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Energy and environmental assessment of pellets produced from solid residues of the winery industry

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Abstract

The study assessed the potential of waste by-products from the Cypriot winery industry as raw material for solid biofuels. Two different biomass blends were pelletized and assessed as an energy source for domestic hot water boilers. The samples were composed of Grape Pomace (P1) and Grape Pomace & Vine Shoots Blends (P2) provided by a Cyprus winery: Aes Ambelis (Nicosia, 35°01'12.4"N 33°09'19.5"E). The raw material was dried and pelletized at the facilities of the Agricultural Research Institute (ARI), Cyprus. The pellets were analyzed for moisture and ash content using well-established standardized methods at the Sustainable Solid Fuels Lab of Frederick University, Cyprus. Combustion tests with the pellets were also carried out at the Boilers Lab of Frederick University. The measurement campaign focused on flue gas analysis – in particular carbon monoxide, carbon dioxide, oxygen, lambda – as well as water temperature and boiler efficiency. The results obtained from analysis of the samples showed that most of the examined pellets satisfied the minimum requirements of EN ISO 17225-2 and EN ISO 17225-6 standards for woody and non-woody pellets respectively. Ash content and moisture content for both samples also complied with the standards. The results of the measurement campaign were in good agreement with results delivered by other studies conducted for similar biomass raw material. Study results showed that grape pomace and grape pomace vine shoots blend could potentially be used as an energy source for producing heat which could be exploited for the domestic and industrial sectors. Harvesting this waste stream for energy production purposes could offer economically and environmentally smart solutions for the winery industry in Cyprus, satisfying the circular economy principles which are currently at the forefront of European environmental policy.

Keywords: solid biofuels; grape pomace; vine shoots blends; pellets; ash content; moisture content; combustion emissions

1. Introduction

1.1. Solid Waste from Wine Industry in Cyprus

Biomass is the biodegradable fraction of products, waste and residues of organic origin from agriculture (including plant and animal substances), forestry and related industries as well as the biodegradable fraction of industrial and urban waste. The heat produced by combustion of biomass can be used directly for space heating, crop drying and other industrial processes. It can also be used to generate steam for electricity generation [1]. According to the work of Christophorou & Fokaides (2016) in Cyprus, the main resources of agricultural origin that can be exploited as biomass are olive pomace, marc and tree prunings. Through works already carried out for thermochemical assessment of the above resources, it is clear that in many cases these raw materials meet the minimum composition and thermochemical behavior requirements of EN ISO 17225-2 and EN ISO 17225-6 for woody and non-woody agglomerates respectively [2]. Cyprus has significant potential for agricultural residues and potential biogas. According to the Cyprus National Action Plan for the Promotion of Renewable Energy Production by 2020, the contribution of biomass to the energy mix of Cyprus is expected to be 3.2 ktoe for heating and 13.5 ktoe for power generation.

Biodegradable waste in Cyprus mainly consists of the biodegradable fraction of municipal solid waste, sewage sludge, solid and liquid agricultural residues, and solid and liquid wastes from the food and beverage industries [3]. The winemaking industry, one of the most important markets in Cyprus, produces large quantities of solid waste on an annual basis. The compacted residue remaining after the grape juice is extracted during the wine production process con-

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sists of the bark and the grape seed. While the components of the solid residues of the winemaking process vary according to the variety of wine (white or red), generally they contain bark, pulp, seeds and fruit strains. In the production of wine, about 25% of the weight of the grapes remains as a by-product / waste. In Cyprus, according to the Corine land use database, 8892 hectares of arable land are devoted to viticulture, with 96.8% (8605.7 hectares) dedicated to the wine industry, while table grapes account for the remaining 286.3 hectares.

1.2. Pelletizing biomass

Biomass pelletization is considered a standard method of mechanical treatment of solid woody and non-biomass to produce solid biofuels. During pelletization, the processed raw material is compressed and condensed for more efficient combustion and easier management (storage and transport). Pelletization increases the energy density of the biomass, making combustion more efficient. Pelletization also improves the overall quality, stability and durability of biofuels [4]. An important parameter in the pelletization process is the moisture content, since in several cases it is possible to avoid the addition of binders or other additives through proper selection, thus achieving agglomerates which satisfy the minimum mechanical properties of EN 17225 [5].
Depending on the state of the feedstock, the stages of the pelletization process are: drying, grinding, agglomeration, cooling, sorting and packaging [6]. Pelletizing is currently considered to be one of the most cost-effective and economical ways to convert woody and non-woody solid biomass into a fuel of high energy density and good quality [7]. The use of aggregates for heat production in the domestic and commercial sectors remains dominant in the renewable energy market in the EU. The use of solid aggregates for heat production showed an increase of 25% between 2011 and 2014 [8].
There are two main technologies currently in service for space heating using aggregates: boilers and individual heaters. Domestic pellets are typically utilized for rated thermal inputs up to 10 kW. The heat in the case of agglomerates is transferred to the target space with radiation. As for boilers, its power starts from 20 kW for smaller ones and reaches a few hundred kW for large buildings and industrial applications. Aggregate boilers are distinguished according to how the agglomerates are fed to the burner in boilers with the bottom burner, horizontal feed and top feed [9]. The efficiency of the agglomerate boilers ranges from 80 to 90%. According to the work of Miranda et al. [10], marble aggregates show quite good thermo physical properties during the combustion process.

1.3. Biomass Aggregate Burning Processes

Irrespective of biomass heat conversion technology, the combustion process is divided into two zones. The primary zone is the area where primary combustion takes place in three stages (drying, pyrolysis, combustion). In the secondary zone, dry aggregates decompose into flammable, volatile components and carbon. Coal is burned during primary combustion while flammable gases are burned in the secondary zone. During biomass burning, the biomass aggregates are fed into the main combustion zone, primary and secondary combustions nevertheless occur simultaneously. The amount of excess air in the secondary zone is important for the concentration of carbon monoxide (CO) and unburnt hydrocarbons (UHC). Insufficient air in the chamber results in increased CO and UHC emissions, low NOx concentration, and increased micro particle concentration in the flue gas [11].
The optimal level of excess air varies between different technologies and applications. However, the usual practice is to regulate excess air in biomass aggregate boilers at 10%. Optimized air / fuel ratios can deliver energy savings of up to 25% [12]. The residence time of the flue gas and the temperature in the combustion chamber are important parameters for maintaining low carbon carbon monoxide, unburned hydrocarbons and nitrogen oxides.

2. Methodology

2.1. Sampling of raw material

In the context of this work, the raw material used was the solid waste of the wine industry, which includes the marc (bark, pits and a small part of the fruit) as well as other solid organic wastes from the industry (shoots, stems, leaves and branches). The raw material was collected according to the procedures described in standards EN 14778 and EN 14780 from the Aes Ambelis winery, 28 kilometres southwest of Nicosia. Aes Ampelis is a well-known winery in Cyprus, founded in the early 1990s and is located on the slopes of Kali Mountain Village. The winery harvested the endemic variety Maratheftiko as well as the imported varieties Syrah and Chardonnay. In the context of this work, two different mixtures of raw material were analyzed: a mixture of Maratheftiko (M1) marc, and a second mixture consisting of 70% (v/v) marathae and 30% from other solid biomass (leaves, branches, stems, etc.) (M2).

2.2. Pelletizing raw material

The raw material was pelletized at the Agricultural Research Institute of the Ministry of Agriculture, Rural Development and the Environment at Athalassa in Nicosia. The main parts of the pelletizing unit are: the grinder used for cutting the raw material, storage silo, screw conveyor, which transports the raw material from the storage silo to the pelletizing unit, pelleting press, sieve cooling unit, electric unit control panel and dust filters. The raw material was dried to reduce its moisture content to pelleting levels (10%) as defined in EN ISO 17225-6: 2014. The dried raw biomass was milled to obtain a powder of uniform diameter, no larger than 6 mm. In the pelletizing process, the very high pressures and heat generated in the pelletizer press lead to a rise in lignin temperature, so that it softens and the feedstock can be formed into aggregates. During cooling and screening, dust and other foreign

Table 1: Moisture content and ash mixed study content

Analysis	Mixture 1	Mixture 2
Moisture content (Mad), w%	10	9
Ash, w%	8	10

particles which can potentially fall on aggregates during the process are removed.

2.3. Moisture and ash analysis

The aggregates were analyzed for their physical properties in the laboratories of the Sustainable Energy Research Group of Frederick University. In particular, the moisture content of the study mixtures was determined according to the procedure set out in EN 14774-3: 2009. The samples were placed in a drying oven (SNOL type 20/300) and dried in successive cycles at 105°C until the successive mass measurement was less than 0.2%. A KERN ABT 220-5DM precision balance was used to measure the sample mass.
The ash content of the samples was determined using a drying oven (SNOL 4/1100) in compliance with EN 14775: 2009 procedure. The furnace temperature of 250°C was set to 30 minutes with heating of 6°C/min. It was then kept at this temperature level for 60 minutes to allow the volatile components of the sample to evaporate before ignition. The temperature was then raised to 550°C over a period of 30 minutes with a heating rate of 10°C/minute and remained at that temperature for at least 120 minutes. The results were reported, taking into account the calculated moisture content of the samples.

2.4. Measurement of combustion emissions

The combustion emissions of the samples were measured at the Frederick University boiler laboratory using a BIOPLEX-HL boiler rated 29 kW with 75% efficiency. Based on EN 303-5, the boiler was classified by efficiency and rated thermal input as a class 3 boiler. The boiler has the ability to supply water at a maximum temperature of 95°C and is adapted to operate in pump heating plants protected by an open pressure vessel. The minimum return water temperature in the boiler was set at 60°C. Exhaust gas composition was measured using a KANE 455 analyzer. The measurement campaign focused on the composition of the exhaust gases and in particular on measuring the carbon monoxide and carbon dioxide concentration, excess oxygen, exhaust temperature and boiler efficiency. The measurements were carried out over six hours in order to allow sufficient time for the solid fuel to complete successive combustion cycles.

3. Results

3.1. Contained moisture and ash

Table 1 shows the moisture content and ash content of the two mixtures examined in this work.

To determine the moisture content, the final mass was defined as change from the previous measurement to not exceed 0.2% in the mass during a further heating period at 105 (± 2)°C over a period of 60 minutes. The accuracy of the mass measurement of both samples was 0.1 mg. The required drying time was 3 hours for both samples. To determine the ash content, the containers on which the organic matter was placed were heated for one hour at 250°C. After cooling, they were placed in a desiccator for 10 minutes and weighed. After the samples and the tray were weighed, they were placed in an oven for heating for 1 hour at 250°C and 3 hours at 550°C. After 4 hours of the heating process, the samples were cooled and placed in a desiccator for 10 minutes.

3.2. Combustion emissions

The combustion experiments were performed for two types of mixtures, measuring the emissions during the combustion boiler process. The boiler used in this study was BIOPLEX HL25 together with the ecoMAX 250RZ control system. These measurements were compared with the nominal limits set by the European standard CYS EN 303-5, 2012. Using the model helped assess the suitability of the boiler and of the biofuel used in the context of this work, checking in particular whether the carbon monoxide (CO) and carbon dioxide (CO_2) were within the standard limits of EU standards and investigating the relationship between these two concentrations. The boiler used for the experimental study was designated Class 3 in accordance with standard procedures.
Before the experiment started the ash was removed from the combustion bed and agglomerates from a previous experiment were removed from the burner, in order to prevent emissions from extraneous raw materials. Then the agglomerates whose combustion behavior would be determined were placed in a box in which, with the help of an endless screw, they were transported to the combustion chamber. During the process, the air supply was regulated to maintain the carbon monoxide concentration at low levels and the water temperature and efficiency at higher levels. In this context, the feed rate of solid biofuels was regulated in the burner. Measurement of the exhaust gas started approximately two hours after the fuel feed started and the boiler was in thermal balance. The exhaust gas sensor was placed in the exhaust duct (chimney), at a distance not exceeding three diameters of the tube after the extraction of gases from the boiler. Using the exhaust gas analyzer the required emission measurements were taken at specific time intervals, in particular every 10 minutes. After steady-state operation at constant exhaust temperatures was reached, the gas emissions were measured using a KANE 455 exhaust gas analyzer with constant exhaust gas flow. Concentrations of various gases such as carbon monoxide (CO), carbon dioxide (CO_2) and oxygen (O_2) were measured. Additional measurements were made, such as exhaust temperature (°C), lambda (-) ratio and efficiency (%).

Table 2: Combustion emissions, exhaust efficiency and temperature—Mixture 1

Time, min	CO, ppm	CO_2, %	O_2, %	TFc, °C	Yield, %	Water temp., °C
10	1511	5	15.4	67.4	92.9	35.1
20	1352	4.8	15.7	63.4	93.1	34.7
30	1372	4.5	16	65	92.4	34.7
40	1207	3.6	16.5	50.6	94	35
50	1502	4.6	16	67.1	92.1	35
60	1433	4.4	16.1	63.8	92.5	34.7
70	1474	4.2	16.4	62.9	92.1	34
Avg.	1407.3	4.4	16.0	62.9	92.7	34.7

Table 3: Combustion emissions, exhaust efficiency and temperature—Mixture 2

Time, min	CO, ppm	CO_2, %	O_2, %	TFc, °C	Yield, %	Water temp., °C
10	3641	7.5	12.7	69.2	95	30.5
20	2840	6.2	14.2	68.5	94.1	31.5
30	2781	6.4	13.9	68.4	94.3	33
40	1749	6	14.3	66.9	94.1	34
50	1516	4.9	15.2	60.9	94	34.4
60	1251	5.1	15.4	67.1	92.9	34.7
70	1558	5.4	15	67.1	93.4	34.8
Avg.	2190.9	5.9	14.4	66.9	94.0	33.3

The results of the measurements for the first mixture are given in Table 1. Measurements started after the flame had reached a steady state. For the first mixture, the mean concentration of the excess O_2 was measured as 16% and the CO concentration in ppm was on average 1407.3. As shown in the table, carbon monoxide levels are within the acceptable limits of EN 303-5. The emissions of carbon monoxide from the combustion of biomass depend mainly on three factors: the temperature of combustion, the proper mixing of fuel and oxygen and the residence time of fuel in the combustion chamber. Higher oxygen concentrations correspond to lower load, lowering the temperature of the gas and thus resulting in higher CO emissions.

For the second mixture, the values of the measured parameters are given in Table 3. The average concentration of CO (ppm) was 2190.9 ppm while with respect to the excess oxygen the average was measured at 14.4%. As shown in the table, carbon monoxide levels are within the acceptable limits of EN 303-5. Oxygen concentration is an important indicator of overall performance. Excess air led to lower adiabatic combustion temperatures and thus to a process with lower efficiency, which is not considered to be fair.

For a better understanding of the relationships between the measured parameters, a correlation analysis was performed for the combustion measurements of the two mixtures. This analysis is considered to be probitive, since in the case of a solid biomass combustion cycle, the solid fuel is in different combustion phases, hence it is not possible to draw documented conclusions about the interdependence of the various combustion parameters. For the carbon monoxide levels of blend 1 (Table 4), they were found to be positively correlated with carbon dioxide and exhaust temperature, and negatively correlated with the lambda number and the combustion process yield. The level of carbon dioxide was correlated with the lambda and oxygen figures. Process efficiency was negatively correlated with the temperature of exhaust gases and carbon monoxide levels. Similar conclusions can also be drawn from regression of the measurements for Mixture 2 (Table 5).

Table 4: Measurement regression analysis—Mixture 1

	1	2	3	4	5	6	7
1	100%						
2	13%	100%					
3	-53%	69%	100%				
4	77%	-48%	-93%	100%			
5	-14%	89%	89%	-69%	100%		
6	-45%	-81%	-43%	10%	-79%	100%	
7	-63%	-16%	19%	-44%	-5%	47%	100%

1—time (min), 2—CO (ppm), 3—CO_2 (%), 4—O_2 (%), 5—TFc (°C), 6—yield (%), 7—water temperature (C°)

Table 5: Measurement regression analysis—Mixture 2

	1	2	3	4	5	6	7
1	100%						
2	-92%	100%					
3	-86%	94%	100%				
4	88%	-94%	-99%	100%			
5	-46%	60%	72%	-61%	100%		
6	-87%	85%	83%	-90%	23%	100%	
7	95%	-96%	-89%	89%	-56%	-81%	100%

1—time (min), 2—CO (ppm), 3—CO_2 (%), 4—O_2 (%), 5—TFc (°C), 6—yield (%), 7—water temperature (C°)

4. Conclusions

This work assesses the potential that residues from the Cyprus wine industry have for use as a raw material for solid biofuels. In the framework of this study, blends of marc and other solid residues from the Cyprus wine industry were collected and pelletized, and tests were carried out for moisture and ash content. The results obtained from analysis of the samples showed that they meet the minimum requirements of EN ISO 17225-2 and EN ISO 17225-6 for wood and non-wood biomass pellets respectively. Exhaust and other combustion parameters were measured by utilizing aggregates produced in a solid biomass boiler. The results of the study showed that solid residues from the Cypriot wine industry could be used as a source of energy for the production of heat for industry and for the heating of domestic buildings.

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