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Review
Derleme

MECHANICAL PROCESSING OF SOLID BIOFUELS

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ABSTRACT: Solid biofuels are preferred as alternative source of energy in recent years. Although it's not yet popular in Turkey but, there's a big potential concerning agricultural residues. With the depletion of fossil fuels world wide researches for alternative energy sources, especially efforts for obtaining the energy from agricultural non-food products became important. Generally, two methods are used in mechanical processing of biofules obtained from plants and agricultural residues. These are pelleting and briquetting methods. In the pelleting process loose material is converted to compressed material. As a result of the pressure and heat applied to the substances, the density of the material is increased by a factor of up to 10, in pellets with diameters of 3 up to 30mm. However, briquetting is a process where some type of solid biofuel materials is compressed under high pressure. In the basic briquetting, input parameter is the moisture content, which is important for the pressing of materials as biomass. If the moisture content of material exceeds 20 %, the biomass in the pressing chamber will not be in the desired size and the briquettes will break up. The goal of this work is to give general information on mechanical processing methods of these types of biofuels.
Key words: Biofuel, processing, pellet, briquette, presser

KATI BİOYAKIT MALZEMELERİN MEKANİK İŞLENMESİ

ÖZET: Son zamanlarda katı bio-yakıtlar alternatif enerji kaynağı olarak tercih edilmektedir. Bu konu Türkiye'de henüz yeteri kadar popüler olmamasına rağmen, tarımsal atıklar açısından ülkemizde bu anlamda büyük bir potansiyel bulunmaktadır. Dünya genelinde fosil yakıt rezervlerinin azalması ile birlikte özellikle gıda özelliği taşımayan tarımsal ürünlerden enerji elde etme çabaları için yapılan araştırmalar çok önem kazanmıştır. Bitkilerden ve tarımsal atıklardan elde edilen bio-yakıt malzemelerinin mekanik olarak işlenmesinde genelde iki yöntem kullanılmaktadır. Bunlar peletleme ve briketleme yöntemleridir. Peletleme işleminde gevşek materyal sıkıştırılmış hale dönüştürülmektedir. Uygulanan basınç ve ısıl işlem sonucunda çapları 3 ile 30 mm olan pelet materyalinin yoğunluğu 10 katına kadar arttırılmaktadır. Bununla birlikte, briketleme işleminde ise bazı katı bio yakıt materyaller yüksek basınç altında sıkıştırılmaktadır. Briketleme işleminde temel parametre, ürünün bio kütle olarak sıkıştırılmasında önemli olan nem içeriğidir. Eğer materyalin nem içeriği % 20'den fazla olursa sıkıştırma ünitesindeki bio kütle istenilen boyutlarda olmayacak ve yapılan briketler dağılacaktır. Bu çalışmanın amacı bu tip bio-yakıt malzemelerin mekaniksel işlenmesi hakkında genel bilgiler vermektir.
Anahtar Sözcükler: Bio-yakıt, işleme, pelet, briket, pres makinesi

1. INTRODUCTION

Biomass is a general term for material derived from growing plants or from animal manure. Bioenergy refers to the technical systems through which biomass is produced or collected, converted and used as an energy source. A wide variety of conversion routes can be distinguished that produce a variety of energy carriers either in a solid, liquid or gaseous form. These energy carriers address all types of energy markets: heat, electricity and transportation. Bioenergy already provides the majority of renewable energy worldwide and is considered to have the potential to provide a large fraction of world energy demand over the next century. At present, biomass covers approximately 11% of the global total primary energy consumption of slightly more than 430 EJ/year[3] (Heinimö, 2008). At the same time, if biomass systems are managed properly, bioenergy will contribute to meet the requirement of reducing carbon emissions (Anonymous, 2009-a).

Biomass is the only renewable source of fixed carbon and therefore it has attracted considerable attention as a renewable energy source in recent years. It includes agricultural residues, municipal wastes, fuel wood, animal wastes and other fuel derived from biological sources. Compaction of biomass waste materials makes the material denser and easier to handle, thus reducing the cost of transportation and handling. Compaction can also increase the heating value per unit volume, making the biomass fuel more compatible with coal and more efficient in combustion.

Among the different forms of renewable energy, biomass energy is one of the major resources in Turkey (Başçetinçelik et al., 2005 b). Turkey is an energy importing country. More than about 60% of energy consumption in the country is met by imports and the share of imports continues to grow each year. The total recoverable bioenergy potential is estimated to be about 16.92 Mtoe. The biomass energy production for the year 2001 is 6.98 Mtoe. (Başçetinçelik et al., 2005 a). Energy from biomass fuels is used in the electric utility, lumber and wood products, and pulp and paper industries (Demirbaş et al., 2004). Although this energy use is predominantly in rural areas (comprising mostly wood and dung for heating and cooking), it also provides an important fuel source for the urban poor and many rural, small and medium scale industries (Kaygusuz and Türker, 2001; Başçetinçelik et al., 2005 a).

Biomass can be burnt directly or it can be converted into solid, gaseous and liquid fuels using conversion technologies such as fermentation to produce alcohols, bacterial digestion to produce biogas and gasification to produce a natural gas substitute (Kaygusuz and Türker, 2001) but in general, biomass usually can not be used directly in combustion equipment for energy production. Water and ash matter are consisting into non flammable part of fuel, described as ballast or deadwood. Both of them are decreasing fuel heating power. Their presence straight influences the combustion equipment construction and they are often sources of problems during operations. All of the main tree fuel components (water, ash and flammables) are very important factors during combustion process. Their properties influence the construction of combustion equipment as well as its operation regime (Malaťák et al., 2008). Biomass is often bulky and difficult to burn so various conversion techniques have been developed. One of the oldest of these is briquetting which has been used in Europe since the 19th century to make fuel from low-grade peat and brown coals (Eriksson and Prior 1990). Briquetting is one of several agglomeration techniques which are broadly characterized as densification technologies. Agglomeration of residues is done with the purpose of making them denser for their use in energy production. (Grover and Mishra 1996). That's why it should be adjusted to a suitable shape and dimensions using these techniques such as briquetting and pelleting. Besides the shape and dimensions mechanical properties of briquettes and pellets are also very important. They fundamentally affect not only the method of handling briquettes and pellets (storage, dosage, etc.), but also losses in processing operations.

As the number of industries is growing day by day, the energy required is also increasing proportionately and the present power supply is unable to meet the energy demand. To combat this energy shortage, developed as well as developing countries are putting more efforts into Research and Development areas. These efforts should be undertaken to make pelleting and briquetting technology economically profitable and socially acceptable to the public so that it might be widely adopted. In this study, general information about mechanical processing of solid biofuels is given.

2. THE MOLDING EQUIPMENT

Different systems of molding equipment for biomass are as follows:

a) Hydraulic or mechanical presses forming a single brick with a diameter of 50 to 60 mm, usually used for straw, sawdust, paper, chops with a capacity of 250 $kg.h^{-1}$. Generally, made up of a mill with two presses having about 50 kW power and efficiency of up to $0.5t.h^{-1}$.

b) Screw presses with single or double spindle with capacity around 0.5 $t.h^{-1}$ and 50 kW or up to 70 kW (with the necessary auxiliary equipment for drying) power. Briquettes from screw presses are characterized by high compression and long durability. These presses are suitable for pressing sawdust, they are not appropriate for pressing culm crops.

c) Extruder derived from granulation presses for the production of textured feed based on straw. There are two types of extruders, with a circular vertical matrix and with a horizontal stamping die desk.

The capacities of these presses may be greater than 1 $t.h^{-1}$ at powers up to 150 kW. Recently, extruders equipped with self-propelled facilities are developed (Pastorek et al., 2004).

Wooden briquettes and pellets are formed with suitable sizes (usually with dimensions 8 × 8 × 1 mm, depending on the parameters of briquette press) at high pressures (up to 31.5 MPa) and temperatures when the lignin plasticizes and assumes the function of binder. It leads to volume reduction of input materials in approximately 12:1 ratio. Sometimes briquettes and pellets are produced from combination of wood waste and coal dust. In that case, it's mixed with a small amount of grinded limestone, which binds sulfur from coal.

Bio-briquettes or wood pellets from another combustible organic material (e.g. cob), enables further use of the hearth to the classic solid biofuels (mainly wood and wood chips). This is especially advantageous for low heat powered furnaces with intermittent operation (small boilers for wood chunks with a heating power up to 50 kW).

Energetically, the production of briquettes and pellets is quite difficult because it requires a higher level of disintegration of input material while reducing its moisture content. Therefore, it's advantageous to produce them from dried and disintegrated side-materials obtained during other previous technological processes such as; sawdust and shavings from the dry wood in carpenter shops.

The result of pressing wood material is improved by fuel with low sulfur content (up to 0.07%, for comparison; sulfur content of brown coal is just below 2%), with a calorific value from 18 to 20 $MJ.kg^{-1}$, relative humidity of 5 to 9%, bulk density 800 to 1000 $kg.m^{-3}$, with 1.2 % ash content, capable of saving storage space, at conditions up to 80% air relative humidity for almost unlimited time period.

3. PELLETING

3.1. The pelleting process

In the pelleting process loose material is converted to compressed material. As a result of the pressure and heat applied to the substances, the density of the material is increased by a factor of up to 10, in pellets with diameters of 3 up to 30mm. The pellets produced in this manner are compact, dustless and easy to transport. Compactness and dimensions of all pellets are always identical (under identical production conditions). By producing pellets out of fluff (lightly compacted materials) a high quality of substitute fuel is obtained. In order to achieve a homogenous processing of the different primary materials, steam or water can be added in our conditioner before the material is transported to the pellet mill (Anonymous, 2008-a).

The best raw material for pellet production is wood in the form of saw dust with a minimum dust content, which worsens the strength of pellets. The optimal dimensions for sawdust are 2 to 3 mm. Moisture content in the raw material should be around 10%. The raw material with higher moisture contents must be dried before processing. The most economic way of drying is by means of gas heated drum type dryers. But in recent years, hot air dryers (160 °C) are preferred for avoiding loss of volatile flammable substances (Sladký et al., 2002).

3.2. Wood pelleting

Wood pelleting process includes machinery for wood grinding and pelleting inclusive chippers and dryers to process wet and/or green wood prior to the pelleting process. Compression by pelleting of biomass results in a substantial increase in density. When turning wood chips into compressed wood pellets in increase in density typically corresponds to a rise from 150 kg.m^{-3} to 650 kg.m^{-3}. The steps of this process are as follows (Anonymous, 2008-b):

- √ Pre-grinding size reduction: Raw material supplied as wooden chips with sizes 100+ mm require size reduction in chipper and hammer mill previous to the subsequent drying process.
- √ Drying: Generally, Drum Driers are used for this process. Raw material is dried before the fine-grinding (Figure 1).
- √ Fine grinding: Usually, raw material is not in optimal condition for the production process (as sawdust, shavings, and wood chunks) therefore, it should be homogenized before the main pelleting. This is usually done by an efficient hammer mill with suitable screens (Sladký, 1995). The large surface open fiber of the ground products facilitates absorption of steam in the cascade mixer. Steam and increased temperature in the cascade mixer soften the lignin in the wood, after which pelleting can go on without addition of binders.
- √ Pelleting: The main manufacturing machine for pelleting is matrix extrusion press, designed as disk-type flat or orbicular (Figure 2). Extrusion dies are made of stainless steel which is equipped with a set of holes for required cross-sections and above a spin off roller which pushes the processed material through the matrix. A considerable heat is released while processing, which softens and releases lignin in the raw material (Pastorek et al., 2004).
- √ Cooling: Cooling pellets after exiting from pellet machine is essential, because the pellets receive the required strength and durability, as lignin hangs with the added binder (Sladký et al., 2002). Due to the friction generated in the die during the pelleting process, additional heat is developed in the pellets. The heat must be removed before the pellets are sifted and stored. The pellets are cooled by air taken from the surrounding room, and therefore the pellet temperature will always be 5-10 ^{o}C above room temperature. Cooler retention time and wood pellet diameter are decisive for dimensioning of the cooler.

Figure 1. Drum dryer

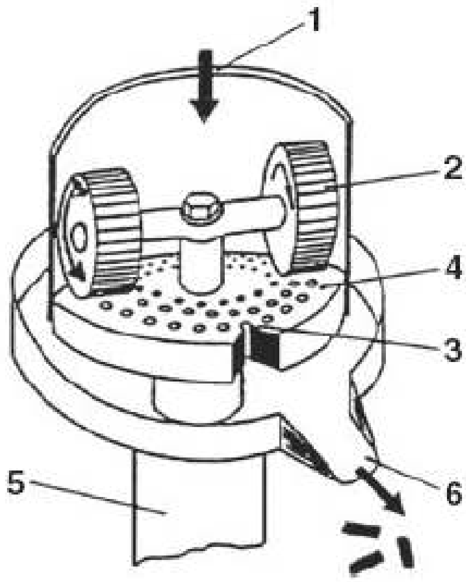


Figure 2. Matrix granule extruder with horizontal matrix and rolling wheels (Pastorek et al., 2004) (1. insertion of crushed straw, 2. extrusion wheel, 3. matrix openings, 4. horizontal matrix, 5. transmission and electric motor, 6. removal of pellets)

3.3. Advantages of Pellet Fuel

The advantageous of pellet fuels are as follows (Anonymous, 2009-b):

- √ Storage: Since pellet fuel is compressed, storage space is cut in half or more.
- √ Handling: Pellet fuel is free flowing and can be easily handled by bulk conveying equipment.
- √ Durability: Pellet fuel can be either manually or automatically handled with little degradation.
- √ Transportation: Pellets can be moved in bag or bulk at double or more payloads on trucks and rail cars.
- √ Packaging: Pellets can be bagged in various size bags (including the one ton "tote" bag) or trucks.
- √ Availability: Pellets are available over all of North America.
- √ Longevity: Pellet quality is maintained indefinitely if kept dry.
- √ Renewable: Pellet fuel is made from waste materials that would largely go into landfills.
- √ Blending: The raw material can be easily mixed with other ingredients to lower emissions.
- √ Aeration: The shape and density of pellets assures combustion air is circulated throughout the fuel.
- √ Pricing: Cost per kW is competitive to oil, propane and coal and cheaper than chunk wood or electricity.
- √ Ignition: Ignition is quick and easy due to density, aeration and surface area.
- √ Standard Uniformity: Pellets are uniform in size and moisture.
- √ Residues: Pellet fuel ash is good soil enhancement, mostly potash.
- √ Environment: Pellets are usually made from organic, non-polluting materials and are clean burning.
- √ Clean: Densified fuel is clean and stays that way to keep living and work areas clean.
- √ Combustion Chamber: Because pellets are densified, the combustion chamber can be adaptable, much smaller and less expensive to build and will work in existing solid fuel system.
- √ Standardization: Pellets meet the standards set by the Pellet Fuels Institute for dependability of heat, cleanliness, size and moisture.

3.4. Pellets

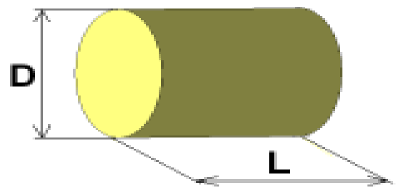
Pellets are usually circular cross-section with a diameter from 6 to 20 mm and a length of 10 to 50 mm which are made exclusively from organic materials and biomass (wood, wood waste, sawdust, culm crops) without chemical additives and binders. Pellets are pressed in high pressured extrusion matrixes. The characteristics of pellets for domestic use are given in Table 1 (Anonymous, 2009-a).

Wood pellets have a calorific value from 18 to 19 $MJ.kg^{-1}$, which is in between the black and brown coal the list of fuel ranks, in this sense. They have, however, higher combustion efficiency and unlike in coal which has up to 30% of solid waste, wood pellets only have 0.5-1% of waste (ash). Ash from the wood pellet is an excellent garden mineral fertilizer. In comparison with conventional timber, which has 15-20% moisture content and also lower calorific value approximately 14 $MJ.kg^{-1}$ after two years of storing, wood pellets have moisture content among 8-10%. They provide higher life span for combustion equipment. Pellets are produced in two types; pellets from culm crops and wood pellets (Sladký, 1995). Other specifications of pellets are given in Table 2.

Table 1. Pellet characteristics for domestic use (Anonymous, 2009)

Heating value	> 4,7 kWh (>17 MJ/kg)
Moisture content	Max. 10%
Ash content	Max. 0.5%
Dimension	Diameter: 6 mm; Length: 25 mm

Table 2. Properties of pellets

Origin	Biomass from wood, plants, fruits or mixtures
Commercial form	Pellets
Dimensions DxL (mm)	
Diameter (D) and length (L)	
D06	≤ 6 mm ± 0.5 mm and L ≤ 5 x diameter
D08	≤ 8 mm ± 0.5 mm and L ≤ 4 x diameter
D10	≤ 10 mm ± 0.5 mm and L ≤ 4 x diameter
D12	≤ 12 mm ± 1.0 mm and L ≤ 4 x diameter
D25	≤ 25 mm ± 1.0 mm and L ≤ 4 x diameter
Water (%)	
M10	≤ 10 %
M15	≤ 15 %
M20	≤ 20 %
Ash (%)	
A 0.7	≤ 0.7 %
A 1.5	≤ 1.5 %
A 3.0	≤ 3.0 %
A 6.0	≤ 6.0 %
A 6.0+	> 6.0 %
Sulfur	
S 0.05	≤ 0.05 %
S 0.08	≤ 0.08 %
S 0.10	≤ 0.10 %
S 0.20+	> 0.20 %
Mechanical resistance (%)	
DU 97.5	≥ 97.5 %
DU 95.0	≥ 95.0 %
DU 90.0	≥ 90.0 %
Amount of fine parts (%)	
F 1.0	≤ 1.0 %
F 2.0	≤ 2.0 %
F 2.0+	> 2.0 %

4. BRIQUETTING

Briquetting is a process where some type of material is compressed under high pressure. If the raw material is wood, the lignin content of the wood is liberated under this pressure thus binding the material into a briquette. During the compression of the material, temperatures rise sufficiently to make the raw material liberate various adhesives (Anonymous, 2009-c). The basic briquetting input parameter is the moisture content, which is important for the pressing of materials for biomass. If the moisture content of material exceeds 20 %, the biomass in the pressing chamber will not be in the desired size and the briquettes will break up. Moisture content up to 15% is recommended for high quality compaction (Plíštil et al., 2002; Plíštil and Malaťák, 2004).

Mechanical and chemical properties of materials are used for briquetting by means of high pressure compresses into the compact shapes without using a binder just with the resin contained in the material.

Limiting factors for the processing of material are the moisture content of the material which should not exceed 15 % and granularity which should not exceed Φ 15 mm in one direction. The pressed material should not contain more than 6-8% of bark and 20% of dust. The degree of compression affects the quality of parameters such as calorific value, shape stability, etc.

Briquetters originated in Europe and were used for converting wood particulate in smaller woodworking shops to a format which could be used for heating the building. Many European woodworking operations today use these machines for this reason. Briquette presses may have different structures according to driving unit, press chamber or pressing tool functioning at 400 MPa or more pressures and temperatures at about 70 ^{o}C (Figure 3). They provide a volume reduction of approximately 12:1 (Plíštil et al., 2004-a). There are basically two types of briquetters; hydraulic types with hydraulic pumps and mechanical types. The hydraulic systems come in vane, gear and positive piston displacement pumping systems. Vane and gear types tend to be less expensive and should be used only where daily operation is a few hours. The reason for this is they are viscosity dependent. As they continue to operate the hydraulic oil heats up and gets thinner, causing the pumps to work harder and causing the oil to heat up even more eventually resulting in pump failure.

Mechanical type briquetters are usually for larger capacity operations and lack the complications of hydraulic types while still employing modern automated control systems (Anonymous, 2009-d). Two types of mechanical briquetters are available, piston presser and screw presser. Although both technologies have their merits and demerits, it is universally accepted that the screw pressed briquettes are far superior to the ram pressed solid briquettes in terms of their storability and combustibility. (Grover and Mishra 1996). Best briquettes are produced by screw pressers (compaction to 100:1) used for producing fire-briquettes which has a central hole on it for better combustion. Table 3 shows a comparison between a screw extruder and a piston press.

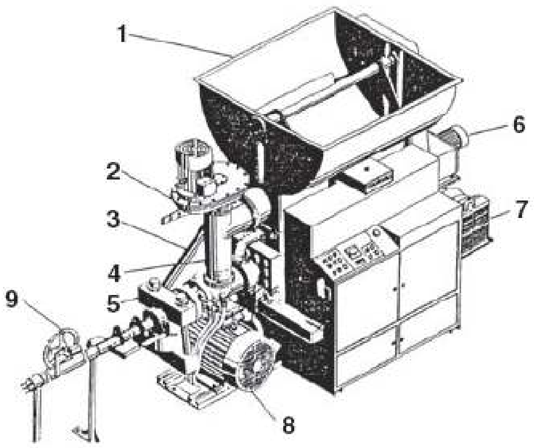


Figure 3. Briquette press (1. hopper crushed straw (sawdust) with spiral discharger, 2. transmission of electromotor for vertical spiral feeder, 3. V-belt of balance wheel for crank mechanism, 4. vertical bailer of straw for presser, 5. pressure regulator, 6. electromotor for discharging spiral conveyor, 7. condenser of cooling unit, 8. electromotor of presser, 9. counter for produced briquettes (length))

Table 3. Comparison of screw extruder and a piston press

	Piston press	Screw extruder
Optimum moisture content of raw material	10…15%	8…9%
Wear of contact parts	Low in case of ram and die	High in case of screw
Output from the machine	In strokes	Continuous
Power consumption	50 kWh.ton^{-1}	60 kWh.ton^{-1}
Density of Briquitte	1…1.2 g.cm^{-3}	1…1.4 g.cm^{-3}
Maintenance	High	Low
Combustion performance of briquittes	Not so good	Very good
Carbonization to charcoal	Not possible	Very good
Suitability in gasifiers	Not suitable	Suitable
Homogeneity of briquettes	Non-homogeneous	homogeneous

Normally, briquettes have 18 to 20 MJ.kg^{-1} calorific values according to the quality standards but, high calorific values up to 33 MJ.kg^{-1} can be achieved with hard wood and wood dust materials. (Plíštil et al., 2004-b).

Briquettes

Briquettes are fuels artificially made by pressing bulk material without additional binders into the desired forms for burning. Different types of briquettes are demonstrated in Figure 4 (Anonymous, 2009-e). It is created by pressing the heterogeneous components (stems, leaves etc.). It is therefore impossible to speak of a homogeneous body. Local bulk density (ρ) of briquettes is a function of (x, y, z) and depends on:

- Pressing pressure
- Structure of the material
- Moisture content of the material
- Type of pressing material

Figure 4. Briquettes (Anonymous 2009-e)

Briquettable materials are; waste wood, bark, old forest, chips and dusts from the wood and paper working, jute fibers and dust, filter dusts from exhaust air and flue gas dust collection of garbage invineration plants, paper scraps from shredder, hay straw, particle board chips, tobacco dusts, polystyrene, polyurethane foams, cotton stalks, vine cuts, rigid PVC dust, gypsum, spelt, peanut shells, coconut fibers, etc. (Anonymous 2009-e).

Briquettes must meet the safety, health, technical, trade and other requirements including provisions relating to the protection of the environment.

Standard form of fuel for its other usage in combustion equipment is achieved in briquetting. This is achieved by volume reduction and increase in the bulk density therefore increase in available energy. From the mechanical properties of standards for briquettes essential parameters are bulk density and mechanical strength. These parameters are dependent on used materials, its structure, moisture content and compression pressure.

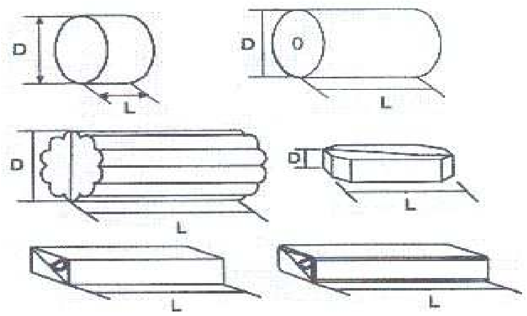
Wood briquettes are mainly suitable for burning in furnace, stoves and garden grills. They are advantageous for their small demands on storage space, insensible of relative humidity and the possibility of using the ash as an excellent mineral fertilizer (ash content is 0.5-2%). Average density for briquettes varies among 1000-1200 $kg.m^{-3}$. Other properties of briquettes are given in Table 4.

Agricultural residues are also very suitable for briquetting especially briquettes from energy plants can be a good source for heating (Malaťák and Vaculík, 2008) (Figure 5). There's a big potential for briquetting of hazelnut shells or husks in Black Sea region in Turkey. Unprocessed hazelnut shells are already used as a source of heating energy in the region. They can be well managed if they are briquetted like almond shells (Figure 6). But, more researches must be done on mechanical processing of hazelnut shells and husks especially searching their appropriateness for pelleting or briquetting.

Figure 5. Briquettes from energy plants

Figure 6. Briquettes from almond shells

Table 4. Properties of briquettes

Origin	Biomass from wood, plants or mixtures
Commercial form	Briquettes
Dimensions DxL (mm)	
Diameter (D)	
D40	$25 \leq D \leq 40$
D50	≤ 50
D60	≤ 60
D80	≤ 80
D100	≤ 100
D125	≤ 125
D125+	≤ 125, actual measured values
Length (L)	
L50	≤ 50
L100	≤ 100
L200	≤ 200
L300	≤ 300
L400	≤ 400
L400+	≥ 400, actual measured values
Water (%)	
M10	≤ 10 %
M15	≤ 15 %
M20	≤ 20 %
Ash (%)	
A 0.7	≤ 0.7 %
A 1.5	≤ 1.5 %
A 3.0	≤ 3.0 %
A 6.0	≤ 6.0 %
A 10.0	≤ 10.0 %
Sulphur	
S 0.05	≤ 0.05 %
S 0.08	≤ 0.08 %
S 0.10	≤ 0.10 %
S 0.20	≤ 0.20 %
S 0.20+	> 0.20 %, actual measured values
Density (kg.dm^{-3})	
DE 0.8	0.80 to 0.99
DE 1.0	1.00 to 1.09
DE 1.1	1.09 to 1.19
DE 1.2	≥ 1.20
Nitrogen (%)	
N 0.3	≤ 0.3 %
N 0.5	≤ 0.5 %
N 1.0	≤ 1.0 %
N 3.0	≤ 3.0 %
N 3.0+	> 3.0 %, actual measured values

5. BRIQUETTES VERSUS PELLETS

Briquettes are an attractive alternative to pellets. There are many advantages in favour of a briquetting plant when making the comparison with the investment in a pellet plant. The advantages are as follows (Anonymous, 2009-c):

- √ Briquettes can be produced on a mechanical briquetting press from volumes of 225 kg per hour up to 1800 kg per hour,
- √ The mentioned production volumes makes it attractive to a larger number of investors to invest in their own plant,
- √ The overall investment is considerably lower than a pellet plant, but also the calculated investment per ton,
- √ Operating costs such as labor and electricity are lower per ton produced,
- √ Maintenance costs such as wear parts are lower per ton produced,
- √ Briquettes can be produced from material not acceptable to pelleting,
- √ Particle sizes can be larger than for pellets – moisture level is similar,
- √ Transportation, loading and storage system are similar,
- √ Bulk density and fuel values are similar.

Comparison between briquettes and pellets is given in Table 5 (Anonymous, 2009-a).

6. BASIC TYPES OF SELECTED SOLID BIOFUELS

A summary of basic types and properties of selected biofules which are used in international markets are given below (Malat'ák and Vaculík, 2008):

Wood pellets: Mechanically processed under high pressure, from dry, clean wood chippings, sawdust (6 to 12% moisture content), with some wood dust in the form of cylinders with a diameter of 6 and 20 mm (exceptionally to 40 mm), length from 10 to 50 mm, with density 1 to 1.4 $kg.dm^{-3}$. Calorific value 16.5 to 18.5 $MJ.kg^{-1}$ and ash content in dry matter from 0.5 to 1.1 %. Maximum allowable content of pollutants, bark and organic binder is up to 2%. Has good bulk and storage properties and high concentration of energy for local automatic furnaces, small family stoves, can also complement the coal in boiler plants. The ratio of diameter to the length should not be greater than 1:3.

Wood briquettes: Mechanically processed under high pressure from dry wood pulp, sawdust and fine shavings (6 to 12 % moisture content) in the form of cylinders, prisms, or hexahedron, with a diameter of 40 to 100 mm, length 300 mm and density 1 to 1.4 $kg.dm^{-3}$. Calorific value 16.5 to 18.5 $MJ.kg^{-1}$ and ash content in dry matter from 0.5 to 1.5%. Allowable content of pollutants and organic binder is set by standards. It can be used in small stoves, local heaters and in manually charged boilers and hearths.

Wooden, straw, rind and paper packets: Composite roughly crushed biomass pressed with medium pressure (25 MPa) in the form of cylinders with a diameter up to 150 mm and length of 300 to 500 mm, with density of 0.3 $kg.dm^{-3}$ and moisture content below 18%. It has a calorific value of 15 $MJ.kg^{-1}$. They are not common commercial fuels, needs technological modifications of mixed fuel, production residues and packing in storage before combustion chamber. The aim of the adjustment is to increase energy concentration and saving storage space. Suitable for boilers with an output power over 500 kW as an energetically supporting fuel.

Table 5. Comparison between briquettes and pellets

	Pellets	Briquettes
Appearance		
Raw material	Dry and grinded wood or agricultural residues	Dry and grinded wood or agricultural residues. Raw material can be more coarse than for pelleting, due to the larger dimensions of final product
Shape	Cylindrical (generally Ø 6 to 12 mm, with a length 4 to 5 times the Ø).	Cylindrical (generally Ø 80 to 90 mm) or parallelepiped (150*70*60 mm)
Structure	Stable, hard, without dust	Relatively friable, fragile
Bulk density	Min. 650 kg/m3	600 to 700 kg/m3
Aspect	"Smooth"	Mostly "rough"
Transport	Bulk, bags, big bags	Unit, pallet
Handling	Manual or automatic use	Manual use

Pellets from culm crops: Mechanically processed under high pressure from dry, crushed culm crops (cereals straw, oilseeds, grass, energy plants; having moisture content of 8 to 15 %), in the form of cylinders with a diameter of 6 to 20 mm (exceptionally prisms with a diameter of 40 mm), length from 10 to 50 mm with density of 1 to 1.4 $kg.dm^{-3}$. It has a calorific value of 16.5 to 17.5 $MJ.kg^{-1}$ (from straw of oil plants up to 19$MJ.kg^{-1}$) and ash content of 5 to 6%. Allowable content of pollutants and organic binder is set by standards. It can be used as additive fuel in automatic furnaces with heat output over 25 kW. Combustion, ash and emission problems may occur while burning pellets with diameter greater than 6 mm.

Briquettes from culm crops: Mechanically processed under high pressure from dry, crushed or short cut culm crops (cereal straw, oil plants, grass, energy plants, weed seeds; having moisture content of 8 to 14%) in the form of cylinders, prisms or hexahedron having a diameter of 40 to 100 mm, length 300 mm with a density of 1.2 $kg.dm^{-3}$. It has a calorific value of 16.5 to 17.5 $MJ.kg^{-1}$ and from straw of oil plants up to 19$MJ.kg^{-1}$ and ash content of 5 to 6 %. Impurity and organic binder is set by standards. It can be used in stoves and in manually charged boilers and hearths having powers over 25 kW.

Bark as fuel: Dry bark from conifers is a part of wood fuel or used separately, in the form of briquettes, small pellets. Calorific value with regard to the resin content is up to 20 $MJ.kg^{-1}$, but if polluted with soil it has higher ash content (up to 6%).

Composite briquettes and pellets: Mechanically processed under high pressure from dry, crushed substrates dominated by wood or stalk substances with low sulfur, lime dust, paper contents and organic binders (starch, molasses). They have moisture contents 8-15% and calorific value up to 22 $MJ.kg^{-1}$, diameter to 20 mm and length 50 mm, Ash content up to 8%. They are prospectively formed biofuels for universal use in automatic boilers with higher heat output

Culm crop bales: There are four types of bales; bales with low density of about 60 $kg.m^{-3}$ and weighing 3 to 10 kg/bale. Second type; high density bales (120 $kg.m^{-3}$) and 10 to 20 kg/bale. Giant cylindrical bale with density of 110 $kg.m^{-3}$ and weighing 200 to 300 kg/bale. The last type is giant prism bale with density about 150 $kg.m^{-3}$ and having 300 to 500 kg/bale.

7. CONCLUSION

The mechanical process of solid biofuels was analyzed in terms of molding equipments, pelleting and briquetting technologies. Basic types of selected solid biofuels were also introduced.

Solid biofuels are used to recuperate energy from the wastes mainly from agricultural wastes. Support of agricultural non-food products for its use as a renewable energy source is considered as innovative but, biofuels are not competitive with the classical energy sources without subsidizes. Current agrarian policy of EU accentuates for such use of agricultural products. But, of course a state support is also needed to gain a larger share on the market.

Biofuels can not be used directly in combustion equipment for energy production. It should be adjusted to a suitable shape and dimensions using methods of briquetting and pelleting. Solid biofuels in the form of briquettes or pellets and mechanical processing of them is a quite new topic for Turkey. When viewed from this aspect, Turkey has big potential of biomass especially when the agricultural residues concerned. The total agricultural biomass potential was approximately 363.1 PJ per year in Turkey. Even though Turkey has such big biomass potential, adequate enterprises yet to be established. This huge waste must be utilized by carrying out more scientific researches and by developing appropriate mechanization systems for them. In this study a theoretical approach was provided in a comprehensive manner, in this sense.

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