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AN ASSESSMENT OF THE ENERGETIC PROPERTIES OF FUEL PELLETS MADE BY AGRICULTURAL WASTES

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Abstract

In this study, it is aimed to produce pellets for use as solid biofuel from corn production wastes. Palletization of the biomass material increases volumetric heat value, reduces transport and storage costs, improves combustion properties, reduces emissions of particulate emissions, and produces a biofuel of the same size and shape. For this purpose, corn stalks were milled with a hammer mill and pellets were produced in an automatic feed pelletizing machine. Pellets produced from corn waste; hardness resistance, water absorption resistance, moisture content, ash content, equivalent moisture content, gas emission values released in the combustion result and calorific values which are important indicators of energy content have been determined. The upper calorific value of maize pellets with an average length of 17.28 mm and a diameter of 6.26 mm was determined to be 18.11 MJ/kg. The CO_2, NO and NO_x emission values of pellets from corn stalks were measured as 4.7 ppm, 38 ppm and 40 ppm, respectively. The evaluation of corn waste as pelletized solid biofuel will contribute to the prevention of agricultural land damage and environmental pollution as a result of the burning of residual vegetable waste from corn production.

***Key words**: ash content, biopellet, corn wastes, heating values.*

INTRODUCTION

Global emissions of greenhouse gases, caused by the use of fossil fuels all over the world, have led to further global warming threats and the steady decline of fossil fuel reserves has encouraged countries to be more interested in environmentally friendly, renewable energy sources. Between 1970 and 2004, CO_2 emissions from fossil fuel use increased by about 80% and global temperature by 0.5°C. If the air pollution continues at this level, it is predicted that the temperature will rise to 4-5°C and the sea level will rise to 2.2 m in the next 100 years (IPCC, 2011). On the other hand, estimating that energy demand across the globe will increase by about 55% between 2005 and 2030 does not justify worries about the anticipated drawbacks of global climate change, but also obliges the energy sector to reduce fossil fuel consumption. Therefore, to reduce fossil fuel consumption, the European Commission has set a goal of raising the renewable energy consumption rate, which is currently 5% in Europe, to 20% by 2020. In Turkey as well, priority is given to strategic planning to ensure resource diversification by prioritizing domestic resources and to increase the share of renewable energy resources in energy supply. In this context, in order to reduce the external dependency rate of 73% on energy, it is aimed that the share of renewable energy resources in electric energy production in 2023 should be at least 30%.

In today's Turkey, some industries are benefiting from agricultural wastes on a small scale. Nevertheless, the private sector is not yet sufficiently interested in the biomass and solid waste-based power plants, due to the financial and technical obstacles to the use of biomass energy in Turkey, and the inadequacy of policy and market instruments. The fact that any residual vegetable waste is not evaluated and destroyed as a result of agricultural production seriously causes environmental pollution and creates economic loss. The aim of this research is to improve the use of agricultural biomass resources in Turkey by using sustainable methods and taking into account the environmental-economic-social benefits of new technologies. In this study, it is aimed to produce pellets for use as solid biofuel from the remaining biomass material except corn in seed production. In Turkey corn production areas are treated by burning or crushing soil to remove remaining plant wastes. The incineration of corn plant wastes causes beneficial organisms in the soil and harmful environmental effects. On the other hand, the process of shredding plant wastes into the soil causes considerable energy consumption. As a result of the production of corn, the remaining palletization of biomass waste will be eliminated and the environmentally friendly, clean and renewable fuel will be produced with improved physical properties and combustion characteristics. The pelletizing process will facilitate the transport and storage of residues and at the same time reduce shipping costs. Most importantly, the evaluation of such biomass materials through palletization will provide for the economization of waste and will partially or even reduce our country's external dependency on energy.

The utilization of pellet fuel not only protects the environment, but also the best substitute for coal and natural gas. The cost of pellet fuel is less than half price of the coal, but it has the same heat as the coal, and a kilo of pellet can be burned for hours. The raw materials of biomass pellet fuel are very extensive; they can be the crop straw, wood processing waste such as wood chips, bark, etc. All of the raw material with lignin can be used to make biomass pellet fuel. For that reason, in the present study, it was aimed to pelletize biomass waste from corn stalks as solid biofuels. The pelletization of corn waste has reduced storage and transport costs and improved combustion characteristics, resulting in a cheap, quality, environmentally friendly, domestic and renewable biomass solid fuel. The physico-mechanical properties of the produced pellets and the emission values resulting from combustion are determined. Endurance resistance, hardness resistance, dehydration resistance, moisture content, ash content, equivalent moisture content, gas emission values released as a result of combustion, and thermal values which are an important indicator of energy content of the pellets produced from corn stems were identified. The higher and lower heating values (HHV and LHV) were determined and compared to the standards used in the European Union for biomass-produced pellets.

MATERIALS AND METHODS

Biopellets production

The evaluation of agricultural wastes in the form of solid fuel as a source of energy is of great importance in Turkey as well as in the whole world. One of the easiest and most effective ways to generate energy from agricultural wastes is to use these wastes as solid fuel. However, the most important problem encountered in using vegetable wastes as solid fuel is the low density of vegetable wastes and the high moisture content. Low density and high moisture content also bring with it transportation and storage problems. For this reason, one of the methods to be applied in order to use vegetable wastes efficiently and easily in order to produce energy is to dry these wastes and to pellet them after grinding.

One of the effective methods for using agricultural residues as improved solid fuels is pelletizing. In recent years, palletization has become increasingly prevalent and the use of pellets has become widespread. The pellet has a small, cylindrical shape resembling animal feed. Biomass pellets are generally 6-12 mm in diameter and 10-30 mm in length. The process of bringing the material into a smaller size (about 30 mm) under pressure is called pelletizing. Pellets can be produced from materials such as wood chips, wood chips, tree bark, agricultural products, grains, nuts, almonds, walnut shells, and even paper. Biological crops such as corn cobs, beet pulp, sunflower spices, dried olives, cherry seeds and soybean can also be used in the production of pellets. The pelletizing process increases the density of the material, reduces transportation, storage and transport costs, and ensures homogeneity in size and shape can be fed automatically to the combustion systems for thermal purposes, thus enabling more efficient use of the material.

Roller presses are used in biomass pelletizing machines. Small press (approx. 30 mm) is used in the cylinder presses. For this reason, this type of press is also called pellet press. There are a number of molds arranged in thick steel discs or holes drilled on the ring. The material is forced into the molds by means of 2 or 3 cylinders. The process flow and main components for biomass palletization is given in Figure 1. Biomass pellet production consists of following processes; raw materials, screening, drying, cyclone separation, forming granulation, cooling, screening, finished products. At the same time, each part is equipped with strict quality control system to ensure the product quality.

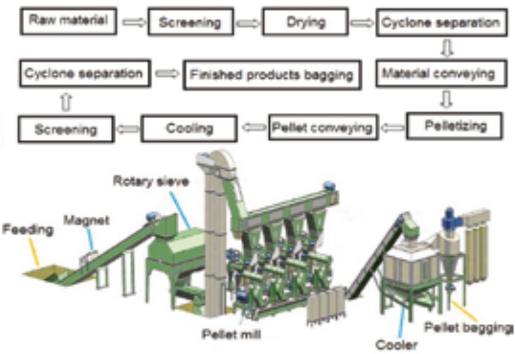

Figure 1. Pellet process flow diagram and main parts of the pellet plant (Kyriakopoulos et al., 2016)

Agricultural wastes can be used singly or as a solid fuel by mixing. In this case, when the wastes with higher quality and higher thermal value are used together with wastes with lower thermal value, the thermal value of the mixture is increased. High quality agricultural wastes, in terms of thermal value and ash content, are used as solid fuel in excess amount when they are mixed with agricultural wastes which are high in quantity and low in thermal value. Among the remaining wastes from field crop production, the thermal values of rice paddy and rice paddy are the lowest values (14.65 MJ/kg).

Pellet material and palletization process

Approximately 200 kg corn stalks were harvested from corn grown during the first crop corn production period in 2016 and 2017 at Cukurova University Agricultural Faculty Research and Application Farm. Corn pellets using collected corn wastes were produced at a pellet production facility in the Adana Organize Industrial Zone. Corn stalks were passed through the mill and made into small powder. Then, the powdered material was dried in the oven to reduce the humidity. The dried material was pelletized by pressing under high pressure. The pressed material was cooled and ready for use at the end of packaging.

Determination of physical and chemical characteristics of biopellets

Moisture content

The moisture content of the biomass material was measured in two steps, before and after pelletizing. The moisture content of the pellets was determined according to the ASAE D245.6 standard (ASAE, 2007). For this purpose, the biomass material was stored in a drying oven at 105°C for 24 hours. Moisture contents were determined according to wet basis, taking into account the masses measured before and after drying.

Dehumidification resistance

The damping resistances of the pellets were determined using a conditioning test cabinet. In this test, pellet specimens of 300 g mass were analyzed at 4 different temperatures (15ºC, 25ºC, 35ºC and 45ºC) and 3 different moisture contents (50%, 65% and 80%) in the air conditioning test cabinet, depending on the temperature and humidity content, they were kept waiting for a time period of 22-68 hours.

Equivalent moisture content

The pellets produced were stored 21 days under normal environmental conditions and the difference between the recorded first and last masses was calculated as the equivalent moisture content.

Water intake resistance

Water intake (or sorption) resistance is intended to monitor the amount of water that the water immersed pellets absorb to their structure after a certain period of time and consequently the deterioration of their structure. For this purpose, the pellets were weighed and stored before the water was immersed in the water. Each pellet sample was then submerged at a depth of 25 mm into a water-filled container at a temperature of about 27°C. After a total of 30 s, the pellets were removed and the masses were again measured.

This process was repeated four times for the same pellet sample.

Durability resistance

The durability of the pellets was determined using a durability tester made in accordance with the resistance standard ASAE S269.4 (ASAE, 2007). In this test, 500 g of pellet samples were placed inside the test device and continuously stirred for 10 minutes to reduce the test device. After the test, the pellets were taken out and sieved using a sieve having a hole diameter of 5.4 mm. The masses of the pellets remaining on the sieve were weighed and recorded. The resistance of the pellet was determined to be % depending on the mass loss during the test.

Compression resistance

Pellet compression resistance or hardness is defined as the maximum load applied prior to breakage of pellet. This test is performed during transport and storage to calculate the pressures that the upper pellets apply to the underlying pellets. The hardness of the densified products is often determined by the compression resistance test. For this purpose, a manually controlled pressure tester was used. In this test, 50 randomly selected pellets were used from the pellet samples. Each pellet was placed between two plates and compressive loads were applied to the pellets by compression strength tester. The applied compressive loads were recorded on the computer and the maximum compressive force before the pellet breakage was determined as pellet hardness. Compression resistance results are given as Newton (N).

Breaking resistance

In determining the breaking (shatter) resistance, the pellets were weighed before the test and their masses were recorded. Then, the pellets were dropped 10 times from a certain height (1-1.8 m) onto a hard surface. After the dropping process, the pellets were weighed again and their masses were recorded. The shatter resistance is calculated as percent (%).

Calorific value

The upper calorific values of the produced pellets were determined using a calorimeter according to ASTM D5865-04 standard (ASTM, 2010). For this purpose, the pellets were kept at 105°C for 24 hours to remove the moisture. In the calorific value test, samples of 1 g mass furnace samples are burned in an oxygen environment in a calorimeter bomb under standard conditions. The calorific value is determined according to the increase in the temperature of the water in the calorimetric vessel and the average actual heat capacity of the system. The combustion heat is calculated by monitoring the temperature before combustion, at the moment of combustion and after combustion, and applying thermo-chemical and heat exchange corrections to them.

Flue gas emissions

In order to determine the pellets produced, their combustion characteristics and their environmental effects, flue gas emissions that have been burned and formed as a result of combustion have been measured. Pellets are burned with solid fuel-burning layer. A flue gas measuring device was used to measure the flue gas emissions resulting from the combustion of the pellets. The values of O_2 (%), CO (ppm) CO_2 (%), NO (ppm), NO_2 (ppm) and SO_2 (ppm) were determined in the emission measurements.

Ash content

The ash content of the pellets was determined by thermogravimetric tester according to ASTM D5142 standard (ASTM, 2010). In order to determine the ash content, pellet samples were first dried in a drying oven at 105ºC for 24 hours. The ash content was then calculated by burning samples of 2 g mass in an ash oven for 5 hours at 800ºC.

RESULTS AND DISCUSSIONS

Physical properties of biopellets

The physical and chemical properties of crude biofuels are different from petroleum derived fuels. Biofuels with very complex structure contain more than about 300 components. In general, crude biofuels consist of a mixture of organic acids, alcohols, aldehydes, esters, ketones, phenols, furans and lignin-derived oligomers (Xiu & Shahbazi, 2012). The

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physical and thermal analyzes of the produced corn pellets were carried out in laboratories of the Department of Energy Plants of the Black Sea Agricultural Research Institute. In the following sections, the results of the analysis are given and the evaluations are carried out.

Dimensions of biopellets

The average length of pellets produced from corn stalks (Figure 2) is 17.28 mm. The diameter of the produced pellets is measured as 6.26 mm on average. For biomass pellets, it has been reported in the European standard EN 16127 that pellet length should be 3.15-40 mm and diameter 6-8 mm. The length and diameter of pellets produced from corn stems are in line with the EU standard EN 16127 (EN, 2013).

Figure 2. Pellets made from corn stems

Strength of biopellets

Strength resistance of the pellets produced from corn stalks was determined to be 93.82%. The durability of the produced pellets was determined to be slightly lower than the durability (> 97.5%) specified for the forest and wood waste in the EU standard EN 15210-1 (EN, 2013).

The breaking resistance and hardness of the pellets produced from corn stalks were determined to be 99.14% and 488.33 N respectively. The pellet hardness is defined as the applied maximum load before breaking the pellet. Water sorption resistance is an indication of the amount of water that the submerged pellets have absorbed into their bodies after a certain period of time and consequently the deterioration of their structure. The water sorption resistance of the corn pellets produced was determined as 76.9% in the first minute and 120.4% in the second minute.

Moisture content of biopellets

As the amount of water contained in biofuels increases, the thermal value decreases. If the amount of water in the fuel is excessive, it is the most important obstacle to its use as transportation fuel. According to the ASAE D245.6 standard, the moisture content of the pellets produced from corn stalks was determined to be 2.29% (ASAE, 2007). It has been determined that the moisture content of the produced corn pellets is compatible with the moisture content (% 10) specified for forest and wood waste in the EU standard EN 14775-1 (EN, 2013). In DIN 51731 standard, the pellet moisture content has been reported to be at most 12% (DIN, 1996). The moisture content of the produced corn pellets was found to be in accordance with DIN 51731 standard. The equivalent moisture content of corn pellets was determined to be 1.012% after 1 week and 1.013% after 3 weeks.

Calorific values of biopellets

The calorific value of a fuel is the quantity of heat produced by its combustion at constant pressure and under normal (standard) conditions (i.e. to 0°C and under a pressure of 1013 mbar). The combustion process generates water vapor and certain techniques may be used to recover the quantity of heat contained in this water vapor by condensing it. Therefore, are there mainly two types of calorific values:

Higher Calorific Value (HCV or Gross Calorific Value-GCV, or Higher Heating Value-HHV): When 1 kg of a fuel is burnt, the heat obtained by the complete combustion after the products of the combustion are cooled down to room temperature (usually 15°C) is called *higher calorific value* of that fuel (HCV). The water of combustion is entirely condensed and that the heat contained in the water vapor is recovered.

Lower Calorific Value (LCV or Net Calorific Value-NCV, or Lower Heating Value-LHV): When 1 kg of a fuel is completely burned and the products of combustions are not cooled down or the heat carried away the products of combustion is not recovered and the steam produced in this process is not condensed then the heat obtained is known as the *lower calorific value* (LCV). The products of combustion contain the water vapor and that the heat in the water vapor is not recovered. The LCV is the energy that turns on as a result of burning the fuel.

The relation between HCV and LCV is the amount of LCV can be obtained by subtracting the amount heat carried away by the combustion products especially the heat carried away by the steam. The LCV is about 8-9% lower than the HCV due to the condensation heat of the water vapor which is released as a result of combustion (Antmen, 2019).

The HCV of the pellets produced from corn stalks were determined to be 4325 cal/g (18.11 MJ/kg) using the calorimeter apparatus according to ASTM D5865-04 standard (ASAE, 2007). If the LCV of the produced corn pellets is assumed to be 8% lower than the HCV, it was calculated as 16.66 MJ/kg. It has been reported that the pellet calorific value in the EU standard (EN 14918) must be within the range of 16-19 MJ/kg for biomass pellets. The LCV of pellets produced from corn stems is suitable to the EU standard (EN 16127) (EN 2013). However, it has been reported that for the pellets the calorific value should be at least 17.5 MJ/kg in the German DIN 51731 standard. On the other hand, the LCV of the corn pellets (16.66 MJ/kg) is higher than that of industrial lignite (12.56 MJ/kg), central lignite (8.37 MJ/kg), Elbistan lignite (4.60 MJ/kg), wood (12.56 MJ/kg), animal and plant waste (9.62 MJ/kg) reported by Ozturk, 2008.

Ach content of biopellets

It is desirable that the ash content in a good fuel is low. The ash content of the corn pellets was determined to be 2.01% by thermogravimetric analyzer according to ASTM D-5142 standard (ASTM, 2010). The ash content of the produced corn pellets was determined to be in accordance with the ash content (< 3%) specified for the forest and wood waste (EN-B) in the EU standard EN 14775 (EN, 2013). On the other hand, it has been reported in the DIN 51731 standard (DIN, 1996) that the pellet ash content should be at most 1.5%. The moisture content of the corn pellets produced was found to be in accordance with DIN 51731 standard.

Flue Gas Emissions for Corn Pellets

The flue gas analysis of the produced corn pellets was carried out at the laboratories of the Energy Plant Department of the Black Sea Agricultural Research Institute. The flue gas emission results of the corn pellets are given in Table 1.

Table 1. Flue gas emission values of corn pellets

Emissions	Values
O_2	16.1%
CO_2	4.7%
CO	1028 ppm
NO	38 ppm
NO_x	40 ppm
SO_2	2 ppm

Oxygen

It is desirable that the ratio of oxygen (O_2) is as low as possible in the flue gases, so as not to cause carbon monoxide (CO) formation, depending on the type of fuel and air excess coefficient. Oxygen is considered to be the ideal value for flue gas analysis for natural gas 2-3%, for liquid fuels 3-4%, for solid fuels 5-6% (Bilgin, 2001). O_2 value of the produced corn pellets was determined as 16.1% as a result of flue gas analysis.

Carbon dioxide

Carbon dioxide (CO_2) is the least harmful gas in the emissions resulting from combustion. Depending on the fuel type, CO_2 is preferred to be present in the flue gases in high proportions. CO_2 values are accepted as suitable for flue gas analysis, 11% in natural gas, 14% for liquid fuels and 14% for solid fuels. As a natural consequence of good combustion, the high CO_2 demand in flue gases is considered an undesirable emission in recent years, due to the greenhouse effect caused by the atmosphere. The solution here is possible with the widespread use of low-carbon, high-hydrogen-containing fuels and the limited use of fossil fuels over time (Bilgin, 2001). The CO_2 value was determined as 4.7%. The CO_2 emissions determined for corn pellets produced are much lower than the reported values for solid, liquid and gaseous fuels. This result indicates that burning of corn pellets will result in less CO_2 emissions compared to other fuels. This is important for the widespread use of biofuels in order to prevent environmental pollution.

Carbon monoxide

Carbon monoxide (CO) is considered to be unwanted and harmful emission in flue gases due to energy loss and pollution as a result of soot. By increasing the amount of O_2 supplied, the CO must be converted to CO_2 by completing the incomplete combustion. In the flue gas analysis, the amount of CO is considered normal up to 100 ppm (Bilgin, 2001). As a result of the flue gas analysis of the produced corn pellets, the CO value was determined to be 1028 ppm.

The main reason for the presence of CO among the combustion products is the inability to meet the fuel with oxygen. If the CO value is higher than desired, it can be said that there is not a complete combustion, in other words, the fuel does not meet with enough oxygen. CO reduces blood oxygen carrying capacity. In this case, due to local oxygen deficiency, malfunctions occur in sensitive organs and tissues such as the blood vessel walls, brain and heart.

Nitrogen monoxide

During the combustion process, especially at high temperature (1200°C), the nitrogen (N) molecule in the air used with the burning reaction reacts with the radical oxygen (O_2) to initiate a chain reaction with oxides and nitrogen monoxide (NO). At temperatures above 1700°C, such reactions occur more rapidly. As a result of combustion, NO and nitrogen dioxide (NO_2) generally occurs in a lesser amount. NO generally occurs during combustion in air fuel mixtures near stoichiometric. Parameters that increase NO formation are gas temperature and O_2 concentration. NO released from the exhaust and the exhaust is rapidly converted into NO_2 by the ozone gas as oxides. NO_2 is a strong oxidant that enters the reaction to form nitrate acid. As a result of flue gas analysis of the produced corn pellets, the value of NO was determined to be 38 ppm.

NO is an odorless gas. It disrupts the functioning of the lungs, irritates the mucous membrane and has a paralyzing effect. It causes the formation of nitric acid. It is unstable in environmental conditions and it combines with O_2 and turns into NO_2. The maximum acceptable concentration (MAC) is 9 mg/m^3.

Nitrogen oxides

Nitrogen oxides (NO_x) are formed due to the air excess coefficient and furnace design, depending on the fuel type, and are harmful to the environment. There is no possibility to interfere with the nitrogen oxides other than the possibility of the fuel air adjustment, and it is regarded as a criterion to be taken into consideration when buying the boiler. Excessive NO_x in emissions indicates excessive rise in combustion temperature. As a result of flue gas analysis of the produced corn pellets, the NO_x value was determined to be 40 ppm.

Along with many nitrogen oxide compounds, the most common are NO and NO_2. NO_x gases are acidic gases. NO_x gases can be carried at very long distances in the atmosphere with the help of wind. One of the most important gases causing air pollution is NO_2. NO_2 is very dangerous for human health. NO_2 not only cause air pollution itself, but also cause ozone formation and ozone pollution, especially in summer. An alarm is issued when the concentration of NO_2 is higher than 400 mg/m^3 in one hour in the European Union Countries. Restrictions are made especially on the use of motor vehicles. When the concentration of NO_2 is 150 ppm (285 µg/m^3) or higher, it has a lethal effect on human been. NO_x combines with the neighboring hemoglobin. NO_2 is irritating to the lungs and causes respiratory infections. NO_x also causes eye irritation, infection in the upper respiratory tract (especially in children), asthma exacerbation, and increased bronchitis. NO_x negatively affects the throat and lungs. NO_2 is a gas with a pungent reddish-brown mixture. Even at low concentrations, it irritates the lungs and damages the tissues and mucous membrane. The MAC value for NO_2 is 9 mg/m^3.

Sulfur dioxide

Sulfur dioxide (SO_2) is the most common of air pollutant emissions. The most important part of the SO_2 emissions is exposed to thermal power plants that burn very large quantities of sulphated solid and liquid fuels to generate electricity. SO_2, which is produced by the combustion of sulfur in the fuel, is considered to be the beginning of dangerous emissions to the environment. This gas, which is not concerned with the burner and the measures to be taken, can only be reduced in flue gases with low sulfur fuels. When natural gas is used, SO_2 value which is zero in the flue gas can be 150–200 ppm in the flue gas when imported coal containing 0.5% sulfur is used (Bilgin, 2001). SO_2, in flue gases, at low temperatures, combines with water vapor to form sulfuric acid and causes destruction in boilers. As a result of the flue gas analysis of the produced corn pellets, the SO_2 value was determined to be 2 ppm.

CONCLUSIONS

In the corn production areas of Turkey, landfill mixing processes are applied in order to remove remaining plant wastes by burning or shredding. The incineration of corn plant wastes causes beneficial organisms in the soil and harmful environmental effects. On the other hand, the process of shredding plant waste into the soil causes significant energy consumption. Clean and renewable fuels with improved physical properties and improved combustion characteristics will be produced, eliminating these problems as indicated by the pelletization of corn biomass waste. The pelletizing process will facilitate the transport and storage of residues and at the same time reduce shipping costs. Most importantly, the evaluation of such biomass materials through pelletization will provide for the economization of waste and will partially or even reduce our country's external dependency on energy.

It is primarily necessary to evaluate such wastes and bring them to the national economy. One of the most important benefits that can be achieved in the medium and long term in case of widespread application of such practices is to enable the establishment of agricultural based industry which is one of the most important elements of rural development by evaluating the wastes generated as a result of the production of some agricultural products intensively cultivated in Cukurova Region as biofuels, to provide employment to people living. In the case of establishing pellet production facilities in rural areas from agricultural wastes, it will provide a useful service for rural employment and rural development. The efficient use of biomass in Turkey is a matter of enabling new business areas to open up. In addition, because there is no carcinogenic substances and sulfur present in fossil fuels in the biomass material structure, it will contribute to the prevention of air pollution as there is very little damage to the environment.

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