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Production of Smokeless Bio-briquettes from Hazelnut Shell

H.Haykiri-Acma, and S.Yaman

Abstract—**Woody shells of hazelnut which is a high potential biomass species in Turkey was carbonized in a horizontal tube furnace at 600ºC to eliminate the volatiles and to obtain smokeless char. Then, the solid product was briquetted in a stainless steel mold using a hydraulic press under pressure of 50-100 kg/cm^2. In order to improve the mechanical strength of the bio-briquettes molasses and the pyrolytic liquid that obtained during carbonization was used as binding agents. Some parameters such as Shatter index, compressibility strength, and water resistance were considered to evaluate the strength of the briquettes.**

Index Terms—**Biomass, hazelnut, bio-briquettes, smokeless.**

I. INTRODUCTION

The need for renewable and sustainable alternative energy sources are growing due to the rapid depletion of the non-renewable fossil energy resources and the negative impacts of the increasing prices of these fuels on the developing economies. In this respect, biomass is of great interest because of its miscellaneous advantages such as easily finding, low price, carbon dioxide neutral feature, and very high worldwide potential.

Agricultural and forest residues, industrial wastes, municipal solid wastes (MSW), and refuse derive fuels (RDF) are the well-known types of the biomass energy resources which are numerous in number.

However, direct combustion of biomass is not preferable because of the negative aspects coming from the intrinsic properties of biomass such as low density, low calorific value in a unit volume, and high moisture, etc.

From this point of view, it is important to develop strategies by which biomass is converted to secondary fuels which have better characteristics in comparison to the parent material. On the other hand, in order to reduce the environmental pollution risks of such fuels, some precautions must be taken. In this context, production of smokeless fuel briquettes from biomass which have quite high calorific value and almost hardly any volatile matter is a reasonable technique to take advantage of the energy potential of biomass in environmental friendly way. For this purpose, biomass is first carbonized to eliminate the moisture and volatile matter contents and then the volatile matter-free solid char, which is called as “smokeless fuel”, is briquetted to form firm bio-fuel briquettes. It is reported in literature that serious increases take place in the calorific value of the product owing to the elimination of the volatile matter, leaving a solid product having higher carbon content [1]. Furthermore, transportation and storage costs are apparently lowered as a result of the densification of biomass. Consequently, a non-polluting solid fuel which can be competitive with coal with respect to calorific value can be produced applying this procedure.

In order to improve the mechanical strength of the bio-briquettes, some additives and binding materials are added to biomass and they are briquetted together in the same briquetting mold. For this purpose, various additives such as humates, molasses, H_3PO_4, and sulphite liquor have been used in briquetting.

It is reported in literature that the exothermic reaction of some binders such as molasses and lime during briquetting provides the removal of the moisture in the briquettes [2].

Blesa et al. reported that carbonization of coal and olive husks at 600ºC and then briquetting of the chars from carbonization with molasses under pressure of 125 MPa shows the best mechanical strength when they are waited for 2 hours at 200ºC [3]. Besides, the optimum carbonization temperature for low rank coals was found as 600ºC [4].

Similarly, mechanically durable fuel briquettes could be produced from low rank coal char and sawdust char in the presence of humates under a briquetting pressure of 125 MPa [5].

Briquetting of coal and some biomasses such as sawdust, straw, olive husks, and almond shell using the binders of humates and $Ca(OH)_2$ at ambient temperature under 125 MPa gave the best results when the feedstock materials were subjected to heating up to 160ºC with a rate of 2ºC/min prior to briquetting [6].

Also, it is reported that the water resistance for the coal briquettes which obtained under 125 MPa using some binders such as humates and sugar cane was very satisfactory [7].

Coal and olive husks were carbonized at 600 °C to be used in the production of durable briquettes under 125 MPa using a binding agent which contains humates (6%) and sugar (16%) [8].

Mayoral et al. determined that the briquetting of a smokeless fuel that obtained from the carbonization of coal and olive husks at 600ºC gave very good results in terms of mechanical strength when the briquetting was performed under 125 MPa and at 200ºC using sugar cane as a binder [9].

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In the view of the previous works, the aim of this study is to carbonize a biomass source which is a different type of biomass material, and then usage of molasses and an alternative binding agent such as the pyrolytic liquor which is obtained from the carbonization of biomass as a liquid product. Woody shells of hazelnut have been selected as biomass material due to its potential in Turkey. In fact, Turkey supplies nearly 75% of world hazelnut production and consequently a great amount of woody shells are obtained every year.

II. MATERIALS AND METHODS

Prior to grinding to a particle size of -250 µm, hazelnut shells were first air dried and then completely drying was carried out in an oven at 105°C for a day. Proximate and ultimate analyses were performed according to ASTM standards.

Scanning Electron Microscopy (SEM) image of the sample was obtained using a Hitachi TM 1000 Tabletop Microscope linked with an Energy Dispersive (EDS) attachment.

Thermogravimetric Analysis (TGA) was used under nitrogen flow up to 900°C with a heating rate of 40°C/min in order to predict the final temperature of the carbonization experiment. For this purpose, a TA Instruments SDTQ600 model thermogravimetric analyzer was used. Derivative Thermogravimetric Analysis (DTG) profile was derived to interpret the mass losses from the biomass sample.

Carbonization run was conducted in a horizontal tube furnace under nitrogen flow using 10 g of ground (-250 µm) hazelnut shell which is placed into a quartz crucible. Nitrogen flow was allowed for 30 min to purge the furnace prior to heating, and then heating was applied from ambient to 600°C with a heating rate of 15°C/min. A hold time of 45 min was allowed at 600°C to assure that the volatile matter removal is completed. After hold time, the remaining residue was kept in the furnace under nitrogen flow until its temperature drops to the room temperature.

The maximum pressurizing capacity of the hydraulic press used in the briquetting experiments was 1110 MPa between two plates with a speed of 50 mm/min. The cylindrical briquetting mold was made of hardened steel.

Some standard tests were applied to determine the shatter index, compressive strength and water resistance of the briquettes. The shatter indices were determined according to ISO-R 616. The compressive strength of the briquettes was determined using an Instron table model 1195 testing machine. The water resistance of the briquettes was tested by immersing them in a glass container filled with water and measuring the time required for dispersion in water.

III. RESULTS AND DISCUSSION

Table 1 presents the proximate, ultimate, and structural analyses results of hazelnut shell. According to these results it is clear that the hazelnut shells have a typical biomass structure with respect to high volatile matter and low fixed carbon compared to coal. On the other hand, oxygen content which leads to high reactivity during thermal processes such as combustion, gasification, carbonization, and pyrolysis is very high. In addition, lignin is the dominant organic ingredient found in this biomass material.

Table 1. Analysis Results of Hazelnut Shell

Proximate Analysis (%, dry)	Volatiles	72.0
	Fixed carbon	21.0
	Ash	7.0
Ultimate Analysis (%, dry-ash-free)	C	54.8
	H	6.7
	N	1.0
	S	0.1
	O*	37.4
Structural Analysis (%, dry)	Extractives	6.2
	Lignin	51.5
	Holocellulose	38.6
Calorific Analysis (as received)	Higher calorific value (kcal/kg)	4512

* calculated by difference

SEM image of the biomass is seen in Fig.1. This figure reveals that hazelnut shell is very rich in fine particles and some of which have the dimensions of several microns.

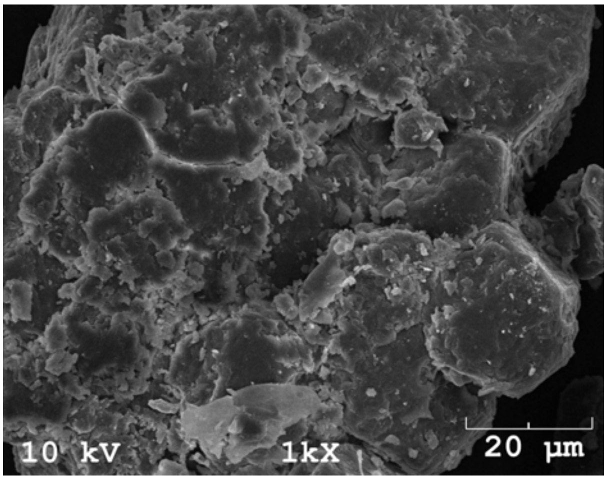

Fig. 1. SEM Image of Hazelnut Shell

Fig.2 illustrates the DTG profile which shows the rate of the mass losses from the sample depending on temperature. Based on this curve it is possible to say that the most of the volatiles left the biomass structure at around 400°C, and beyond that temperature the rate of the mass losses became very low. However, 600°C was selected as the final temperature of the carbonization process to provide a satisfactorily removal of the volatiles and to produce a smokeless fuel.

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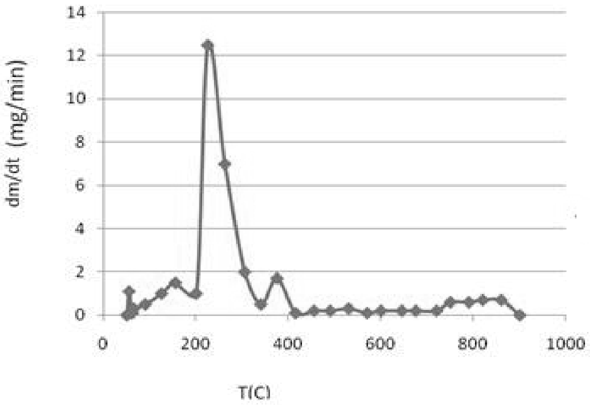

Fig. 2. DTG Curve

Carbonization decomposed the biomass structure, and a porous residue remained as volatiles eliminated. That is, the recovered solid remnant from the carbonization of hazelnut shell was around 28 wt% basing on the proportion of the recovered weight to the initial weight of the feedstock.

The higher calorific value of the char was 7783 kcal/kg which is very high compared to that of the original sample (4512 kcal/kg). Elimination of the volatile species such as carbon dioxide, carbon monoxide, molecular water, and light hydrocarbons left a structure which contains much more carbon, and this is responsible for the increase in the calorific value of the solid char.

As to the briquetting experiments, it was first attempted to produce a fuel briquette in a stainless steel mold using 5 g of char under a briquetting pressure of 50kg/cm^2. Since, the strength of the briquette was not satisfactory, the operation was repeated by increasing the briquetting pressure to 100kg/cm^2. But, it was seen that the increase in the briquetting pressure was not enough to obtain firm briquettes yet. After that, briquetting operation was tried ones more using a mold with a diameter of 3 cm under the pressures of 50kg/cm^2 and 100kg/cm^2 without adding any binding agent.

The results of these tests showed that the variations in the mold diameter nor briquetting pressure did not provide suitable conditions to obtain strong bio-briquettes without using any binder. Therefore, it was decided to add some binding agent to the char before briquetting. For this purpose, molasses and liquid product of carbonization have been used.

Briquetting runs were conducted using binders in different ratios to establish the optimum conditions under which desirable bio-briquettes can be obtained. Firstly, a mixture containing 10 wt% of molasses was tested. Although a slight improvement took place in the properties of the briquette as a result of the presence of the binder, the mechanical strength of the briquettes were still not at the desired level. Thus, the weight of the mixture containing molasses was reduced to the half (2.5 g). The mixture containing 15 wt% of molasses gave briquettes which have not enough mechanical strength. Therefore, it was decided to use the liquid product of carbonization (LPC) as another binder instead of trying higher ratios of molasses in the mixture. For this purpose, the ratio of this new binder was chosen as 10 wt% in the mixture to be briquetted. So, the next run was carried out using binary binder materials (15 wt% molasses + 10 wt% LPC) under a pressure of 100kg/cm^2 for a mixture of 3 g in the mold with the diameter of 2 cm. The briquetted that obtained under these conditions gave fairly good values reflecting the mechanical strength. The calorific value of the obtained briquette was 6864 kcal/kg. The reason why some reduction occurred in the calorific value is that the calorific values of the added binders are not as much as the char to be briquetted. On the other hand, XRF results of LPC revealed that this binder contains 0.12% of sulfur, 0.01% of calcium, and 0.002% of iron.

The obtained briquettes are seen in Fig.3.

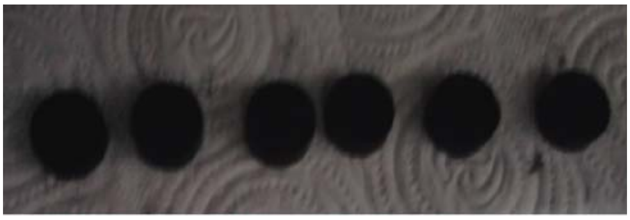

Fig. 3. The Smokeless Briquettes from Hazelnut Shell

The durability of the obtained briquettes against physical effects was investigated considering Shatter Index and compressive strength methods. The compressive strength test results showed that a pressure of 81 kg/cm^2 is required to break the briquettes, whereas the weight loss during Shatter Index test was only 0.0204 g. These values are quite high and it can be said that the mechanical strength of these briquettes is sufficient to overcome the physical effects that act toward disintegration. On the other hand, water resistance of the briquettes was measured as 4.8 min. This value is not very high, but an effective packaging that supplies water-proof conditions may be helpful to meet the market requirements.

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