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ARAŞTIRMA MAKALESİ RESEARCH ARTICLE

Environmental impact of bio-briquettes produced from agricultural residues concerning to CO_2 emissions

Tarımsal artıklardan üretilen biyo-briketlerin CO_2 emisyonları açısından çevresel etkisi

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Ö Z E T / A B S T R A C T

Aims: This study examined the flue gas emissions of bio-briquettes produced from agricultural residues.
Methods and Results: The briquettes were produced from residues of tea (*Camellia sinensis*) processing plants, pruning residues of persimmon (*Diospyros kaki*), tomato (*Solanum lycopersicum*) stalk and pruning residues of peach (*Prunus persica*) tree. The residues were briquetted using a hydraulic briquetting machine with a horizontal course. Solid cylindrical briquettes were produced under different compression pressures ranging from 40 MPa to 240 MPa, with a moisture content of 10%-12% and having a particle size of 5 mm. Flue gas emissions of bio-briquettes were measured.
Conclusions: The results of the study showed that CO_2 emissions increased with increase in the briquetting pressures. The lowest CO_2 emission was (2.50%) obtained at 120 MPa pressure for the briquettes produced from tomato stalk residues, where the highest was (8.90%) at 240 MPa for the briquettes produced from peach tree pruning.
Significance and Impact of the Study: This study deals with the CO_2 emission of biomass resulted from residues/wastes from the intensive farming of tea (*Camellia sinensis*), persimmon (*Diospyros kaki*), tomato (*Solanum lycopersicum*) and peach (*Prunus persica*).

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INTRODUCTION

Energy is a vital element for the economic growth of countries and social life in today's society. However, the depletion of fossil fuel sources has started already and the demand for energy increasing day by day as the world's population increases. Fossil fuels such as petroleum, coal and natural gas meet the demand for world's energy (Wang and Sarkar, 2018). Given that the main task of the energy sector is to ensure the continuous availability of reasonably priced energy for a growing population and the emerging economy, it is clear that fossil-based fuel consumption should be reduced and new and renewable energy sources should be investigated (Ültanır, 1996). Amongst the existing global challenges, indiscriminate burning of fossil fuels and the ensuing climate change impact due to CO_2 emissions are the most serious problems of 21st century. Of the renewable energy sources, bioenergy as sustainable and environmentally friendly alternative to the fossil fuels has stirred substantial research worldwide (Karaca, 2017). Biomass conversion processes have emerged as a rapidly growing field of science and technology endeavored to fulfil ever-growing energy deficit as well as reduce CO_2 emissions by 70–90% (Timung et al., 2015; Sohni et al., 2018).

Figure 1. Residues from a) tea, b) tomato, c) persimmon, d) peach

The issue of energy utilization of waste material is a subject of the International and European policy in the field of waste management (Malatak and Bradna, 2017). Biomass has received tremendous attention both in developed and developing countries as a renewable energy source (Grover and Mishra, 1996; Muazu and Stegemann, 2015; Karaca, 2019). Biomass energy, i.e. energy obtained from plant and animal-based natural materials composed mainly of carbon-hydrate compounds (Ölçüm, 2006; Chen et al., 2011; Prakash and Karunanithi, 2008), represents a source of environmentally friendly and inexhaustible renewable energy. The energy use of waste biomass as a renewable source of energy has many positive aspects and helps solve problems not only ecological but also in agro-forestry (McBurney, 1995). The biomass-based fuels contain almost no sulfur and sulfur dioxide emissions (Hajek et al., 2013). Other pollutants in emissions from waste biomass are favorable in comparison with emissions from fossil fuels (Malatak and Passian, 2011). Production of high-quality biofuels with good mechanical, chemical and energy properties is strongly desired (Ndindeng et al., 2015). Biomass, which includes agricultural residues, accounts for approximately two-thirds of all potential sources of renewable energy in Turkey (Angın and Şensöz, 2006), whose vast areas of agricultural production offer great potential in terms of renewable energy resources.

Agricultural residues produced out of huge agricultural productions everywhere on the world are becoming a very popular not only for organic material based fertilization but, also for producing renewable energy by means of biofuels. This study examined the CO_2 emission from cylindrical briquettes made of the residues of four different agricultural products tea (*Camellia sinensis*), persimmon (*Diospyros kaki*), tomato (*Solanum lycopersicum*) and peach (*Prunus persica*) (Figure 1). Full cylindrical briquettes were produced with a hydraulic briquetting machine under different compression pressures ranging from P: 40 MPa to 240 MPa, with a moisture content of M12 (M12: 10%-12%) and having a particle size of (PS: 5 mm). results revealed a close relation between the briquetting pressures and CO_2 emissions.

MATERIALS and METHODS

This study was conducted using residues from tea processing plants, tomato residues after harvesting and pruning residues from peach and persimmon gardens.

Briquetting

Briquetting, one of the densification technologies, is a fundamental and promising method for conversion of the biomass into solid biofuels (Hoover et al., 2014). It is achieved by forcing loose particles together into a larger, more compact and shaped form, by application of mechanical force to create particle-to-particle bonding (Kaliyan and Morey, 2010; Karunanithy et al., 2012). The residues of particular products were collected from the gardens, greenhouses and processing facilities and brought to workshop and laboratories of Agricultural Faculty at Ondokuz Mayis University in Samsun Turkey. They were ground 5 mm by a 3 kW powered hammer mill consisting of 8 hammers rotating at a speed of 2,850 rpm. Then, they were sun dried under normal conditions until the M12 (M12: 10%-12%) was achieved as defined by standards (EN 14774-1, 2009; EN ISO 17225-3, 2015). Solid cylindrical briquettes were produced by a hydraulic type briquetting machine having a mold with a wall-thickness of 25 mm (Figure 2).

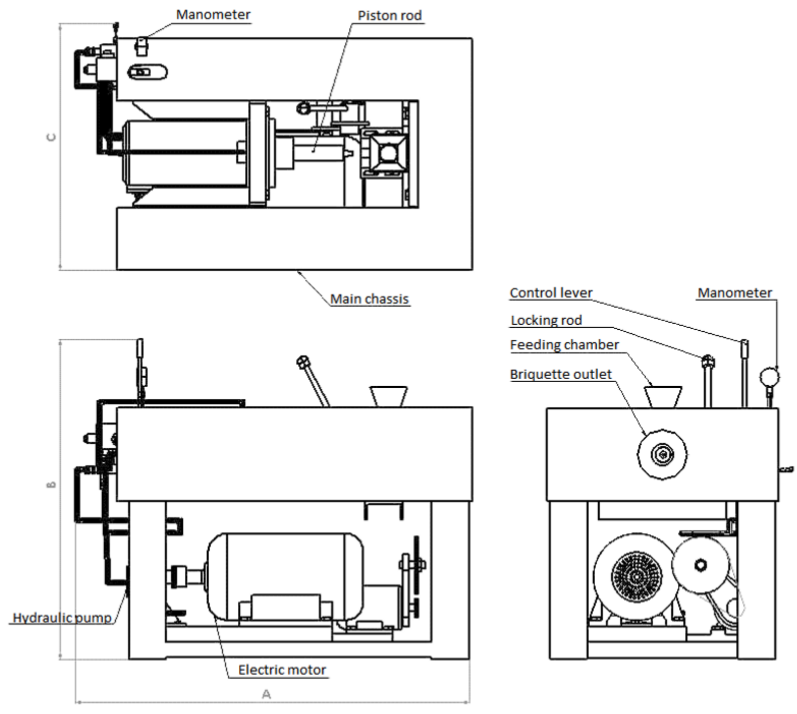

Figure 2. Hydraulic briquetting machine (A: 1280 mm; B: 1155 mm; C: 740 mm)

Flue gas emissions of briquettes

Briquettes were burned in a briquette stove and the flue-gas emissions during burning were measured using an Ecom EN2 flue-gas sensor. The probe of the device was installed approximately 1 m above the stove, and all readings were performed from this constant point as shown in Figure 3. The pellets were burned in a pellet stove with an auxiliary air flow. Flue gas emissions were recorded after a regular burning of pellets were provided.

Data analysis was performed using the IBM SPSS Statistics 21 software. The normality analysis was performed with the Kolmogorov-Smirnov single sample test and the variance homogeneity was assessed by the Levene test and the variances were homogeneous ($P > 0.05$), with normal distribution of the data.

Figure 3. Flue gas emission readings

RESULTS and DISCUSSION

In this study, CO_2 emission from burning of biomass obtained from four different residues/ wastes concerning the greenhouse gases due to global warming were determined. The briquettes from those residues were produced by a laboratory type hydraulic briquetting machine and the briquetting pressures varied from 40 MPa to 240 MPa, which were in line with studies described by (Krizan et al., 2015; Zhang and Guo, 2014; Sun et al., 2014) to obtain satisfactory durability and shape. Moisture content of briquettes was very important for successful extrusion (Oladeji, 2015; Wachira et al., 2015). Moisture content of the material (M12: 10%-12%) in the present study was selected based on EU standards (EN ISO 17225-3, 2015) and previous studies, which reported material moisture contents of between 8%-15% to be suitable for briquetting using hydraulic equipment (Zhang and Guo, 2014; Oladeji, 2015; Coşereanu and Lunguleasa, 2015).

Table 1. Maximum measured CO_2 emissions (%) of briquettes at different pressures

P (MPa)	Tea processing residue	Tomato residue	Persimmon branch	Peach branch
40	$2.60{\pm}0.00^{b}$	$3.00{\pm}\ 0.00^{a}$	$3.10{\pm}0.00^{e}$	$3.50{\pm}0.00^{f}$
80	$2.80{\pm}0.00^{c}$	$2.70{\pm}0.00^{c}$	$3.20{\pm}0.00^{a}$	$3.60{\pm}0.00^{e}$
120	$2.80{\pm}0.00^{c}$	$2.50{\pm}0.00^{d}$	$3.90{\pm}0.00^{c}$	$4.70{\pm}0.00^{d}$
160	$3.00{\pm}0.00^{d}$	$2.60{\pm}\ 0.00^{b}$	$4.10{\pm}0.00^{b}$	$6.60{\pm}0.00^{b}$
200	$3.10{\pm}0.00^{a}$	$2.60{\pm}\ 0.00^{b}$	$6.40{\pm}0.00^{d}$	$7.90{\pm}0.00^{c}$
240	$3.10{\pm}0.00^{a}$	$3.70{\pm}0.00^{e}$	$6.40{\pm}0.00^{d}$	$8.90{\pm}0.00^{a}$

**The difference among the values carrying the same letter at each column is insignificant at $P \leq 0.05$*

Flue gas emissions

Many countries are known to suffer from air pollution caused by burning coal for heating purposes, and burning petroleum-based fuels are known to have high levels of SO_x, NO_x and CO_2 emissions (Ross et al., 2002). Reductions in emissions can be achieved by using biofuel briquettes made from agricultural residues in combustion chambers in place of coal. The flue-gas emission values of all the briquettes produced from different agricultural residue in the present study indicated their use as solid fuel to be environmentally appropriate. Table 1 shows the maximum CO_2 emission values of the briquettes. CO_2 emission were recorded by a special device after a regular burning was achieved and they were averaged by time during the measurement.

Relationship between briquetting pressures and CO_2 emissions can be expressed as follows:

$$y = a.x^2 + b.x + c \qquad \text{Eq. (1)}$$

Where; y is CO_2 emission (%) and x is hydraulic pressing pressure valid for the range 40 to 240 MPa and a, b and c are the coefficients (Table 2). However, a more reliable expression of the mathematical models and their equations along with the R^2 values were given in Figure 4.

Table 2. Parameters of the mathematical equations for CO_2 emissions

Residue	a	b	c
Tea processing	$-7E-06$	$4.4E-03$	2.44
Tomato	$-9E-05$	$-2.2E-02$	3.82
Persimmon branch	$-7E-05$	$3E-04$	2.87
Peach branch	$-6E-05$	$1.33E-02$	2.57

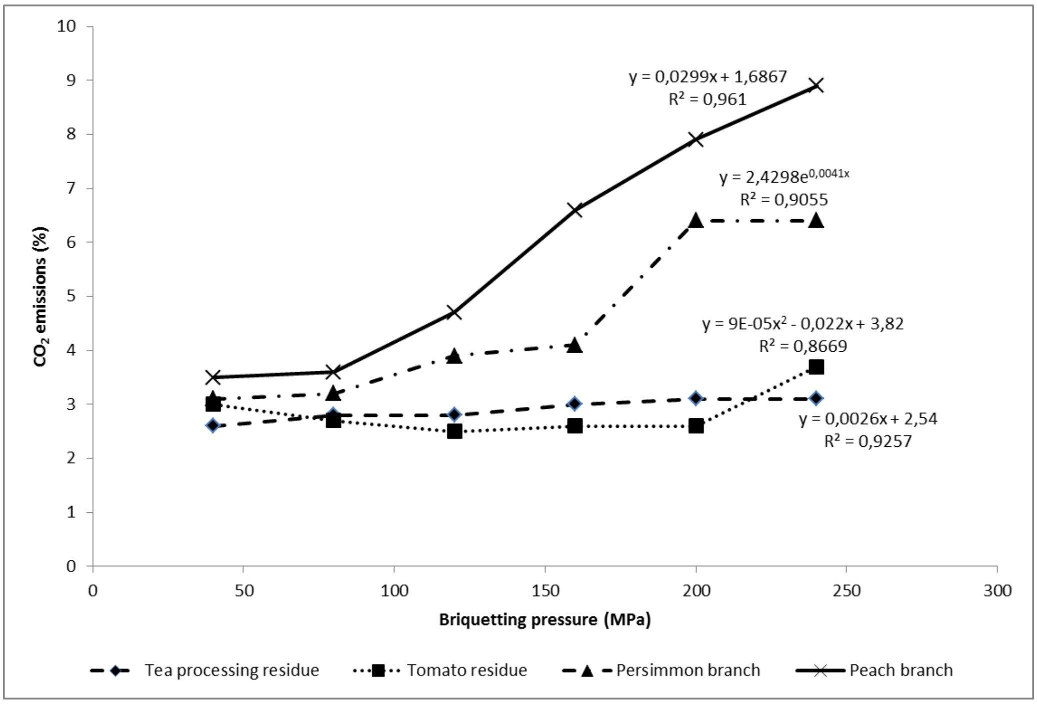

Figure 4. Variations in CO_2 emission of briquettes produced under different pressures

The highest CO_2 emission was obtained at 240 MPa pressure for peach tree pruning briquettes (8.90%), where the lowest was at 120 MPa for the briquettes produced from tomato stalk residues (2.50%). The difference in CO_2 emissions for particular residue is found to be statistically significant (*P* >0.05). In the meantime, it was determined that CO_2 emissions increased with increase in briquetting pressures. These findings are in line with the studies (Bradna et al., 2017; Bradna et al., 2016) where they measured flue-gas emissions from biomass pellets produced from rape and wheat straws. The results for CO_2 emissions are also in line with the study done with pruning residues of apple tree (Kazimirova and Opath, 2016), with the studies bio-briquettes and pellets produced from hazelnut and peach tree residues (Gürdil et al., 2016; Gürdil and Melki, 2018). These findings are also in compliance with the results of a research which is done with corn stalk residues (Dok et al., 2019). Where they found the CO_2 emissions of the briquettes 2% to 2.64% and the results were statistically significant according to the change in particle size of the ground materials. Fortunately, CO_2 emission values of all the bio briquettes in this study fall within the limits (CO_{2max}= 20.3%) of legal Regulations for Air Pollution Control for Heating in Turkey (IKHKKY, 2014).

CONCLUSIONS

The present study used a hydraulic briquetting machine to produce cylindrical briquettes with varying briquetting pressures in order to determine the effect of densification to CO_2 emissions of the briquettes. The result of the study revealed that there was a direct proportion between the briquetting pressures and CO_2 emissions. The CO_2 emissions of the bio briquettes produced from tea, tomato, persimmon and peach tree residues ranged from 2.50% to 8.90%. The highest was obtained from peach tree pruning briquettes (at 240 MPa) where the lowest was from the briquettes produced from tomato stalk residues (at 120 MPa).
However, all the emission values for CO_2 were within the defined limits for environmental pollution. In the Regulation on Control of Air Pollution caused by heating (IKHKKY), 13% O_2 (% of standard oxygen content) and 20.3% CO_{2max} (% of maximum carbon dioxide in dry residual gas for each fuel). It's well understood from the literature that the higher greenhouse gases emissions in particular CO_2 emissions for this study causes from irregular combustion of solid fuels. Therefore, the options for reducing emissions of incomplete combustion process include uniform fuel supply, sufficiently high temperature in the combustion chamber and sufficient intake of secondary or tertiary air or choice of optimal moisture of biofuel. The briquetting of unused agricultural residues for use as solid biofuel could be useful in meeting today's energy deficits and reducing global warming. In addition, the use of agricultural residues as an alternative energy source can contribute to employment in agricultural regions by promoting the establishment of new, agricultural-based industries. Additional research is important not only for enhancing the quality and quantity of scientific data, but also as a means of focusing public attention on the energy potential of agricultural residues.

ÖZET

Amaç: Bu çalışmada bazı tarımsal artıklardan üretilen biyo-briketlerin baca gazı emisyonları incelenmiştir.
Yöntem ve Bulgular: Briketler, çay (*Camellia sinensis*) işleme tesislerinin kalıntıları, budama hurması (*Diospyros kaki*) kalıntıları, domates (*Solanum lycopersicum*) sapı ve budama şeftali (*Prunus persica*) ağacının kalıntılarından üretildi. Bu tarımsal artıklar, yatay bir rotaya sahip bir hidrolik briketleme makinesi kullanılarak briketlendi. Katı silindirik briketler, P12: 40 MPa ila 240 MPa arasında değişen, M12 (M12: % 10-% 12) nem içeriğine sahip ve partikül büyüklüğü (PS: 5 mm) olan farklı sıkıştırma basınçları altında üretildi. Biyo briketlerin baca gazı emisyonları ölçüldü.
Genel Yorum: Çalışma, briketleme basınçları arttıkça CO_2 emisyonlarında artan bir eğilim bulmuştur. Domates sapı kalıntılarından üretilen briketler için 120 MPa basınçta en düşük CO_2 emisyonu (% 2.50), şeftali ağacı budamadan üretilen briketler için en yüksek (% 8.90) 240 MPa briketleme basıncında.
Çalışmanın Önemi ve Etkisi: Özellikle, CO_2 gibi en popüler sera gazlarından birinin emisyon değerleri konusuna ve küresel ısınma sorunlarına odaklanılmıştır. Ölçülen tüm CO_2 emisyonları, çevre kirliliği için izin verilen sınırlar dahilinde çıkmıştır.

Anahtar Kelimeler: Biyoyakıt, briket, karbon dioksit, çevre, baca gazı, artık.

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