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Original Research

Development of a Newly Designed Hydraulic Type Briquetting Machine Used in Briquetting of Apricot (*Prunus armeniaca* L.) Plant Residues at Different Compaction Pressures

Bahadır Demirel*

Erciyes University, Faculty of Agriculture, Department of Biosystems Engineering, Kayseri, Turkey

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Abstract

In this study, briquettes were obtained with a redesigned hydraulic press machine using the pruning residues released after the apricot harvesting and the possibilities of obtaining solid biofuel were investigated. In the experiments solid briquettes were obtained with a moisture content of approximately 8-10%, particle size of 2-5 mm and five different compression pressures (80, 100, 120, 140 and 160 MPa). The physical properties of the briquettes, the capacity of the machine and the specific energy consumption were determined for the durability of the briquettes. The densities of the briquettes varied between 975.55-1286.78 kg.m^{-3} on the wet basis. The obtained data results were subjected to statistical analysis results (PCA,ANOVA) and tried to be evaluated. It has been observed that different compression pressures are important on the volume weights of the briquettes ($p<0.01$). The average highest briquette firmness (12525.36 N), tumbler test (97.55%) and shatter test (98.45%), briquette density (1269.85 kg.m^{-3}) values were obtained at 160 MPa compaction pressure. The average highest capacity (5.75 kg.h^{-1}) values were obtained at 80 MPa compaction pressure and the average highest specific energy consumption (0.20 kWh.kg^{-1}) values were obtained at 160 MPa compaction pressure. It has been determined that different compression pressures have an effect on the solid biofuel properties of the briquettes obtained from apricots, and it has been observed that these effects are very important at high compaction pressures (160 MPa). While calorific value of the of wood dust briquettes were obtained 4522 kcal.kg^{-1}, apricot briquettes is 4605 kcal.kg^{-1}, average percentage ash content wood dust 3.87% apricot briquettes calculated as 0.77%. Also, it was observed that the flue gas emission values of the apricot briquettes as a result of burning were within acceptable limits. These results indicate that the briquettes made from apricot residues have high heating values enough for domestic use and small-scale industrial cottage applications.

Keywords: apricot, agricultural residues, biomass, briquette, energy

*e-mail: bahdem@erciyes.edu.tr

Introduction

Biomass is a carbon-based natural energy source obtained from plant and animal origin materials. Biomass energy can produce biogas, liquid fuels and electricity as a fuel due to its many different aspects [SaidurR]. As a biomass source, it can be used as a fuel source after necessary conversion technologies in agricultural residues. One of these agricultural residues is fruit pruning waste. Considering the variety and potential of fruit grown in the world, pruning residues have an important place among the woody biomass resources [1]. Due to the high production capacity in field and horticultural agriculture worldwide, researchers' interest in evaluating these residues and using them as a biomass energy source is increasing [2-4]. When these studies carried out by the researchers are examined, the determination of this biomass potential and the evaluation of these pruning residues have become very important in terms of meeting the energy need, especially in rural areas.

Apricot (*Prunus armeniaca* L.) has been cultivated for more than 5000 years across a wide area of the world, including Türkiye, Iran, Turkestan, Afghanistan, Central Asia, and Western China [5]. Apricots consumed fresh and dried are among the agricultural products with high nutritional value [6]. With an apricot production of 833398 tons.year^{-1}, Turkey is ranked first in fresh apricot production and dried apricot exports worldwide [7]. The most economically important apricot-growing area in Turkey is the eastern Anatolia region [8] where 65-70% of the world's dried apricots are produced in this region [5]. Considering that approximately 5 kg of pruning waste is taken per tree [9], it is seen that the total amount of waste is approximately 100000 tons, which will be approximately 80000 tons of waste that can be converted into solid fuel.

Briquetting is an important technology in the evaluation of biomass residues with high potential as an energy input to reduce these energy inputs. The purpose of briquetting is to reduce the transportation cost by increasing the energy density of the raw material and to produce briquettes with standardized properties for incineration [10, 11]. Differences in the production conditions of the briquette press used in the briquetting process, depending on the type of raw material, should be taken into account. It is important that the briquetting machine to be designed works properly in these different conditions in each production site [12]. In industry, the design of machines is somewhat based on experience. Briquettes produced for briquetting machines should be able to meet the optimum parameters, provide low energy consumption while maintaining quality production from trial and error processes and at the same time meet international standards or certificates [13, 14].

In this study, the apricot plant was selected. This is because it requires more pruning than other fruit trees. This is because the fruits are formed on 1 year old branches. Annual shoots must be in sufficient quantity every year in order to get crops every year. Pruning residues discarded after pruning is an important source of solid fuel.

In this study, the design parameters of the redesigned briquetting machine will be determined and it is aimed to better understand how they affect the briquetting process. Apricot residues were used for this machine and at the same time optimum briquetting pressure was determined for these residues. Determining the parameters that can be used in the redesigned briquetting machine for this purpose will shorten the briquetting preparation time. By defining the important process parameters for briquetting, the most suitable briquette combination was tried to be determined for the residues selected in the study. Apart from that, with this type of machines, especially in small businesses, the purchasing costs can be high due to their large capacity. As a result of this study, it will pave the way for the possibilities of producing machines that are easy to buy. In addition, agricultural enterprises will gain economically by converting their own waste into valuable products.

Material and Method

Briquette Production and Characterization

The residues obtained before briquetting were dried in natural environment (In summer, outdoor temperature: 28ºC, outdoor humidity: 42%). In addition, in order to accelerate the drying time of the residues, the drying process was accelerated by taking the residues into the glass greenhouse (outdoor temperature: 36ºC, outdoor humidity: 35%). For the briquetting experiments, the moisture content of the residues was determined in the range of 8-10% in accordance with the standards [15]. Agricultural residues, which were dried, were ground in a hammer mill and 2-5 mm particle size determined for the study and in accordance with the standards for the briquetting process.

A specially designed hydraulic type briquetting machine was developed and briquetting of the residues was carried out. In the developed hydraulic type briquetting machine, the compression pressures can be adjusted between 0-240 MPa. The specified working pressures have been set on the machine with the help of a pressure gauge. The hydraulic press carries out the compression process with a horizontal positioning of its cylinder and piston. Here's the optimized content: Fig. 1 shows the hydraulic briquetting machine used for agricultural residue briquetting, while Fig. 2 displays the mold features. In the experiments, the briquettes were obtained as full. The cylindrical mold has a length of 135 mm, an inner diameter of 50 mm and a wall thickness of 25 mm.

The new design briquetting machine was tested at five different working pressures to determine its optimal performance. These three instances, Krizan P. [17],

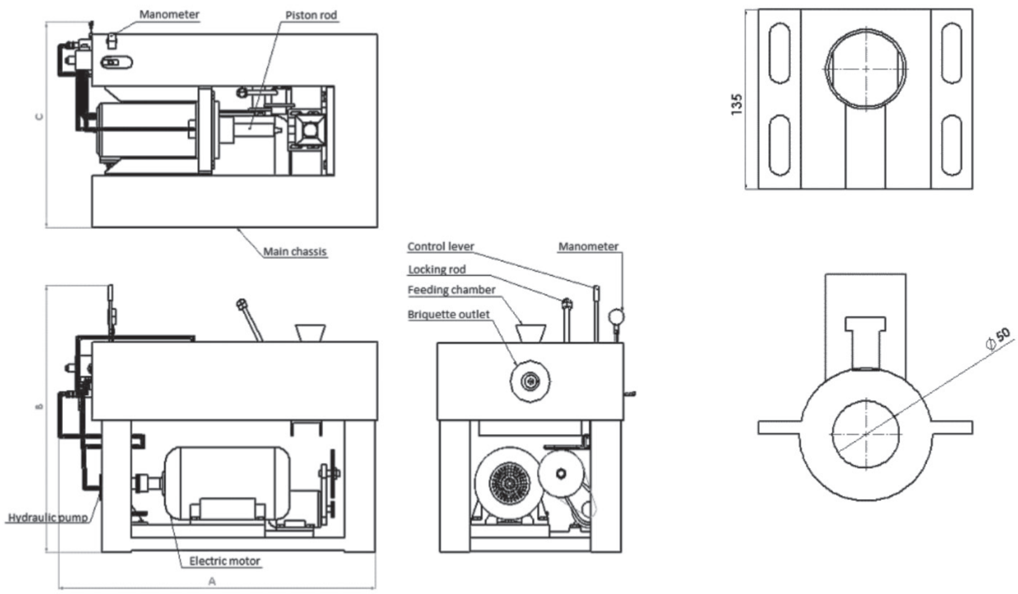

Fig. 1. General view and main structural elements and mold used of the specially designed hydraulic type briquetting machine (A: 1280 mm; B: 1155 mm; C: 740 mm) [16].

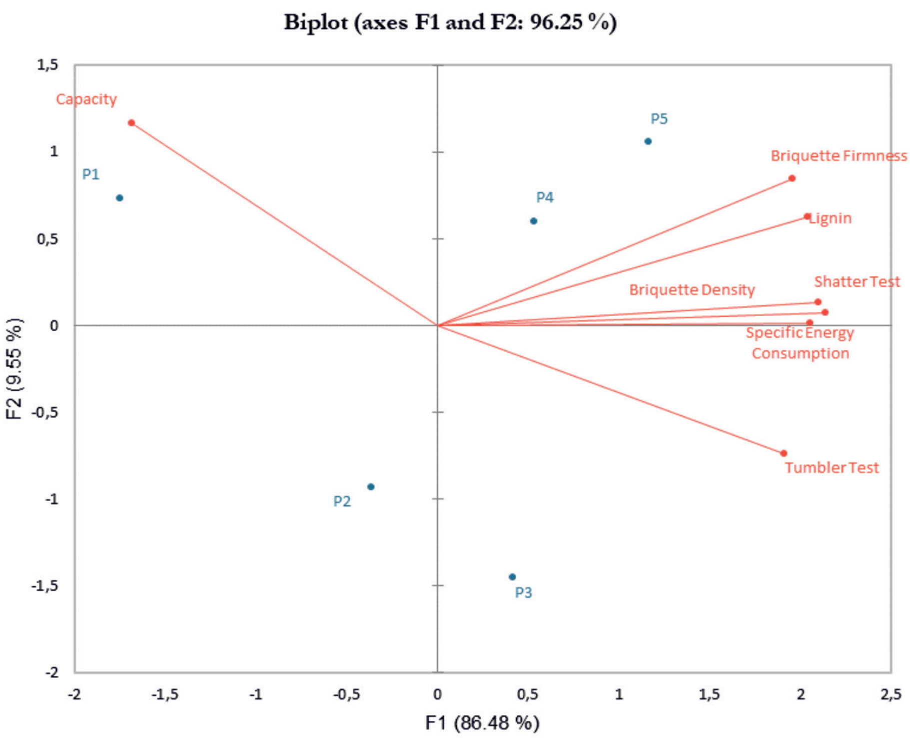

Fig. 2. PCA graph of operating characteristics P: pressure P1: 80 MPa, P2: 100 MPa, P3: 120 MPa, P4: 140, MPa, P5: 160 MPa.

et al., Zhang J. and Guo Y. [18] and Sun B. [19] et al. demonstrate similarities with their respective studies. The agricultural residues were ground in a hammer mill after being dried, and then brought to an appropriate particle size for the briquetting process. The compaction process was carried out without the use of any additional material. No extra materials were added during the process. The residue was transferred to the material tank and then pushed into the cylindrical mold using a piston. In each trial, approximately 150-250 g residue was poured into the mold gradually, depending on the filling state of the mold. Afterward, the compaction process was performed. The compacted material was pressed for an extra 20 seconds to avoid any expansion after the compaction process was completed. Briquettes measuring 50 mm in diameter and 80-110 mm in length were produced as a result of the briquetting process.

Briquetting Process

Huang Q.B. [20] et al. and Saeed A.A.H. [21] et al. reported that moisture content is very important in both material strength and compaction. With these studies in parallel with EU standards, the moisture content has been determined as 8-10% for apricot pruning residues depending on these standards [22]. The dried material was ground using an electric hammer mill equipped with 8 hammers rotating at a speed of 2850 rpm and powered by 3 kW. The ground particles had a size range of 2-5 mm, and the moisture content was measured again. Subsequently, the particles were compacted into briquettes using a briquetting machine [23]. Table 1 provides the properties of the apricot pruning residues utilized in the briquetting experiments.

Briquette Tests

The tests made for the briquettes obtained from the residues released after the pruning of the apricot tree are given in the Table 2 together with the standards.

Work Capacity and Energy Consumption

After the briquetting machine entered the regime, a specific amount of material was added to the material warehouse to determine the machine's capacity and energy consumption. The machine's work capacity was determined by measuring the briquetting time of the material poured into the warehouse and was calculated as $kg.h^{-1}$. The machine's energy consumption was determined by reading the electricity meter it is connected to, measured in kWh. The processes were conducted thrice in order to ascertain the mean machine work capacity and energy consumption.

Specific Energy Consumption

The machine's briquetting capacity was determined by dividing the mass of produced briquettes by the time taken to complete the briquetting process. The specific electrical energy consumption of the machine was determined by calculating the ratio of consumed electrical energy to machine capacity ($kWh.kg^{-1}$) during a certain amount of briquette production while the machine was operating under regular conditions.

Statistical Analysis

The use of the SPSS statistical package program was employed to analyze the alterations in briquette parameters based on pressure and size. The article

Table 1. Properties of apricot pruning residues at 8-10% moisture content in the experiments.

	Sieve analysis and size distribution of material				
	0-1.00 mm	1.00-2.00 mm	2.00-3.36 mm	3.36-4.75 mm	>4.75 mm
	15.25	9.13	23.87	60.45	4.89
Density: 301.66 $kg.m^{-3}$					
ACP (MPa)	80	100	120	140	160
D ($kg.m^{-3}$)	995.45	1147.63	1195.36	1201.25	1269.85
CR	3.29	3.80	3.96	3.98	4.21

Table 2. Standard test methods applied to briquettes.

Briquette Tests	Applied Standard Method
Briquette moisture content	EN14774-1 2009 [24]
Particle density	EN15150 2011 [25]
Bulk density	EN 15103 2009 [26]; EN15150 2011 [25]
Briquette density	EN14961-3 2011 [27]
Mechanical durability (Tumbler) test	EN 15210-1 2009 [28]; EN14961-3 2011[27]
Shatter test	ASTMD 440-86 1998 [29]; ASAE S269.4 2000 [30]; EN14961-3 2011 [27]
Briquette firmness	ASTM E9-89 2018 [31]; EN12504-1 2019 [32]
Ash content	EN14775 2015 [33]
Heating value, ADL lignin and elemental analysis values	EN 14918 2017 [34]; EN14961-3 2011 [27]

contains the relationship between significant variables was subjected to Duncan multiple comparison test. The XLSTAT package program was utilized to perform principal component analysis (PCA) on the variables.

Results and Discussion

Density of Raw Materials and Briquettes, Compaction Rate and Moisture of the Material

Density is an important parameter that determines physical quality of briquettes. According to Davies R.M. and Davies O.A. [35] and Ikubanni P.P. [36] et al. the higher the density, the better and higher is the energy/volume ratio. When the moisture level of particles is high, fine materials are unable to bind and instead only grind and become dirty, whereas coarse materials turn into pulp. Smaller particles have a greater capacity to absorb moisture compared to larger particles, resulting in a more intense grinding process. However, when it comes to high density briquetting, the size of the particles does not greatly affect the quality of the briquettes. This is due to the high pressure applied during compaction, which, combined with the heat applied, causes the lignin to melt and bind the material particles together. The densities of the materials used in the experiment before and after briquette were determined and given in Table 3. Acceptable briquette density should be 900 kg.m^{-3} and above [27]. In the study by [37], higher density briquettes were obtained with more small particles in the particle size distribution [38,39]. However, in hydraulic briquette machines, the power of the machine also determines the density of the briquette. It has been seen that the different compaction pressures used in the briquette machine used are sufficient to obtain the desired density briquette. In these new designed hydraulic type of briquette machines, it is recommended that the moisture content of the material be in the range of 8-10%. The compaction ratio of the material is important for the storage, storage and transportation of the raw material [40]. As the compression ratio increases, it is better understood that briquetting of the material is necessary for storage and transportation. In this respect, the apricot branch is close to the tree dust. The particle sizes of the materials are important for compaction, but they do not need to be crushed too small. Particle sizes vary according to the type of material.

Table 4. Eigenvalue values resulting from PCA analysis.

	F1	F2	F3	F4
Eigenvalue	6.058	0.675	0.215	0.107
Variability (%)	86.488	9.551	3.186	1.502
Cumulative %	86.488	96.247	98.635	100.000

Tumbler and Shatter Test, Deformation Resistances

These are the tests carried out to determine the strength of the briquettes and the losses that may occur as a result of the vibrations that may occur during storage and transportation [41]. These tests are performed on special devices and are expressed as %. The generally acceptable value should be 95% and above [27]. According to [42], the gravitational resistance to drop should attain a value higher than 90%. According to the test results, apricot pruning residues gave values below 95%. It has been observed that the relevant standards are met at pressures other than 80 MPa compression pressure in the shatter test (Table 5). Apricot pruning residue is above the standard in this respect. Another measure of the strength of the briquette (Briquette firmness) is its good deformation resistance. This value is calculated by the pressure applied on the product with a special device. It is desirable that the value be high (at least 2000 N). Table 3 shows the values obtained as a result of the analysis.

According to Table 3, it can be observed that the particle size has a more significant impact on the quality parameters of the produced briquettes, specifically when considering their interactions, at a significance level of 1%. As a result of the tests, it was observed that there was not much fragmentation in the briquettes and did not break into pieces for all the durability tests examined. According to the literature, the maximum value for gravitational resistance during a drop is 93.09%, while the minimum value is 89.55%. This aligns with the findings in reference [42], which

Table 3. Changes in the quality parameters of the briquette under different pressure values

Pressure (MPa)	Briquette Density (kg.m^{-3})**	Briquette Firmness (N)**	Tumbler Test (%)**	Shatter Test (%)**	Lignin (%)**	Capacity (kg.h^{-1})^{ns}	Specific Energy Consumption (kWh.kg^{-1})**
80	995.82d	5425.12e	69.25c	94.25d	10.21e	5.75	0.20c
100	1166.25c	6286.36d	95.99b	95.85c	13.12d	5.36	0.21b
120	1182.36bc	8763.95c	98.09a	98.78b	15.26c	5.49	0.22ab
140	1201.12b	10863.45b	98.12a	99.36a	16.88b	5.27	0.22ab
160	1287.63a	13204.27a	98.66a	99.25a	19.67a	5.53	0.23a

Table 5. Heating value, ADL lignin, elemental analysis values, ash content and average flue gas emission.

	Higher calorific value ($kcal.kg^{-1}$)	ADL-(Lignin%)	N (%)	C (%)	H (%)	O_2 (%)	Ash Content (%)
Apricot pruning residue	4605	18.08	0.59	48.56	5.87	47.63	0.77
Wood dust	4522	16.24	0.10	50.93	6.38	42.59	3.87
	Average flue gas emission values						
	O_2 (%)	CO_2 (%)	CO (ppm)	NO (%)	NOx (ppm)	SO_2 (ppm)	
Apricot pruning residue	16.98	4.32	2574.12	92.05	97.25	16.25	
Wood dust	15.83	4.98	1331.1	40.78	42.89	14.67	
Acceptable values	13	20.30	3200	300	300	70	

state that the gravitational resistance during a drop should exceed 90%. For the specified briquette combinations compacted at different pressures, it was observed that the maximum loading power of the samples was 5 kN diametrically to the briquettes in the universal testing device and the samples were broken at the allowable values. A similar briquette compaction method was performed by [43] and it was observed that similar results were obtained. Considering the capacity values for this new designed hydraulic press, it is seen that the capacity and specific energy consumption values are at a significant level compared to different compression pressures depending on the design. However, considering the enterprises that will produce more in rural areas in this type of designed machines, it can be said that this press is suitable for both capacity and specific energy consumption.

Principal Components (PCs) Analysis

Principal Component Analysis (PCA) was conducted to determine the effects of briquette materials at different pressures on the investigated briquette density, briquette firmness, shatter test, capacity, specific energy consumption and tumbler test parameters. According to the PCA analysis, PC1 and PC2 variables explained 96.25% of the total variance. The share of PC1 value in the total variance was determined as 86.48%, PC2, on the other hand was determined to explain only 9.55% of the total variance as a result of the analysis (Fig. 2).

As a result of the PCA analysis, when the eigenvalues of the PC values were examined, the eigenvalues were calculated as 6.058 in PC1, On the other hand, in PC2. The eigenvalue was measured as 0.675 and was determined below the value of 1. PC in the other group had eigenvalues below 1 and explained only 4.69% of the total variance (Table 4).

Heating Value, ADL-Lignin and Elemental Analysis Values

The calorific value, lignin and elemental analysis values of the obtained briquettes are given in Table 5. In order for a briquette to be of acceptable quality, it must have a calorific value over 3800 $kcal.kg^{-1}$ [27]. The heating value of the studied material apricot pruning residue was calculated as 4605 $kcal.kg^{-1}$ as seen in the table and it is well above the accepted value. When the timber industry is considered in terms of fuel, wood dust are mostly used because it is easy and accessible. The heating value of wood dust is 4522 $kcal.kg^{-1}$. Heating value of apricot pruning residue is very close to wood dust and is at a value that can be used easily. Briquettes of materials with high lignin content are expected to be more solid. Because lignin has a natural adhesive property. In this study, this effect of lignin was investigated without using any heating system or additives. Depending on the compression pressure, there was an increase in the level of this lignin with the pressure in the material. The lignin content of the apricot branch is as high as 18.08% and is more than wood dust (16.24%). It was observed that more durable briquettes were obtained with the release of this amount of lignin with the temperature depending on the pressure. Elemental analysis results of apricot branch and tree dust are also shown in Table 5. It is seen that the material is low in nitrogen and rich in carbon. The reason for its high calorific value is its high carbon content. The briquettes obtained in the experiment were burned in the briquette stove and the flue gas emission values were measured. The data obtained are shown in Table 5. As can be seen in Table 5, apricot branch is a cleaner fuel than wood dust in terms of flue gases. The obtained values were found to be within acceptable limits.

Conclusions

When the physical properties of the briquettes obtained from the apricot pruning residues with the new designed hydraulic type briquetting machine used in the study were examined at different compacted pressure, it was seen that they were generally of good quality. However, when examined in terms of different compaction pressures, some physical properties may change. As a result, agricultural pruning residues have an important potential as a renewable energy source. As seen in this study, as a result of examining the fuel properties of the briquettes obtained from apricot pruning residues, it has been determined that there is no objection in terms of both EU pellet and briquette standards and the regulation on the control of air pollution caused by heating. This study is also very important in terms of showing that fruit pruning residues can be used instead of wood chips. It is very important to turn this waste energy source, especially when rural areas and small-scale businesses are considered, into valuable products and to bring them back to the energy economy of the countries. If all kinds of agricultural residues and fruit pruning residues known as "residue" in different regions of our country are used as briquettes, it will be possible to meet a certain part of coal imports. With the development of this type of machinery, small and medium-sized agricultural enterprises will be able to transform the agricultural residues obtained as a result of their own production into valuable products and agricultural residues will be evaluated for the countries.

Conflict of Interest

The authors declare no conflict of interest.

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