lakes and seas [2]. Phototrophic algae organisms use forms of inorganic carbon (CO_2), while heterotrophic algae use forms of organic (glucose, cellulose) carbon sources to generate lipids. The amount and type of lipids that microalgae can produce vary from species to species. These lipids are divided into two types: neutral (triglycerides, cholesterol) and polar (phospholipids, galactolipids). Neutral lipid triglycerides are the main ingredient in the production of biodiesel. These algae organisms use a three-step process to form triglycerides: (a) the formation of acetyl coenzyme A (acetyl-coA) in the cytoplasm; (b) the elongation and desatura-

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tion of carbon chains of fatty acids; and (c) the biosynthesis of triglycerides [1].

The prospect of employing algae as a source of biomass is well documented [3,4]. Much of the related research has focused on producing liquid biofuels [1,7–9]. Only limited research studies were conducted on the algae biomass as direct fuel sources for the replacement of wood, charcoal and other biomasses, which may help control the release of greenhouse gases [5–7]. Activated carbon has bountiful uses in industry, and several forms of organic carbon sources have been examined as precursor materials [10–15]. Therefore, it is time to introduce algae as generators of activated carbon for lake and waste water treatments and hydrogen production. Methods of drying, densification, briquetting, carbonization, and modification are necessary to satisfy the issues and develop sustainable algae fuel in the future [1–6].

Activated carbon is utilized in many industrial applications; therefore, several forms of organic carbon sources have been investigated as precursor materials. Some are readily available and cheaply accessible agricultural refuses, such as pomegranate seeds [11], palm shells [12], peanut shells, and mango nuts [13]. Also, sludge from waste water treatment plants has been investigated as a precursor [14]; therefore, carbon sources can be any form of organic carbon-containing materials [15]. It is proposed that algae biomass can be used to generate activated carbons. However, the research that is available mainly addresses marine algae [16]; the opportunities for using freshwater algae in this field have not yet been properly investigated. Also, because of the fact that many of the algae-based fuel generation and use can create vast amounts of waste precursor materials for many use, it can be seen as a major benefit for activated carbon generation, as well. In particular, the biochar generated from various thermochemical conversions could be utilized. This concept was tested using a low-temperature pyrolysis of mallee wood biomass physically activated by steam. A low conversion was achieved, but it was shown to have a high porosity value [17].

Industrial-scale activated carbon production comes primarily from coal; hence, the cost can be higher based on coal prices and locations [16]. Activated carbon can be prepared by chemical activation and physical activation locally. Chemical activation can be done in one or two steps. The single-step method involves impregnating the precursor material with an activating agent and then carbonizing it. The two-step method involves creating the carbonaceous material and then chemically activating this pre-made carbon source [18]. This method can utilize already-used, burned or carbonized algae residue. Tests conducted to compare the efficiency of the two methods have indicated that the single-step method, or simultaneous activation and carbonization, creates a highly porous and efficient activated carbon for industrial purposes [18]. Physical activation of carbon can be done with steam or carbon dioxide. Both methods have been shown to generate microporosity in the carbon structure. However, a large increase of meso- and macroporosity with steam and high burn-off was observed [19,20].

Algae can provide a source of carbon for generating activated carbon sources for various industrial applications [1,21–25]. However, the problems associated with the direct use of algae as a fuel must be resolved. Major hurdles have involved growing, handling, and transportation issues due to the loose nature of the dried biomass and its specific locations. Densifying the material to be similar to charcoal, wood, and other agricultural waste briquettes could provide the algae biomass with a much more intrinsic value. This densification can provide better mechanical properties and dimensional stability. A great deal of information in the public domain relates to algae biomass densification and the effects of compaction pressure on durability and resistance to various handling conditions [1]. The research involved in this type of investigation could provide a starting point for understanding ways to improve algae briquetting techniques and could lead to efficient use of this abundant energy source. Thus, finding optimal manufacturing pressures that can be used for superior densification with suitable durability, but without spending an immense amount of energy in the process, will be important.

Briquetting can address several handling- and transportation-related issues because it increases the material handling characteristics of the precursor feedstock. Also, the briquetting process could enhance the mechanical properties as well as dimensional stability of the biomass, as opposed to its loose bulk condition [24,25]. Thus, an important step is to study the effects of compaction pressure on durability and resistance of the biomass briquettes. Carbonization of the biomass briquettes will reduce the amount of liquid and gas in the biomass and further increase the carbon content for various applications, such as household heating, industrial steam generation, outdoor barbequing, and so on.

2. Experimentation

2.1. Materials

In this study, two locations were chosen to gather algae: from the City of Wichita Water Center and from a private pond. The algae were washed with tap water to remove mud and visible impurities. Then, after blending the two algae batches together, they were dried in air using solar heat for about one week. Since the collection process of algae is natural and direct sun light can be used to dry the algae biomass up, it can be considered as an economically viable process. The amount of energy and labor are also at minimum level. A pair of scissors was used to cut the dried algae biomass into approximately 2.5 × 2.5-cm pieces. Before using the biomass, the dried algae was stored in a five-gallon bucket with a tightly sealed lid. The bucket was kept in a dry, cool place to avoid exposure to additional moisture or extreme environmental conditions. In addition to this, steel mold was used for algae briquetting and a PVC pipe was needed for drop test. Besides, muffle furnace was used for ignition test and MTS machine helped to test the compression strength of briquettes.

2.2. Methods

2.2.1. Algae briquetting

Prior to the briquetting tests, a cylindrical die and punch mold with a diameter of 12.5 cm were designed in CATIA and manufactured using high carbon steel in the university's machine shop. Three grams of dried and sieved algae were measured and placed into the steel mold to make the briquettes. A thin film of vegetable oil was applied to the punch rod to decrease resistance during the punch/piston removal and release of the briquette after fabrication. A traditional hydraulic press was used to apply the compression load on the samples. When the desired pressure was reached, two minutes of load was continuously applied on the samples to create strong briquettes. The pressure was released after two minutes, and the mold was opened to remove the produced briquettes. External pressures of 2, 3, and 5 tons/cm^2, which were equivalent to about 178, 267, and 445 MPa compression loads, respectively, were applied to produce the briquettes. Earlier studies conducted on wood residue found that lignin melts around 150 MPa because of the heat generation within the immense pressure mold (about 120 °C), which creates stronger and compacted briquettes [1]. In fact, algae play an important role for a better briquetting process because most of them have smaller amounts of lignin and fibrous structures. Densities of the briquettes were determined after using different loads. Fig. 1 shows the hydraulic press with the metallic