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Comparison of ashes from fixed/fluidized bed combustion of swine sludge and olive by-products. Properties, environmental impact and potential uses

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A B S T R A C T

Residues from agriculture and processing industries or from the livestock sector play an important role for the power generation sector. However, ash materials produced during combustion may create several technical and environmental problems. In this work, bottom and fly ashes obtained from lab-scale fixed/fluidized bed combustion of swine sludge, olive by-products and their mixtures, from the island of Crete, were characterized by mineralogical, chemical, particle size distribution and fusibility analyses, as well as by standard leaching tests. Slagging and fouling propensities were determined and their environmental impact and potential uses were assessed. The results showed that the ashes were rich in Ca, Si, Mg, P, K, Cu, Zn and Sr minerals. Slagging/fouling potential of swine manure was significant. Heavy metals showed less preference for fly ashes. Toxic metal ions were released in low quantities through the soil, below the legislative limit values. The low leachability of the elements was attributed to the higher alkalinity of the extracts, as well as the mineralogical and chemical composition of the solids involved. All ashes could be used as secondary building materials, or for road construction. Alternatively, they could be used in mixtures with other byproducts as liming agents and fertilizers on acidic soils.

1. Introduction

Given the trend to replace fossil carbon and gain additional revenue with minimum environmental impact, the power generation sector across the world is considering the use of secondary fuels, such as animal and agricultural wastes. As landfill disposal is no longer a viable solution, due to the high cost and the environmental regulations, thermal treatment of these wastes is an attractive option, by destroying hazardous constituents, reducing their volume, allowing for energy recovery and increasing economic returns to rural communities. European Union directives 1991/31/EC and 1991/676/EC [1] imposed a reduction in the amount of biodegradable wastes going to landfill and the Waste Framework Directive 2008/98/EC [2] set the hierarchy of the waste policy and management for recycling and reuse.

Residues from agricultural production and processing industries or from the livestock sector are readily available in large quantities in Mediterranean countries. In Crete, the largest Hellenic island, the annual production of olive by-products could cover the energy needs of the island if properly exploited and animal breeding is intensive, leaving excessive amounts of manure for safe application to farmlands, according to nutrient management plans [3]. Considering the annual increase of energy demand in Crete due to prosperous tourism industry, creating problems in the power supply, the utilization of these wastes as bioenergy feedstocks seems a feasible long term solution.

Combustion technologies mainly used for solid biomass fuels are fixed or fluidized bed appliances. Fixed bed furnaces usually require lower capital and operating costs and are preferred for smaller power plants [4]. On the other hand, fluid bed furnaces offer many advantages, such as fuel flexibility, high conversion efficiency and low pollutant emissions [5–7]. Nevertheless, all these plants produce bottom or fly ashes, the relative amount and characteristics of which depend on the type of biomass used, the technology, the operating conditions and the emission control devices [8–10]. These ashes create several technical and environmental problems, which reduce the efficiency and the cost of the

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facilities, such as slagging, fouling, corrosion of heat exchanging surfaces and pollutant emissions, due to the presence of alkalis, silicon, chlorine and sulphur [6,11,12]. In addition, heavy metals contained in ash residues may pose a serious threat to human health and the environment, if mismanaged, due to their possible leaching into soil and ground water [13,14]. On the other hand, some mineral nutrients of the ashes, such as Ca, Mg, N, K, P and trace metals, may have a vitalizing effect [15] upon recycling to agricultural or forest soils, or alternatively they may cause eutrophication problems. The availability of elements to plants and their solubility through soils is determined by the chemistry, the mineralogy, the pH and other factors of the solids involved [12].

As biomass materials are very heterogeneous and have diverse biologic origin resulting in different compositions, a thorough knowledge of ash properties is important for the valorification of these ashes in various applications, as well as for the environmental monitoring and protection. Moreover, when mixtures of fuels are used for increasing supply options, data on the final ash materials can make it possible to avoid fuel combinations with unwanted properties.

There is a lot of information in literature on the most important physical and chemical properties of bottom and fly ashes produced from biomass combustion, or on their slagging/fouling tendency [16–18]. Leaching tests have also been conducted to assess risk and select proper management and disposal strategies [19,20]. A considerable research has also been carried out on the potential utilization of these ashes for soil amendment or for construction materials [21–23]. Previous studies have concentrated on ashes from woody agricultural or forestry wastes, sewage sludges, municipal solid wastes [16,19,23,24] and few on animal wastes, principally poultry [25]. Limited work is reported on the composition of pig manure ash from incineration and gasification and its dissolution in citric extractants [26,27]. Incineration of animal manure or co-firing with agricultural wastes, which are available in large quantities in South European countries, offering advantages for energy production as previously mentioned, has not been reported so far, excluding the author. Therefore, there is lack of data on the effect of ash materials from such mixtures on fixed or fluid bed systems performance, or on the valorization and environmental impact of them through leaching tests. Furthermore, there is lack of data comparing such ash blends produced from fixed and fluid bed units.

Based on the above, the aim of this study was to compare bottom and fly ashes generated, in a previous work by the author, during fixed and fluidized bed combustion of swine sludge and olive by-products of Crete, as well as their mixtures, in the context of co-firing applications of these materials for power production. The objectives were to determine slagging and fouling propensities of these ashes through fusibility tests, to characterize them by mineralogical, chemical and particle size distribution (PSD) for assessing their environmental impact and potential uses and finally to study the leaching behaviour of different elements in local soils, in order to investigate the environmental aspect of ash disposal or the suitability of ashes as crop nutrients.

2. Experimental section

2.1. Raw materials

The raw materials selected for this study were an untreated swine manure from Creta Farm industry, located in the municipality of Rethymno of the island of Crete and two agricultural residues, as being abundant in the region of Crete, namely olive kernel and olive pruning, which were provided by a local olive oil factory and cultivated field, respectively, in the neighbourhood of Creta Farm.

The bed material, which was used for the fluid bed experiments, was a Na-feldspar $NaAlSi_3O_8$ with an average particle size range of 421 μm.

The soil sample was collected from the area of Agia, Chania and it was of phyllitic and quarzitic origin. After passing a 2 mm sieve, it was subjected to particle size analysis and determination of the sand, silt and clay proportions, via the hydrometer method [28]. Total organic carbon (TOC) was measured by Gasometric Carbon analyzer 572-100, while cation-exchange capacity by applying the ammonium acetate method [29]. Mineralogical and chemical analyses were performed using the same techniques as for the biomass ashes described below.

Representative samples of the biomass fuels obtained after homogenization and riffling, were characterized according to the European standards drawn up by the Technical Committee CEN/TC335, by proximate analysis, ultimate analysis and calorific value. For combustion tests, the fuels were air dried and ground, swine manure in a jaw crusher and ball mill and agricultural residues in a cutting mill, to a final size of −2.8+1 mm. Blends of swine manure with each of the woody residues at ratios 50:50 (wt%) were also prepared.

2.2. Combustion experiments

An atmospheric lab-scale fixed/fluidized bed reactor system (ID = 70 mm, H = 2 m), as described in detail in a previous work [7], was used for the tests.

When the system was operated in the fluidizing mode, the minimum fluidization velocity was determined by measuring the pressure drop across the bed and air diffuser plate versus the superficial velocity, using a cold reactor model. For each pre-dried material/mixture, the feed rate was 0.6 kg/h, excess air ratio was 1.4 and air flow rate varied between 3.1 and 4.3 m^3/h, depending on fuel (bubbling bed). The results of two replicates, presenting temperature profiles along the reactor height, efficiency and flue gas emissions, have been reported in a previous article [7]. This study aimed at evaluating fly and bed ashes through various analyses. Thus, at the end of each run, which lasted about 4 h, bed material and fly ash were drained, weighed, and combusted in the oven at low temperature for not altering mineralogical composition, in order to calculate combustion losses due to unburned carbon. Subsequently, they were analyzed for PSD, major and trace elements, mineral phases and species leachability through the soil.

When the system was operated in the fixed bed mode, the fuel was fed into the reactor pneumatically, without charging inert material, as soon as the temperature reached the desired value (furnace temperature set at 700 °C). Combustion air, supplied from reactor top, flowed at the same excess ratio (1.4) as in the case of fluid bed tests, for comparison reasons. When the process was complete, bottom ash was cooled by the air supply and subjected to the same analyses as above.

2.3. Ash analyses

The fusibility test, for determination of initial deformation temperature (IDT), softening temperature (ST), hemispherical temperature (HT) and fluid temperature (FT), was conducted according to European standards DDCEN/TS 15370-1:2006 [30], using an Ash Fusion Determinator type 789–900.

The PSD of fly and bottom ashes derived from a diffraction pattern resulting from a laser irradiated suspension of ash and water, using a Mastersizer S laser diffractometer by Malvern Instruments and from dry sieving, using a sieve shaker Analysette 3 PRO of Fritsch, respectively.