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Evaluation of urban wastes as promising co-fuels for energy production – A TG/MS study

Despina Vamvuka *, Stelios Sfakiotakis, Sevi Saxioni

Department of Mineral Resources Engineering, Technical University of Crete, University Campus, Hania 73100, Greece

HIGHLIGHTS

- Combustion characteristics of lignite/urban waste blends were evaluated.
- Waste paper was the most reactive among the species studied.
- Emissions of C_xH_y, CO, SO_2 from blends decreased as compared to lignite combustion.
- Sewage sludge increased C_xH_y and NO_x released from the mixtures.
- Combustion characteristics of mixtures showed synergy between component fuels.

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ABSTRACT

This work aimed at investigating the potential of using urban wastes and lignite mixtures for energy generation. The objective was to determine the combustion characteristics and the gaseous pollutants of indigenous lignite/urban waste (MSW, RDF, waste paper, sewage sludge, demolition wood) blends, as well as to evaluate the compatibility of each component in the blend. The experiments were conducted in a thermogravimetric analysis system, at non-isothermal heating conditions, over the temperature range 25–900 °C. Combustion gases and emissions of SO_2, NO_x and hydrocarbons were continuously monitored through a quadrupole mass spectrometer coupled to the thermobalance system. The results showed that the ignition behaviour of the fuels was determined by the amount of volatiles, the H/C ratio, the content of impurities in the samples and in the case of mixtures the blending ratio. Waste paper was the most reactive among the species studied. Emissions of hydrocarbons, CO and SO_2 from blends decreased as compared to lignite combustion only, whereas those of NO_x remained unchanged. However, sewage sludge increased C_xH_y and NO_x released from the mixtures. Lignite and biomass fuels showed synergy when blended. Co-firing urban wastes with lignite allows for energy recovery, economic benefits and some advantages in terms of thermal reactivity and toxic emissions.

1. Introduction

Nowadays, there is an increasing demand for power generation, due to growth of population, in addition to technological and economic development. Coal is the primary energy source worldwide for electric power generation [1]. However, depletion of coal reserves and the environmental burden from their use have made necessary the use of alternative renewable fuels. In this context, biomass is considered one of the viable replacement options, as it offers a remarkable potential reduction of greenhouse emissions [2]. Hence, the target of European Union is to increase its utilization [3]. Presently, high quality woody biomass materials are preferred in the energy sector. However, limited availability, competition with the heating sector and high prices are pushing for a more extensive investigation of other biomass types, such as organic solid wastes.

The handling and disposal of the ever increasing quantities of these wastes, which are generated by every social activity, are becoming matter of public concern, due to environmental and human health impacts. Their disposal is no longer viable, due to the limited number of available sites, the high cost and the environmental regulations [4]. On the other hand, thermal treatment of solid wastes is becoming more attractive, as a disposal option, by destroying hazardous constituents [5], reducing their volume, allowing for energy recovery and increasing economic returns to rural communities.

Co-combustion of biowaste materials with coal in existing power plants is a most interesting option, because apart from the

* Corresponding author. Tel.: +30 2821 37603; fax: +30 2821 69554.
E-mail address: vamvuka@mred.tuc.gr (D. Vamvuka).

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environmental benefits, through reduction of greenhouse gases and organic emissions even with high chlorine content [3,6], it offers economic benefits, by replacing part of conventional energy sources, while at the same time using existing infrastructures [7]. However, in spite of many advantages, there are some problems associated with the use of waste derived fuels with coal, such as the diverse composition of industrial and household wastes unlike other biomass, the high moisture and volatile matter contents, the early ignition and the presence of alkali or heavy metals in the ashes [8–14]. These characteristics influence the amount of primary and secondary air required, the temperature profiles along the furnace, the flue gas emissions, the burn out time of the blends and the combustion efficiency. Thus, modifications of the combustion systems may need to be considered, along with other factors. The technical barriers that arise need to be overcome, in order to accelerate the use of biowastes' co-combustion technology. In order to minimize the possible negative impacts of co-firing on the operation of power plants, it is essential to know the behaviour of coal and biomass fuels during combustion not only separately, but also together, as interactions may occur between them that may affect the overall efficiency of the process [12,15,16]. Factors, such as ignition and burn out, fouling tendency and flue gas emissions are seldom linear functions of the fuel mixture [15,17]. The compatibility of the alternate fuel with respect to the combustion performance has to be properly evaluated, for the effective design and operation of the thermochemical conversion units.

Thermogravimetric analysis technique (TGA) has been widely adopted as an inexpensive, simple and reliable method for thermochemical processes and simulation, providing a rapid assessment of the fuels decomposition and combustion characteristics, information which is necessary for predicting the combustion efficiency, boiler design etc. [9,12,14,18–20]. TGA data could be useful for assessing the impacts of the fuels during combustion in fixed bed units. Coupling with a mass spectrometer (MS) is an attractive advantage in interpreting the course of the reactions taking place, as it allows the real-time and sensitive detection of evolved gases and emissions, an important and often a difficult task in many thermal applications [8,21,22].

Much research has been carried out to evaluate the combustion behaviour of coal and biomass blends, based on thermal analysis methods. Most of the previous studies focused on fundamental analysis employing specific fuels such as coal, woody residues, municipal solid wastes (MSW) and sewage sludge [8–10,14,17,21,23]. Both additivity and synergy between individual blend constituents have been reported [9,10,17,20,24]. Published research on TG–MS mainly concerns pyrolysis products from biomass and related materials [22,25–28]. Detailed studies on mass spectra of evolved species during combustion or co-combustion are very few and do not address quantitative analysis of gaseous products [8,19,21]. Furthermore, thermal analysis of lignites and

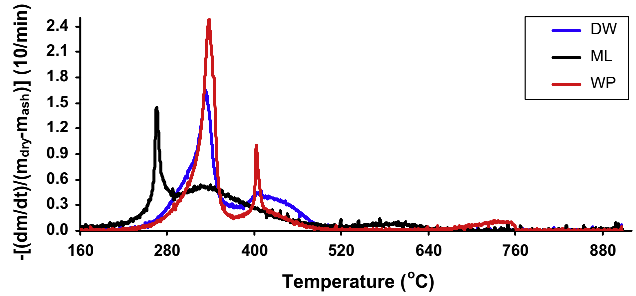

Fig. 1. DTG combustion profiles of (a) waste paper, (b) demolition wood and (c) Megalopolis lignite.

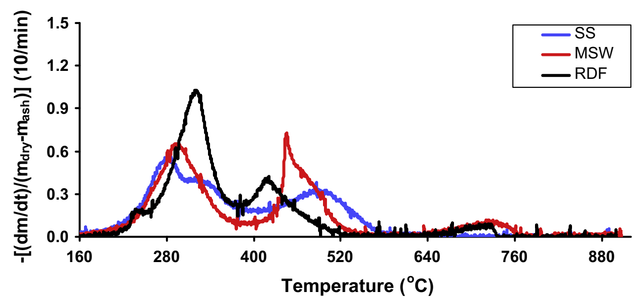

Fig. 2. DTG combustion profiles of (a) MSW, (b) RDF and (c) sewage sludge.

urban wastes in co-combustion processes and an assessment of the effect of various parameters on burning characteristics and emissions produced have not been reported so far.

The present work is an attempt to fulfil the requirement of increased use of biomass materials with local conventional fuels for heat or power production and to provide valuable information for promotion of urban wastes, as co-fuels for energy generation. The objective of the study was to investigate the ignition and combustion characteristics of indigenous lignite/urban waste blends under TGA conditions, to determine the influence of fuel properties and blending ratio on process efficiency, to identify gaseous pollutants during combustion by means of MS and evaluate any interactions between the blend components.

2. Experimental

2.1. Materials and equipment

The urban solid wastes used in the present study were: MSW free of metals and glasses and refused derived fuel (RDF), both from DEDISA factory of the city of Chania in Crete, an undigested

Table 1
Proximate analysis, ultimate analysis and calorific value of the fuels (dry basis).

Sample[a]	Volatile matter	Fixed carbon	Ash	C	H	N	O	S	Cl	HHV[b] (MJ/kg)
WP	75.0	11.0	14.0	38.3	4.1	0.2	43.4	0.01	0.01	14.2
DW	83.4	11.7	4.9	51.3	6.2	0.3	36.8	0.40	0.10	19.0
MSW	62.0	9.0	29.0	30.3	3.4	1.4	35.3	0.05	0.50	11.3
RDF	77.1	1.6	21.3	45.7	6.3	1.5	25.1	0.01	0.10	20.4
SS	62.7	13.8	23.6	35.0	6.1	4.5	28.9	1.9	0.01	14.8
ML	40.5	17.9	41.6	43.9	5.2	2.4	2.9	4.0	0.01	11.8
ML/WP 50:50	56.1	15.8	28.1	41.1	4.7	1.3	23.2	2.0	0.01	13.1
ML/DW 50:50	61.0	16.2	22.8	47.6	5.7	1.3	19.9	2.2	0.10	15.5
ML/MSW 50:50	52.3	13.7	34.0	37.1	4.3	1.9	19.4	2.0	0.30	11.5
ML/RDF 50:50	60.1	8.3	31.6	44.8	5.7	1.9	14.1	2.0	0.10	16.1
ML/SS 50:50	52.2	14.2	33.6	39.4	5.7	3.4	15.9	3.0	0.01	13.2

[a] WP: waste paper; DW: demolition wood; MSW: municipal solid wastes; RDF: refused derived fuel; SS: sewage sludge; ML: Megalopolis lignite.
[b] HHV: Higher heating value.