DETERMINING PELLETING PARAMETERS FOR ORANGE PRUNING RESIDUES

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Abstract
This study evaluates the pelleting parameters of fuel pellets made from orange tree pruning residues. Physical-mechanical and thermal properties of pellets were studied and their suitability were checked according to latest EU standards. The pruning residues collected from orange orchards were first pre-chopped and then sun dried at outside conditions till the desired moisture content M10 (8-10%) is achieved. Then the material grinded with varying particle sizes (PS: 4, 6 and 8 mm) to produce pellets. Pruning residues from fruit orchards are a good solution to generate alternative energy sources. Orange cultivation is very popular worldwide so the unused pruning residues of the trees must be utilized for energy in today's energy based world. Some physical-mechanical properties such as; pellet particle density, bulk density, mechanical duration, firmness, pellet moisture content and some thermal properties such as; lower heating value, ash content and flue gas emissions of the produced pellets were analyzed. Results showed us that the pruning residues of orange trees were suitable both in technical and environmental aspects for energy utilization.

Key words: *energy; orange; pellet; pruning; residue.*

INTRODUCTION

The demand for alternative energy sources increases as the depletion of fossil fuels increases. People are in need for renewable energy sources and biomass could be a very choice. Generally, biomass from agricultural production like residues are not utilized sufficiently. Unfortunately, most of these potential is just left on the fields or on the gardens for natural decomposition or just burned randomly near the garden. An example of it is given in Fig. 1., below.

Fig. 1 Pruning and random burning of orange pruning residues

Shaping the grinded material under pressure to smaller sizes (approx. 30 mm) is called pelleting (*Öztürk, 2012*). The density of material is increased and the transportation and storing costs are decreased by pelleting process. Moreover, homogeneity is provided in size and shape which make them more suitable for automatic feeding systems and effective usage of material is provided (*Werther et al., 2000; Mani et al., 2003; Holm et al., 2006; Nilsson et al., 2011; Theerarattananoon et al., 2011; Celma et al., 2012*). Pelleted biomass is low and uniform in moisture content. It can be handled and stored cheaply and safely using well developed handling systems for grains (*Fasina & Sokhansanj, 1996*). However, pellets can be easily produced from agricultural residues, too. Orange cultivation is very popular in Turkey. It's also important since it contains vitamin C. Turkey is an important producer of fresh fruit and vegetable with about 51 million tons of production. Turkey's citrus production reached approximately 4.29 million tons in the last decade, with an increase of 44% (*TUIK, 2018; MFAA, 2018*). The most common procedure for maintaining the orange gardens is pruning. Pruning improves the strength and productivity of trees. It's also a good way of fighting against diseases. But, it generally ends up with residue problem. So, one must utilize this idle potential in advantage of energy generation. The aim of this study is to utilize orange orchard pruning residues as solid biofuel in the form of pellets. Therefore, some physical-mechanical and thermal properties of produced fuel pellets were analyzed with regards to particular EU standards.

MATERIALS AND METHODS

This study is carried out in labs and workshop of Agricultural Machines and Technologies Engineering Department of Samsun Ondokuz Mayıs University in Turkey with collaboration of Çukurova University in Adana, Czech University of Life Sciences in Prague and Black Sea Agricultural Research Institute in Samsun. Pruning residues of orange tree were provided from the orchards in Adana and Mersin provinces in Mediterranean Region of Turkey. Up to date European standards (*EN 14961-2 & EN ISO 17225-6*) were taken as a reference for this research. The pre-fragmented and chopped material (Fig. 2) was sun-dried under normal conditions until their moisture content was reduced to M10 (8-10 %).

Fig. 2 Pre-fragmentation and chopping of orange branches

Then the dried material was ground in a 3-kW electric hammer mill consisting of 8 hammers rotating at a speed of 2,850 rpm (Fig. 3). Once particles of the required sizes PS: 4, 6 and 8 mm were obtained, moisture contents were re-measured, and the particles were pelleted using a pelleting machine (Fig. 4). Particle density of pellets were calculated according to standard (*EN 15150, 2011*). As defined in that standard the volume of the cylindrical properly shaped pellets was calculated by stereo-metric method and the averaged volume is proportioned to the average mass of the pellet (g.cm^{-3}). Likewise, the bulk density was calculated as defined in the particular standards (*EN 15103, 2009*). Mechanical durability of the pellets was tested according to standard (*EN 15210-1, 2009*). In this test 500 g of test portion is placed into this rotating chamber. It's rotated 500 times at 50 rpm speed and then the sample is removed and weighed again. The weight difference before and after the test gives us the mechanical durability of the pellets. Pellet firmness parameter is important during transportation and storage of pellets. The firmness values were determined with a special device (Fig. 5).

Fig. 3 Grinding

Fig. 4 Pelleting

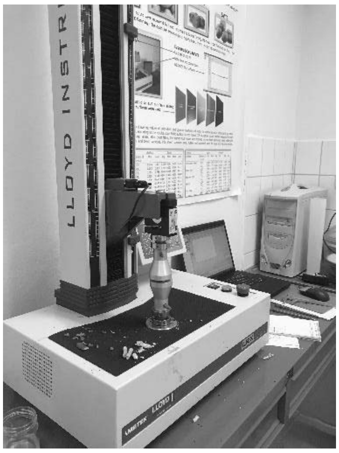

Fig. 5 Pellet firmness tests

As for the thermal properties; lower heating value of pellets were determined by a calorimeter according to the instructions given in standard (*EN 14918*, 2009). Before testing, the pellets were disintegrated in a shredder and kept at 105 ºC for 24 hours to remove the moisture. Samples dried at a weight of 0.5-1 g were burned in oxygen atmosphere in a calorimeter bomb under standard conditions and the calorific value was automatically determined in cal.g^{-1} according to the increase in the temperature of the water in the calorimeter chamber and the average actual heat capacity of the system. Then the values are converted into MJ.kg^{-1} as specified in standard (*EN 14961-2, 2010*). The ash contents of the pellets were determined using an ash furnace according to standard (*EN 14775, 2009*) and the flue gas emissions like O_2(%), CO(ppm), CO_2(%), NO(ppm), NO_x(ppm) were measured and recorded with a gas analyzer.

RESULTS AND DISCUSSION

The effect of particle size on pellet particle and bulk densities was found statistically significant at M10 (Tab. 1).

Tab. 1 Pellet bulk and particle densities

Particle size (mm)	Pellet bulk density* (kg/m^3)	Pellet density* (kg/m^3)
4	542.40 ± 4.75a	1220.10 ± 6.28b
6	537.82 ± 4.75a	1300.17 ± 2.87a
8	530.21 ± 1.08c	1280.83 ± 1.63c
Sig.	<0.001	0.003

**The difference between the values carrying the same letter is insignificant*

Although the study is done in single moisture content (M10) but, some studies proved that the moisture content of the pellets have significant effect on pellet particle and bulk densities (*Colley, 2006; Mani et al., 2006; Liu et al., 2014*). The results for pellet bulk densities were more than the values found for the tomato residues (200 kg.m^{-3}) at M10 (*Celma et al., 2012*). This can be because of the structure of the material since the orange pruning residues have woody and harder structure. According to Colley (2006), durability is regarded as high if exceeding 80%, medium if measured as 70–80% and low if values do not reach 70%. The MD of pellets at al PS was high since they changed among 87.20% to 92.58%.

The effect of pellet particle size (PS) on pellet mechanical durability (MD) and firmness parameters has been found statistically significant (Tab. 2).

Tab. 2 Mechanical durability and firmness of pellets

PS (mm)	MD (%)	Firmness (N)
4	92.58 ± 0.11a	3504.90 ± 24.80d
6	91.30 ± 0.09b	2634.50 ± 19.74b
8	87.20± 0.06c	3163.40 ± 12.70c
Sig.	<0.001	<0.001

It's seen that the firmness of the pellets was relatively higher then pellets produced from plant based residues. This because of the woody structure of the pruned branches. The pellets with smaller PS values had the higher MD values always. Which can be explained by the smaller particle sized material has a better compaction characteristics and has smoother surfaces but, this case was not true for the firmness. Some researchers indicated that the pellet quality is high when the MD value is 80% and higher, medium when MD is ranging from 70 to 80% and low quality when MD≤70% (*Tabil & Sokhansnj, 1996; Tabil & Sokhansnj, 1997*). Materials loose some moisture from their structure during pelleting process due to over-heated mold cause of friction. As a result of this some moisture is removed from the material itself when pelleting the material. Moisture contents (MC) of pellets is given in Tab. 3., below.

Tab. 3 Pellet moisture contents

PS (mm)	Pellet moisture content (%)
4	5.00 ± 0.04b
6	4.88 ± 0.06c
8	4.63 ± 0.03a
Sig.	<0.001

The effect of material PS on pellet's moisture content was found statistically significant. Ironically, the pellets produced from smaller particle size had the highest MC, and MC values decreased as the PS increased. The results were in line with the references given in standards (*EN 14961-2, 2010 & EN ISO 17225-6, 2015*).

Ash content of the pellets made from orange pruning agricultural residue was found as 5.57%, which is in line with the reference value (A10≤10%) given in standard (*EN ISO 17225-6, 2015*). Heating value of pellets was found as 18.65 $MJ.kg^{-1}$. That is also compatible with the value (Q14.5≥14.5 $MJ.kg^{-1}$) indicated in the above mentioned standard. The results showed us that the heating value of pellets produced from orange tree pruning residues are higher than the wood (17.57 $MJ.kg^{-1}$). That is a promising result especially, when the huge idle potential is concerned. The flue gases of the pellets are presented in Tab.4., below.

Tab. 4 Flue gas emissions of pellets

Water content after burning (%)	NOx (ppm)	CO_2 (%)	O_2 (%)	CO (ppm)	NO (%)
8.46	100	4.00	16.90	456.33	95.33

All the measured emission values were in the limits given in Regulations for Air Pollution Control (*IKHKKY, 2014*).

CONCLUSIONS

Energy is the biggest issue on today's world. Renewable energy is a good choice for that since it' sustainable. Biomass energy from agricultural residues is very promising since it's everywhere and environmental friendly, too. Utilization of orange tree pruning residues as source of solid biofuel in the form of pellets were investigated in this study. The pellets were produced with 4, 6 and 8 mm PS at M10 moisture content. Physical-mechanical and thermal properties of fuel pellets were determined and screened out. All the tests were done according to the latest EU standards. The results showed that the fuel pellets have very good physical-mechanical and thermal properties as a fuel. Besides, as from the environmental point of view flue gas emissions were within the defined limits. But, certainly further researches of this kind must be done in order to increase its impact on science. We hope that the obtained results will positively contribute to science and will help agricultural engineers, scientific researches, farmers and even the policy makers to think more globally and wisely for the future and will definitely have a positive contribution to sustainable development in the world.

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REFERENCES

1. Celma, A.R., Cuadros, F., & Rodriguez, F.L. (2012). Characterization of pellets from industrial tomato residues. *Food and Bioproducts Processing, 90*(4), 700-706.
2. Colley, Z.J. (2006). *Compaction of switchgrass for value added utilization* [MSc Thesis]. Department of Chemical Engineering, The Graduate Faculty of Auburn University. Alabama USA. Retrieved from https://etd.auburn.edu/handle/10415/483.
3. EN 14961-2. (2010). Solid biofuels- Fuel specifications and classes- Part 2: Wood pellets for non-industrial use. *European Committee for Standardization*: Management Centre, Avenue Marnix 17, B-1000 Brussels.
4. EN ISO 17225-6. (2015). Solid biofuels -- Fuel specifications and classes -- Part 6: Graded non-woody pellets. *European Committee for Standardization*: Management Centre, Avenue Marnix 17, B-1000 Brussels.
5. EN 14918. (2009). Solid biofuels – Determination of calorific value. *European Committee for Standardization*: Management Centre, Avenue Marnix 17, B-1000 Brussels.
6. EN 14775. (2009). Solid biofuels – Determination of ash content. *European Committee for Standardization*: Management Centre, Avenue Marnix 17, B-1000 Brussels.
7. EN 15150. (2011). Solid biofuels – Determination of particle density. *European Committee for Standardization*: Management Centre, Avenue Marnix 17, B-1000 Brussels.
8. EN 15103. (2009). Solid biofuels – Determination of bulk density. *European Committee for Standardization:* Management Centre, Avenue Marnix 17, B-1000 Brussels.
9. EN 15210-1. (2009). Solid biofuels – Determination of mechanical durability of pellets and briquettes – Part 1: Pellets. *European Committee for Standardization:* Management Centre, Avenue Marnix 17, B-1000 Brussels.
10. Fasina, O. O. & Sokhansanj, S. (1996). Storage and handling characteristics of alfalfa pellets. *Powder Handling and Processing, 8*(4), 361-365.
11. Holm, J.K., Henriksen, U.B., Hustad, J.E., & Sorensen, L.H. (2006). Toward an understanding of controlling parameters in softwood and hardwood pellet production. *Energy and Fuel, 20*, 2686-2694.
12. IKHKKY. (2014) Regulations for Air Pollution Control Caused by Burning. Retrieved from http://www.mevzuat.gov.tr/.
13. Liu, Z., Quek, A., & Balasubramanian, R. (2014). Preparation and characterization of fuel pellets from woody biomass, agro-residues and their corresponding hydro-chars. *Applied Energy, 113*, 1315-1322.

14. Mani, S., Tabil, L. G., & Sokhansanj, S. (2003). An overview of compaction of biomass grinds. *Power Handling and Process, 15*, 160-168.
15. Mani, S., Tabil, L. G., & Sokhansanj, S. (2006). Effects of compressive force, particle size and moisture content on mechanical of biomass pellets from grasses. *Biomass and Bioenergy, 30*(7), 648-654.
16. MFAA, (2018). Citrus report. *Ministry of Food, Agriculture and Animal, Turkish Republic*. ISBN: 978-605-9175-92-0, p. 66.
17. Nilsson, D., Bernesson, S., & Hansson, P.A. (2011). Pellet production from agricultural raw materials- a systems study. *Biomass and Bioenergy, 35*, 679-689.
18. Öztürk, H.H. (2012). *Energy plants and biofuel production*. Hasad yayıncılık Ltd. Şti, İstanbul, p. 272.
19. Tabil, L.G. & Sokhansnj, S. (1996). Process conditions affecting the physical quality of alfalfa pellets. *Applied Engineering in Agriculture, 12*(3), 345-350.
20. Tabil, L.G. & Sokhansanj, S. (1997). Bulk properties of alfalfa grind in relation to its compaction characteristics. *Applied Engineering in Agriculture, 13*(4), 499-505.
21. Theerarattananoon, K., Xu, F., Wilson, J., Ballard R., Mckinney, L., Staggenborg, S., Vadlani, P., Pei, Z.J., & Wang, D. (2011). Physical properties of pellets made from sorghum stalk, corn stoves, Wheat Straw and Big Bluesterm, *Industrial Crops and Products, 33*(2), 325-332.
22. TUIK, (2018). Statistics for plant production. Ankara: *Turkish Statistical Institute*.
23. Werther, J., Saenger, M., Hartge, E.U., Ogada, T., Siagi, Z. (2000). Combustion of agricultural residues, *Progress in Energy and Combustion Science, 26*, 1-27.

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