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Compost of Biodegradable Municipal Solid Waste as a Fuel in Lignite Co-combustion

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In Greece, 5.8 million tons of municipal solid wastes (MSW) are produced annually, of which 2.47 million tons are bio-wastes. Composting is an alternative treatment of bio-wastes instead of landfill. Two composting plants operate in Greece, one in Ano Liossia (capacity 1,200 tons/day, producing 120 tpd compost) and another in Chania (capacity 70,000 tons/year, producing 20,000 tpa compost). In addition, since 2018, the first integrated waste management plant was set off in the region of Kozani (capacity 120,000 tons/year). An alternative utilization of the compost, produced in the latter plant, was investigated in this study. In particular, instead of using compost as fertilizer, the energy recovery from this bio-waste was attested. Utilization of compost of MSW for energy production purposes has rarely been studied in the literature. Several blends of compost with lignite were prepared and their energetic potential was determined. Proximate analyses and gross calorific value (GCV) determination were conducted. Wastes and biomass-based fuels differ in many ways from fossil fuels. The CLOF sample revealed the highest GCV and the lowest ash content than all analyzed samples. Based on all analytical determinations, compost and its mixtures with lignite could be regarded suitable for energy recovery by thermal processes, such us combustion. Further studies should be done including emission analysis, ash deposition during combustion (corrosion, slagging and fouling).

Keywords: compost-like outputs, lignite, calorific value, proximate analysis, co-combustion.

Introduction

The issue of municipal solid waste (MSW) management is receiving major environmental concerns worldwide. In an attempt to reduce the environmental impacts of biodegradable wastes, mechanical biological treatments (MBTs) are being used as a waste management process in many countries. MBT plants attempt to mechanically separate biodegradable and nonbiodegradable components. Nonbiodegradable components are then sent for reprocessing or landfilled, whereas the biodegradable fraction is reduced through composting or anaerobic digestion, resulting in a compost-like output (Donovan et al., 2010). In Europe, bio-waste is about 32% by weight of the total municipal waste. Greece, on the other hand, has the highest share of bio-waste in the total municipal waste, accounting for about 40% by weight (Interreg Europe, 2017). In Greece, only 2% of 2.47 million tons of bio-wastes are composted (EEA, 2016).

Compost of MSW has been used worldwide as a soil amendment or organic fertilizer (Cerda et al., 2018; Wei et al., 2017; Wong et al., 2016; Zhang and Sun, 2016; Zhang et al., 2013; Donovan et al., 2010) but has been rarely studied as a fuel (Malatak et al., 2013). In Greece, until recently, two composting plants have been in operation, one in Ano Liossia (capacity 1,200 tons/day, producing 120 tpd compost) and another in Chania (capacity 70,000 tons/year, producing 20,000 tpa compost). In addition, since 2018 the first integrated waste management plant has been set off in the region of Kozani (capacity 120,000 tons/year). Compost can be a great challenge to waste-to-energy practice, as over 46% of the global solid waste is organic waste (Hoornweg and Bhada-Tata, 2012). Energy research is at the search of renewable resources. One traditional renewable energy resource is biomass. On the other hand, one of the possible energy sources is biodegradable municipal solid wastes (Ball et al., 2017). Since biomass undergoes partial aerobic decomposition in the process, it is possible to utilize the heat that is produced during the composting process (Smith and Aber, 2018). During composting, part of the organic matter, i.e., potential combustible substance, decomposes and along with change in water content an alteration of the fuel characteristics is inevitable (Marron, 2015; Vandecasteele et al., 2016). Compost still has the majority of combustible matter, so there is a chance of producing composts in order to be used as a fuel for direct combustion, gasification or pyrolysis (Finney et al., 2009). Besides composting, MSW incineration has many advantages like waste volume reduction (by 90%) and destruction of organic compounds, viruses and bacteria. Waste incineration transforms heterogeneous wastes into more homogenous residues (flue gas, fly ash and bottom ash) (Zhang et al., 2008).

Coal fired power plants are still the largest source of electricity generation in Greece, contributing about 55% of electricity generation (Vasileiadou et al., 2018), and will keep leading until 2050 (Reitz, 2018).

Coal-waste co-combustion is recognized as an environmentally friendly and economic approach for both waste remediation and energy production, as this technique utilizes wastes for replacement of fossil fuels, decreasing landfills, and providing significant reduction of CO_2, etc. (Sahu et al., 2014). Co-firing can use the infrastructure which is associated with the existing fossil fuels-based power systems and requires only some capital investment. In Europe and in Greece, the transition to a post-lignite era has already begun. Thus, the utilization of biomass/wastes as an alternative solid fuel is of great importance. In addition, the MSW is expected to increase in the next years and could be used for energy production. By waste-to-energy practice, Greece could enhance the waste management system reducing landfill that is the main current waste management practice.

Co-combustion of coal with wastes has been widely investigated in the last years but the option to utilize compost-like outputs as a fuel in lignite co-firing for energy production still has not been investigated. The aim of this study is to evaluate the potential of compost-like outputs samples of biodegradable municipal solid wastes, as an individual fuel or as a fuel in co-combustion with lignite. For that reason, several blends of the compost-like outputs (CLOF) sample with the lignite (LIG) sample were prepared and their energetic potential was determined. Calorific value determination and proximate analyses were conducted.

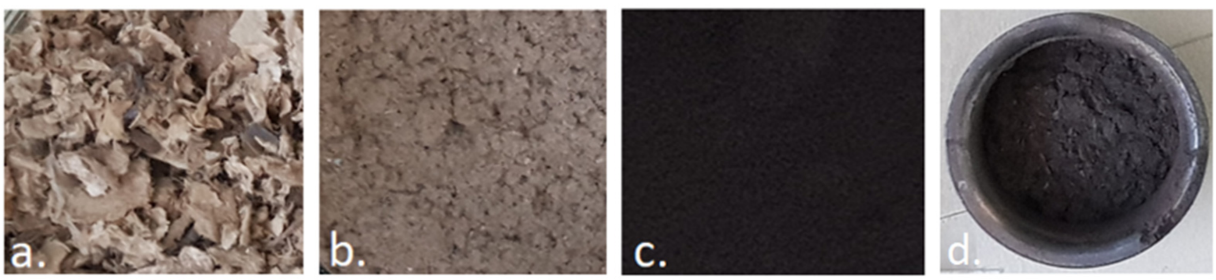
Sampling and Methodology

A CLOF sample was collected from the composting of the biodegradable fraction of bio-wastes from the Western Macedonia first integrated waste management plant (EDADYM, Ellactor group) (Fig. 1a). The biodegradable fraction is mechanically separated and fed into closed bioreactors where the material undergoes rapid composting. During rapid composting, biodegradable organic substances are easily microbiologically transformed within a short time using an air supply control procedure adjusted according to the requirements of biological treatment. The bioreactor control system regulates air supply and temperature. The material exiting the bioreactors is located in trapezoidal shaped piles in a sheltered place and is regularly stirred to achieve the desired degree of maturation. The mature material is led to the refining unit where by mechanical means impurities are removed and the final product is obtained (compost-like outputs or compost type A). The sample used in this study was prepared by mixing samples from the heaps of the final product of the refining unit, i.e., compost-like outputs.

Furthermore, a representative LIG sample from the nearby Kozani lignite mines of the Western Macedonia area was collected (Fig. 1c). The CLOF and LIG samples were firstly air-dried for two weeks. Afterwards, both samples were ground to size less than < 1 mm (Fig. 1b). Eventually, both samples were dried in an oven at 80oC for 24 hours and LIG blends with the CLOF sample in different proportions (10–20–30–40–50–60–70–80–90 wt%) were prepared (Fig. 1d). The raw CLOF sample and the raw LIG sample and their blends were proceeded for proximate analysis (moisture, ash, volatile matter and fixed carbon contents) and gross calorific value determination (GCV).

Proximate analysis was performed with a LECO TGA 701 device, based on ASTM D7582 standard (ASTM D 7582-15, 2015). The determination of gross calorific value was made with the LECO AC-500 isoperibol bomb calorimeter, according to ASTM D5865-13 standard (ASTM D 5865-13, 2013). All samples were analyzed in two replicates.

Fig. 1. *a. CLOF sample before milling, b. CLOF sample after milling, c. lignite powder sample, d. blend CLOF-LIG (LIG: lignite, CLOF: compost-like outputs)*



Results and Discussion

Combustion characteristics of raw materials

Proximate analysis and GCV values of the raw materials (compost-like outputs sample and lignite sample) are shown in Table 1. The LIG sample has a higher moisture content (6.33 wt%) than the CLOF sample (4.95 wt%), which is similar to the moisture compost content (4.26 wt%) that was reported by Malatak et al. (2018). However, this compost was different of CLO since it was a compost of straw, cattle manure, hay, leaves, wood chips, sludge from waste water treatment plant, sawdust, spoiled fruits and vegetables.

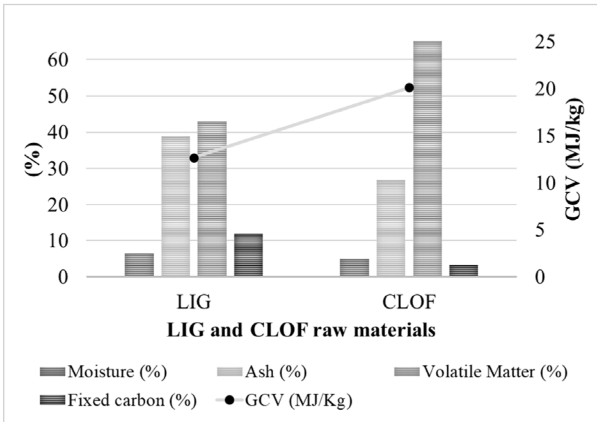
Moisture content and particle size play an essential role in their combustion performance (Sahu et al., 2014; Suksankraisorn et al., 2010). The ash content for the CLOF sample (26.77 wt%) is lower compared with the LIG sample (38.90 wt%). Typically, ash range in lignite is between 10 wt% and 50 wt% and volatile content varies between 35 wt% and 40 wt% (Mazumder, 2013). It is known that organic wastes have high volatile matter and low fixed carbon values (Iordanidis et al., 2017; Vasileiadou et al., 2017; Casado et al., 2016; Vamvuka and Sfakiotakis, 2011; Varol et al., 2010). The volatile matter for the CLOF sample is 65.11 wt% while the lignite sample has a value of 42.93 wt%. The fixed carbon of the CLOF raw sample is 3.17 wt% while the LIG sample has a value of 11.85 wt%. The GCV of the raw CLOF sample is 20 MJ/kg while the LIG sample has a value of 13 MJ/kg. Malatak et al. (2018) studied wood co-combustion with compost (mainly made from material like straw, cattle, manure, hay, leaves wood chips and sludge from waste water treatment plant, sawdust, spoiled fruits and vegetables). The GCV of that type of compost was approximately 8 MJ/kg. The GCV of compost and wood mixture in 50% by weight are influenced equally by both components. Most of the previous studies regarding compost (Garau et al., 2019; Cerda et al., 2018; Wong et al., 2016) focus on composting processes and composition characterization but the GCV values of compost-like outputs have not been reported yet. Thus, the GCV value of the CLOF sample can be compared with GCV of various MSW. Iordanidis et al. (2017) experimentally studied the GCV of paper (14 MJ/kg), plastic (29 MJ/kg) and textile (16 MJ/kg) in Greece. Antonopoulos et al. (2013) reported a similar GCV of MSW (plastic: 33 MJ/kg, paper: 16 MJ/kg, textile: 17 MJ/kg). It can be concluded that the CLOF sample has obviously higher GCV than the above-mentioned wastes, except the plastic sample.

Table 1. *Proximate analysis (moisture, ash, volatile matter and fixed carbon) and gross calorific value (GCV) of the raw materials (LIG: lignite, CLOF: compost-like outputs). All values are in wt%, except GCV (MJ/kg)*

SAMPLE ID	Moisture (%)	Ash (%)	Volatile matter (%)	Fixed carbon (%)	GCV (MJ/Kg)
LIG	6.33	38.90	42.93	11.85	12.68
CLOF	4.95	26.77	65.11	3.17	20.13

Fig. 2 illustrates the proximate and GCV analytical results of the raw LIG and CLOF samples within the same graph. It can be observed that the CLOF sample has 1.5 times more volatile matter than volatile matter of the LIG sample. High volatile matter content indicates easy ignition of fuel. Fixed carbon is the solid fuel left in the furnace after volatile matter is taken off. The amounts of fixed carbon and volatile combustible matter directly contribute to the calorific value of the sample. Fixed carbon acts as a main heat generator during combustion. The ash content is important to the design of the furnace grate, combustion volume, pollution control equipment and ash handling systems of a furnace (Mishra, 2012).

Fig. 2. *Graph of the proximate and GCV analytical results of the raw compost-like outputs and lignite samples (LIG: lignite, CLOF: compost-like outputs).*



Combustion characteristics of lignite blends with compost-like outputs

Proximate analysis and the GCV of all CLOF blends with LIG are presented in Table 2. The blends with the lowest moisture content are those with a proportion of 90 wt% and 80 wt% CLOF, showing values of 4.77 wt% and 5.01 wt%, respectively. The highest moisture content (approx. 6.50 wt%) is determined for the blend with 40 wt% and 20 wt% CLOF. High ash content is displayed for the LIG blends containing 10 wt%, 20 wt%, 30 wt% and 40 wt% CLOF showing values of 37.99 wt%, 36.22 wt%, 34.54 wt% and 33.06 wt%, respectively. Blends with 50 wt% and 70 wt% CLOF have a value of approximately 31 wt%. The lowest content of ash is found in blends with 90 wt%, 60 wt% and 80 wt% CLOF (approx. 28 wt%). The highest percentage of volatile matter (59.69 wt%) is revealed for the blend with 90 wt% CLOF. Blends with 80 wt%, 70 wt% and 60 wt% CLOF have a value of approximately 58 wt%. The blend with 10 wt% CLOF has the lower value of volatile matter (44.76 wt%).

The highest fixed carbon value (11.03 wt%) is displayed for the blend with 10 wt% CLOF, followed by 20 wt% and 30 wt% (approx.10 wt%), followed by 60 wt%, 40 wt%, 50 wt% and 80 wt% (> 8 wt%). The lowest fixed carbon value (6.64 wt%) is revealed for the blend with 70 wt% CLOF.

It is observed that as the content of CLOF is increasing in the mixture, the volatile matter value is also increasing and the ash content is decreasing. As it is expected, blends with higher percentage of CLOF have a lower moisture percentage as the raw CLOF sample has a lower moisture percentage (4.95 wt%) than the LIG sample (6.33 wt%).

The results of GCV and proximate analysis of all analyzed blends are illustrated in Fig. 3. Regarding the GCV of the blends, all LIG blends with CLOF reveal a higher GCV than the raw LIG sample. The blends with 90 wt% and 80 wt% CLOF exhibit the highest GCV of all samples (more than 19 MJ/kg). Blends with 70 wt% and 60 wt% CLOF have a value of about 18.50 MJ/kg. The blend with 50 wt% CLOF has a value of 16.75 MJ/kg. Blends with the lowest GCV are the blends with 10 wt%, 20 wt% and 30 wt% CLOF having a value of almost 13 MJ/kg.

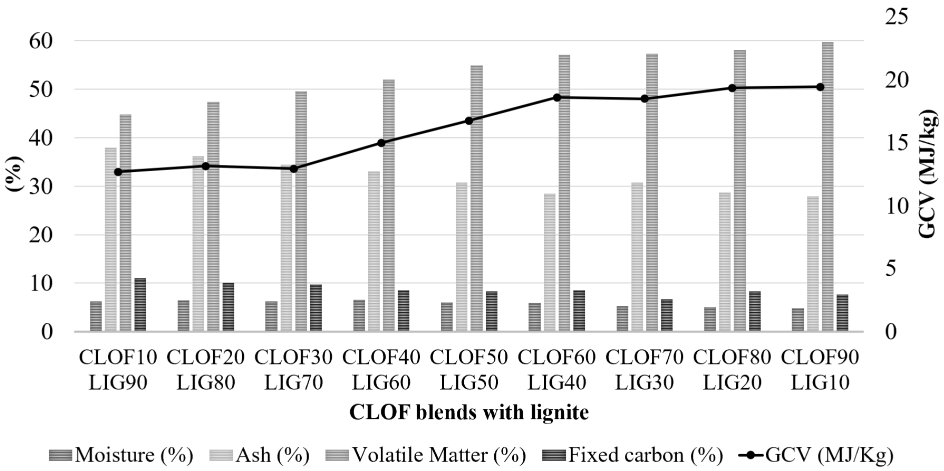
Although a linear correlation between CLOF content of blends and GCV values can be observed (Fig. 3), two samples (CLOF30 LIG70 and CLOF70 LIG30) slightly deviate from this trend. Similar deviation can be observed for the values of other parameters (ash content, etc.) of these two samples. This deviation can be attributed to the inherent inhomogeneity of the CLOF sample.

Lignite blends with compost-like outputs have not been reported yet but other results of studies related to coal co-combustion with wastes/biomass also showed higher concentrations of volatile matter as well as lower carbon content of biomass blends with coal than traditional fossil fuels (Iordanidis et al., 2017; Frazzitta et al., 2012; Atimtay and Varol, 2009; Cliffe and Patumsawad, 2001).

Table 2. *Proximate analysis (moisture, ash, volatile matter and fixed carbon) and gross calorific value (GCV) of CLOF blends (LIG: lignite, CLOF: compost-like outputs) with lignite. All values are in wt%, except GCV (MJ/kg).*

SAMPLE ID	Moisture (%)	Ash (%)	Volatile matter (%)	Fixed carbon (%)	GCV (MJ/Kg)
CLOF10 LIG90	6.22	37.99	44.76	11.03	12.68
CLOF20 LIG80	6.39	36.22	47.43	9.96	13.14
CLOF30 LIG70	6.17	34.53	49.59	9.71	12.95
CLOF40 LIG60	6.51	33.06	51.98	8.45	14.98
CLOF50 LIG50	5.94	30.82	54.92	8.32	16.75
CLOF60 LIG40	5.89	28.51	57.14	8.46	18.58
CLOF70 LIG30	5.26	30.82	57.28	6.64	18.48
CLOF80 LIG20	5.01	28.73	58.04	8.22	19.34
CLOF90 LIG10	4.77	27.96	59.69	7.58	19.43

Fig. 3. *Graph of the proximate and GCV analytical results of compost-like outputs blends with lignite (LIG: lignite, CLOF: compost-like outputs) in different proportions, wt%.*



Conclusions

Different blends of lignite with compost-like outputs wastes and raw compost-like outputs wastes, of MSW, were studied in order to investigate their co-combustion behaviour. The raw CLOF sample revealed a higher GCV (about 20 MJ/kg) than the lignite sample (about 13 MJ/kg). It was observed that as the content of compost-like outputs was increasing in the mixture, the gross calorific value and the volatile matter were also increasing, while the ash content was decreasing. Regarding the calorific value of the blends, all blends reveal a higher gross calorific value than raw lignite. Blends with 80 and 90 wt.% CLOF (CLOF80 LIG20, CLOF90 LIG10) reveal better combustion characteristics (higher GCV, lower ash content) than all other blends. Based on all analytical determinations, the energy utilization of compost-like outputs and their blends with lignite through combustion, may be possible with further processing of CLO (e.g., drying). Compost-like outputs combustion and co-combustion with lignite represent an attractive option for reducing wastes, eliminating the use of fossil fuels and generating energy from wastes. Furthermore, the results of this study could help Greece in a smoother transition to the post-lignite era. Further research is deemed essential for studying emissions, ash deposition and corrosion issues during combustion.

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