

Development of a Pelletizing Process to Improve the Properties of Biomass Pellets

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ABSTRACT

Energy from biomass sources has earned significant interest in recent times. In the present research, an attempt has been made to develop a pelletizing process to improve the properties of biomass pellets, as many of the important properties of the pellets are dependent upon the raw and additives materials. Thus, their proper selection has a vital role in producing better quality pellets. The information about the material properties of raw materials, such as rice husk and sawdust, as well as their effect over the quality of the manufactured pellets were studied. The thermochemical properties of various rice husks have been analyzed to improve the decision to select better quality raw materials for the pelletizing process. The chemical composition of three other biomass raw materials (namely beech, spruce, and straw) has also been analyzed to prove that the presence of hydrophobic extractives has a significant influence on the bonding quality between biomass particles during the pelletizing process. Therefore, choosing a less extractive raw material is beneficial for the pelletizing process. After analyzing the thermochemical properties of various rice husks, ROK 14 and BRRI 46 were found better for pellets production. The beech type of raw materials was found to be more suitable for its adhesive bonding ability during pelletization. The present study also discusses the properties of various starch as additives and their effect on the production of pellet characteristics, and the Oxidized Corn starch was found to be the best additive, in the peasant research, as it not only improves properties but also reduces power consumption.

Keywords: Biomass pellet, Rice husk, Additives, Properties, Extractive, Selection.

1. INTRODUCTION

Biomass has become one of the most commonly used renewable sources of energy in the last two decades [1]. Biomass pellets (shown in Figure 1) are biofuels made from compressed organic matter or biomass [1]. They are fabricated using a custom machine (exemplified in Figure 2). Many of the biomass energy products used today come in the form of wood products, dried vegetation, crop residues, and aquatic plants [1]. In 2000, the European Commission mandated to the European Committee for Standardization, CEN under committee TC335 to prepare standards for solid biofuels, deciding on the standard values of some of the major properties.

Figure 2 depicts a semi-automatic ring die pellet machine, the rotating components of which comprise a Motor (speed of up to 1400 RPM, with Power of

1HP), Sun gear (Module 2, outer dia 98 mm, teeth number 47), Planet gear (module 2, outer dia 47 mm, teeth number 35 mm), and Ring Gear (module 2, Outer dia 220 mm, teeth number 117). The pellets produced from this machine should have a diameter of 10mm and a length of 26mm. The capacity of this machine is 25 kg/hr and is rated to produce at least 18,939 pellets per hour.

The pellets, shown in Figure 1, were produced using rice husk as the raw material. Wetted tissue paper and rice flour were used as binding materials. A ratio of 3:1:1:1 was maintained during pelletization for the following materials: rice husk, wetted tissue paper, rice flour, and water. The average diameter, length, density, and weight of the pellets were 9 mm, 33.4 mm, 0.00074 gm/mm³, and 1.562 gm, respectively.



Figure 1. Biomass Pellets from Rice Husk Produced at Ahsanullah University of Science and Technology, Bangladesh

The properties of biomass pellets are very important in terms of pellet quality. The most important properties of biomass pellets are reported to be moisture content, bulk density, durability, net heating value, ash content, volatile matter content, fixed carbon content, sulfur content, Nitrogen content, and ash fusibility [2].

Different thermochemical properties of various rice husks have been critically analysed for the pelletizing process. Also, the chemical composition of two other materials (namely beech and spruce) has been identified. It is expected that the development of an effective pelletizing process based on the critical analysis of the thermochemical properties of selected raw materials conducted in the present study will help us to attain the objectives of the study. The objectives are,

1. To identify suitable raw materials for the production of biomass pellets; and
2. To develop a pelletizing process to improve the properties of biomass pellets

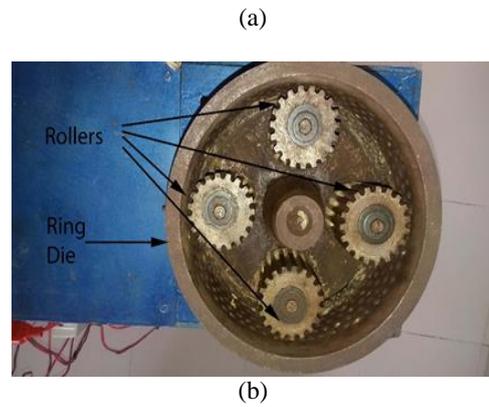


Figure 2. Biomass Pellet Production Machine at Ahsanullah University of Science and Technology, Bangladesh

2. METHODOLOGY

The present research aims to develop a pelletizing process based on a comprehensive literature review for producing improved quality biomass pellets. To achieve this, the main steps are:

- identification of the desirable properties of rice husk;
- identification of the desirable properties of a binding material/additive;

To achieve the above aim, a literature review has been conducted to find information related to the properties of various rice husks, three raw materials (namely rice husk, beech, and spruce) and additives (starch and modified starch) for the production of pellets.

2.1. Identification of the Desirable Properties of Rice Husks

2.1.1. Finding Relevant Codes and Standard

Herbaceous biomass is classified into cereal crops, pastures, oilseed crops, tubers and legumes, flowers, herbaceous biomass of gardens, parks, pruning, vineyards, orchards, and mixtures of all these [3]. This biomass can be used at raw (direct residues of the field) or processed (from the food industry) forms [3]. Residues from cereal crops include the use of the following parts of plants: dried stems, pods, and husks, as well as their mixtures [3]. Rice husk is considered as herbaceous biomass. Pellets from herbaceous biomass are compared with Part 6 (EN ISO 17225-6) for non-woody biomass and the limits of the properties are shown in Table 1 [3]. Information in Table 1 is following the EN ISO 17225-6.

Table 1. Limit values for pellets from herbaceous biomass (National Standards Authority of Ireland: Ireland, UK, 2014) [4]

Property	Herbaceous Biomass
M (% wb)	≤10
BD (kg/m ³ ·wb)	≥600
DU (%)	≥97.5
N (% db)	≤0.7
S (% db)	≤0.10
Ash (% db)	≤6.0
LHV (MJ/kg.wb)	NR
NR – Not Required	

2.1.2. Identification of The Thermochemical Properties

The most important properties of biomass pellets are moisture content, bulk density, durability, ash content, heating value, sulfur, and nitrogen content [3]. Most of these properties are directly related to the selection of raw materials as they are the primary fuel [5]. The selection of raw material directly impacts the quality of the manufactured pellets. The thermochemical properties of six types of rice husks (Lemont, ROK 14, ROK 16, ROK 32, CP 4, and Pa Potho) have been identified and compiled in Table 2.

Table 2. Amount of Moisture Content, Bulk density, Lower Heating Value, N, S, and Ash Content of Various types of Rice Husks [5]

Rice Husk	Moisture Content (%)	Bulk Density (kg /m ³)	Lower Heating Value (Mj/kg)	N ^b	S ^b	Ash
Lemont	9.08	92	14.22	0.38	0.034	23.35
ROK 14	8.68	106	13.24	0.40	0.024	18.76
ROK 16	10.44	86	16.20	0.46	0.021	14.28
ROK 32	10.20	105	14.60	0.46	0.014	19.59
CP4	9.00	114	13.40	0.50	0.015	24.46
Pa Potho	10.16	110	14.12	0.51	0.025	18.04

^aAverage of three replicates
^bValues are in units of wt %, dry basis

Table 3. Amount of Moisture Content, Bulk density, Lower Heating Value, N, S, and Ash Content of Various types of Rice Husks in Bangladesh [6]

Rice Husk	Moisture Content (%)	Bulk Density (Kg/m ³)	Higher Heating Values (Mj/kg)	N (%) (ppm)	S (%) (ppm)	Ash (%)
BRR1 Dhan49	9.13	110	13.69	.62	.19	16.5
BRR1 Dhan 47	9.91	116	13.56	.56	.20	17
BRR1 Dhan46	9.68	108	14.42	.53	.22	16
BR22	9.75	112	13.31	.64	.16	20

2.2. Determination of the Chemical Composition of Beech, Spruce, and Straw

Based on the literature review, the chemical composition of Beech, Spruce, and Straw have been compiled and presented in Table 4 and the compression strength of pellets from those three types are listed in Table 5.

Table 4. Chemical Composition of Beech, Spruce, and Straw [7]

Biomass Type	Cellulose (%)	Lignin (%)	Hemicellulose (%)	Extractive (%)	Ash (%)
Beech	38.7	19.3	27.6	0.6	0.6
Spruce	41.3	21.56	22.2	1.8	0.6
Straw	37.8	29.6	19.1	4.4	4.6

Table 5. Compression strength and their respective standard deviations of biomass pellets [7]

Material	Temperature (°C)	Force at break (kN)
Beech	20	0.93 ± 0.13
Beech	100	1.53 ± 0.18
Spruce	20	1.09 ± 0.08
Spruce	100	1.27 ± 0.13
Straw	20	0.24 ± 0.06
Straw	100	0.37 ± 0.05

2.3. Identification of Desirable Properties for Additives

Additive materials have a significant role in pellet production. With the selection of better additives, the pellet properties can be improved. Also, additives can be selected for modifying certain properties that are lacking in the raw material. For example, clay minerals and dolomite or lime-based additives were successfully used to increase the ash melting temperature and Kaolin also proved to be a very suitable additive [8]. When wheat pellets were combusted with kaolin, added to an equivalent of 20%

of fuel ash content, showed an increase of fusion temperature by 250 °C and in the study, the reduction of slagging tendencies was observed by admixing kaolin and calcite in wood pellet production [8]. Again, Minerals, such as kaolin and dolomite, have been suggested as fuel additives to increase the ash flow temperature. The potassium capture by kaolin partly explains the higher flow temperature of the ash-additive mixture [8].

There are many additives that are available in the market. The selection of additives depends upon the need of the pellet producer. The use of additives in pellets to improve properties has been practiced in industry, and these additives can also reduce energy and maintenance costs associated with pelletization [9].

Additives not only improve the quality of pellets but also by selecting proper additives the power consumption during the pelletizing process can be reduced [10]. Cody et al. [9] suggested that using small amounts of additives in biomass pellets can substantially affect the pellet properties concerning the energy content, durability, and the energy required to produce the pellets. It is possible to use more than one additive in the biomass pellets, assuming the combination does not counteract the other additives [9]. In our study, we have selected starch as our additives because starch fits the criteria of being renewable, having properties that make it a likely candidate to be a useful additive. Here, we are going to discuss which properties of starch should be considered in terms of using it as additives.

2.3.1. Desirable Properties of Starch as Additives

Starches and modified starches have been used in adhesives, binding, film-forming, foam strengthening, gelling, and moisture-retaining, stabilizing, and thickening applications [11]. Native starch is the basic product obtained when cereals or tubers are separated into their starch, protein, and fiber components [10]. Oxidation of starch, performed using sodium hypochlorite is a common process in the starch industry and it depolymerizes the starch molecules, and at the same time, carboxyl and carbonyl groups are introduced on the starch molecules [10]. According to Solam GmbH, the perceived benefit results not from the added groups but the depolymerization [10]. The degradation of the starch affects the behavior of the granules upon gelatinization and thereby its properties as an adhesive [10]. Oxidation is known to improve the tack and adhesive properties of the starches [12]. It depolymerizes the starch molecules, and at the same time, carboxyl and carbonyl groups are introduced on the starch molecules [10]. The degradation of the

starch affects the behavior of the granules upon gelatinization and thereby its properties as an adhesive [10].

Starch is unique among the carbohydrates in that it occurs naturally as discrete particles [13]. Such granules are relatively dense and insoluble and hydrate only slightly in cold water [10]. If dispersed, they produce low-viscosity slurries. Starch suspended in cold water is essentially unable to act as an adhesive [10]. The thickening effect of starch is realized when the granules are heated in the presence of water [13]. Starch is formed from two polymers: (a) linear polysaccharide called amylose, and (b) large highly branched polysaccharide called amylopectin [10].

The various starches differ in the proportion of amylose to amylopectin: regular corn starch contains 25–28% amylose; wheat contains 25–29% amylose; and potato contains 18–21% amylose [13]. Starch granules are made up of concentric alternating layers of crystalline regions interspaced with amorphous layers [11]. As granules absorb water, they swell, losing crystallinity, and leaching amylose [13]. Starch gelatinization is the uptake and swelling that occurs when starch and water are heated together and the reason for choosing oxidized starch is that the gelling behavior is quite different from a native starch [10]. The oxidized starch granules do not swell in one piece as a native starch does; they divide themselves into many small parts during the gelatinization [10].

All starches contain small amounts of lipids and proteins. The lipid content is approximately 0.8% for corn, 0.1% for potato, and 0.9% for wheat, calculated per dry substance [10]. Potato starch is unique in that it contains phosphate groups attached to some hydroxyl groups, which gives it a charge that increases its hydrophobicity and contributes to the rapid swelling of potato starch in warm water [11]. Starch is already used in some markets to achieve reduced operating costs and better durability [10]. Obernberger and Thek [14] found that 7% of 23% producers of pellets (mostly in Austria) used starch as a biological binding agent to reduce the operating cost and achieve higher abrasion resistance.

The starch content among the pellet producers varied between 0.16 and 1.25 wt % [wet basis (wb)] [10]. Nielsen showed by laboratory measurements that, when 5% of potato starch was added, the strength of the pellets increased [15]. Razuan in 2011 tested the pelletization of palm kernel cake and used three different starches as the binder: corn starch, tapioca starch, and potato starch [16]. Corn starch was the most effective of the starch binders; the tensile strength of the pellets improved with up to 10 wt %, and further additions of the three starches, up to 20 wt %, made the pellets deteriorate in terms of tensile strength, even though density increased [10]. In single-pellet compression equipment, Finney et al. [16] tested suitable binders, such as caustic soda and starch and they found that maize-based starch, i.e., corn starch, as much as doubled pellet tensile strength. The tensile strength is not defined in the European standard but can be

considered to be related to durability [10]. When starch is added, the temperature during the pelletizing process seems relevant [10]. Finney tested elevated temperatures to evaluate the softening of starch present and found that an increased production temperature (45–75 °C) improved the overall pellet quality, measured as durability, tensile strength, and density, although an additional temperature increase (of up to 125 °C) did not further improve the quality [10].

The granules of the different starch raw materials have different sizes and shapes and because of the different sizes and shapes, the number of granules present in 1 g of starch differs in quality and gelling behavior which is shown in Table 6. [10]. This could influence the spreading in the wood material and the number of possible “gluing” points in the pellet and it is important to prove that additives or mixes of materials that are introduced on the market significantly reduce the electricity used by the pellet machine [10].

Table 6. Properties of Starches (Data Delivered from Solam GmbH) [10]

Properties	Native Wheat Starch	Oxidized Corn Starch	Native Potato Starch	Oxidized Potato Starch
Granule size (µm)	0.5-0.45	2-30	5-100	5-100
average (weight) ^a	25	15	45	45
average (number) ^b	8	10	30	30
granules/g (×10 ⁶)	2600	1300	100	100
density (kg/m ³)	~600	~600	~700	~700
gelatinization	52-85	62-80	58-65	58-65
Temperature (°C)	~60	~65	58-65	~60
gelling behavior	the granules swell in one piece during gelatinization	the granules divide themselves into many small parts upon gelatinization	the granules swell in one piece during gelatinization	the granules divide themselves into many small parts upon gelatinization
^a The average diameter, as used in the starch business. ^b The median size, as used in the starch business				

From Stahl et al. [10] it was found that among the four starches, oxidized Corn starches were the best as additives as pellets produced from them had better durability, better tensile strength, required less power consumption, and achieved better bulk density. Because there are two important properties found from their experiment [10] and they are the number of granules and their oxidation. The pellet with native starch has a larger number of non-gelatinized granular particles still in the pellet than the oxidized starch [10]. Again, the better the number of granules better the quality of the pellet.

There are two major components of starch amylose (AM) and amylopectin (AP). They help to increase the adhesiveness nature (with the help of water) which helps the particles to hold each other [17]. The other component protein increased heat-resistant capacity and kept the hardness and stickiness of rice flour gel when the temperature is changed, whereas it decreased pasting temperature and also protein increased adhesiveness, springiness, and cohesiveness of the product [17].

3. RESULTS

3.1. Analysis of Thermochemical Properties of Rice Husk to Improve The Pelletizing Process

To select appropriate rice husk-based raw material for the pelletizing process, we should critically analyze the thermochemical properties of the raw materials. From Table 1, we have found that a lesser amount of moisture, ash, Nitrogen, and Sulfur contents are beneficial for the production of biomass pellets. Also, a higher amount of bulk density is desirable. By comparing the information from Tables 1 and 2, we can identify three properties that should be considered before the pelletizing process in a machine. These three properties are (a) moisture content, (b) Nitrogen content, and (c) Sulfur content.

In terms of moisture content, we can select three rice husks (which are Lemont, Rok 14, and CP4) from Table 2 which maintains the standard value of moisture contents shown in Table 1. Among these, ROK 14 has the lowest moisture content. Three of their N and S content are far less than the highest value shown in Table 1. Among them, ROK 14 has less ash content and has great bulk density. Based on these findings, ROK 14 can be considered as the most suitable raw material for pelletizing. Again, after analyzing table 3 BRRI Dhan 46 can be considered as the best raw material for the pelletizing process as it contains high Higher Heating Value, Less N, S, and Ash content. Also, it has less moisture content than two other types of Rice husks.

3.2. Selection of Raw Materials for improving the pelletizing process

From Tables 4 and 5, we can find that beech is a better raw material than spruce and straw for the pelletizing process because of their higher compressive strength at high temperatures. Because the presence of hydrophobic extractives has a significant influence on the bonding quality between biomass particles during the pelletizing process [7] and a material with low extractive is more likely to form better bonding between particles at a high temperature. So, we should select a raw material with low extractive for the pelletizing process. The durability of pellets depends on the compressive strengths and a higher value is desirable. Stahl et al. [7] found pellets produced from beech at high temperature were optimal to form better bonding between the particles during pelletization among the raw material shown in Table 4.

3.3. Selection of Additives for Improving The Pelletizing Process

From section 3.3.1 it was found that a number of granules, oxidation, amylose, amylopectin, and protein content were important properties for the selection of additives among the starch. As we know additives not only improve the properties of biomass pellets it can also reduce power consumption. From Stahl et al. [10] it was found that oxidized corn starch was best as additive among the starch shown in Table 6. Again, sometimes it has been found that the price of additives is higher than the price of raw material. So, it is important to study and compare the price among the additives [18].

4. DISCUSSION

The improvement in the selection of raw materials in terms of thermochemical properties and chemical composition is more beneficial for the improvement of biomass pellet properties. Before the pelletizing process, the properties of the raw material can improve the properties of the biomass pellet.

In the present research, after analyzing the thermochemical properties of six types of rice husks from Table 2, ROK14 was found to be the most suitable for the pelletizing process due to low moisture content, low N, and S content. Again, after analyzing the thermochemical properties of four types of Rice Husk for Bangladesh in table 3, BRRI 46 was found as the most suitable for the pelletizing process because it contains greater High Heating Value, less N, S, and Ash content. The moisture content of rice husk substantially affects its quality as a fuel source. An increase in the moisture content decreases its heating value, which in turn, reduces the conversion

efficiency and performance of the system because a large amount of energy would be used for the vaporization of the fuel moisture during conversion [5]. Furthermore, due to the lower content of NO_x emissions during the combustion process will be lower. In terms of chemical compositions, materials having low extractive were selected as the low extractive material has a significant influence on bonding at high temperature. To prove this point, the compressive strengths of three types of pellets from different sources were analyzed, and it was found that the beech type material has less extractive matter.

Binding material or additives are used in pellets to improve the property of biomass pellets. This comprises the properties that are lacking in the raw material. There are many additives available on the market. Here starch is only discussed among all the additives as it is highly customizable and easily discoverable. Properties of four types of starch had been discussed and among them, Oxidized Corn Starch was best for additives as it has a large number of granules and as it was oxidized the granules divide themselves into many small parts upon gelatinization and improves the adhesion between the particles so as it improves the durability and reduces the power consumption. Before choosing any additives it is important to keep in mind the properties that need to improve and which additives should affect the properties and their costing. If the cost gets too high, it won't be effective to attract the consumer to buy and use pellets.

We haven't been able to produce pellets and testing their properties to verify our research because of the COVID-19. So, we reviewed various journal and thesis papers to search and verify our findings.

5. CONCLUSIONS

The main goal in the present research was to develop a process for improving the properties of biomass pellets by choosing better raw materials and additives. Raw material with better thermochemical and chemical characteristics may affect the properties of biomass pellets. Thus, by using proper additives, higher pellet strength, and reduced power consumption can be achieved. Additives also improve the properties of the pellets by reducing the lacking's present on the raw material. Hence, developing the selection process of raw materials and additives leads to the development of the pellet production process. By analyzing the thermochemical properties of various rice husks, ROK14 and BRRI46 were shortlisted as prospective candidates. Among different types of starch, Oxidized Corn was found to be a potential candidate.

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